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Mountains – Up and Down



Swiss Academy of Sciences Akademie der Naturwissenschaften Accademia di scienze naturali Académie des sciences naturelles



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Large picture: View of the Aletsch Glacier from Bettmerhorn (Picture: Pierre Dèzes, SCNAT) Small picture: An Aebi Terratrac TT 205 working in steep terrain (Picture: Aebi, Burgdorf).

10th Swiss Geoscience Meeting, Bern 2012

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1. Educational Research on Geoscience Teaching and Learning

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- 1.2 Adamina M.: Kompetenzen und Kompetenzentwicklungen von Schülerinnen und Schülern zur räumlichen Orientierung in der Primarstufe
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1.1

Systems thinking – the key concept for geoscience teaching and learning. Avalanche training as a way of promoting it.

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Following the state-of-the-art of different geoscience disciplines the "Educational Standards in Geography for the Intermediate School Certificate" (DGfG 2012) proclaim the systems concept as the fundamental concept of geography education (Fig. 1). According to the current state of knowledge, systems thinking (or more comprehensively, system competence) refers to the ability to recognise a complex segment of reality in its organisation and its behaviour as a system, and to act accordingly in a manner adequate for the system.

Snow avalanches are met with great interest among the population of Switzerland, since snow sport activities are very popular. However, there is also a tragic aspect, because most of the 25 avalanche victims per year are the ones who cause the (slab) avalanches in which they lose their lives. What makes dealing with avalanches so difficult is the fact that they exhibit numerous characteristics of dynamic systems such as openness, non-linearity, emergence, self-organised criticality, and limited predictability. But in contrast to comparable phenomena such as earthquakes, one individual can interact directly, especially in case of slab avalanches. While this circumstance makes avalanches dangerous, it also makes them particularly interesting for researching systems thinking.

Within the scope of a quasi-experimental study, including pre- and post-tests, the demand for the construction of a learning environment in order to effectively improve the competence of systems thinking about the topic of avalanches was the central goal. Therefore a teaching unit on the topic of avalanches, consisting of eight lessons, was initially developed as an intervention tool. Examples of such approaches introduced in greater detail in the presentation include an avalanche experiment (with everyday materials such as flour and salt) and a computer programme for simulating avalanches (Harvey 2006). A total of 555 students (13- to 14-year-old) in 30 classes participated, with 4 classes serving as the control group. A standardised questionnaire was used to collect variables such as subject knowledge and everyday ideas of avalanches as well as system competence for the topic of avalanches. The tool to measure the subject knowledge and everyday ideas was taken and adapted from a pilot study (Rempfler 2010a, b). To operationalise system competence (i.e. 'system organisation' and 'system behaviour'), we followed a structural model which was derived from empirical studies and theoretical-conceptual works (Rempfler & Uphues 2011).

The results show that the everyday ideas of avalanches (mental models) immediately after the treatment are highly significant more differentiated than at time T1 and that this level remains high even after 6 to 8 weeks. In comparison, the control group shows no change or even a negative change. The trend for the system competence (and subject knowledge) of the students is similar, although somewhat less distinct. A multi-level analysis indicates that the mental models for 'system organisation' act as a predictor: students with more sophisticated mental models at time T2 achieved significantly higher 'system organisation' values than students with poorly differentiated mental models. Based on these results the question what elements of the intervention tool could have made a material contribution to changing the mental models and system competence will be discussed. Related and more fundamentally, the question arises what general conclusions for effectively promoting systems thinking can be derived.

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Figure 1. The human-environment system – basic concept in the analysis of space in geography education (DGfG, 2012, 12)

Kompetenzen und Kompetenzentwicklungen von Schülerinnen und Schülern zur räumlichen Orientierung in der Primarstufe

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Die stärkere Ausrichtung des Lernens auf die Förderung von Kompetenzen (Kompetenzorientierung in der Lehr- und Lernplanung und in der Unterrichtsentwicklung), die Einführung von Standards und damit verbunden auch eine veränderte Aufgaben- und Beurteilungskultur bedeuten für die fachdidaktische Forschung neue Herausforderungen. Dazu gehören die Kompetenzmodellierung und –diagnostik, Fragen zu Vorwissen und –können und zu Kompetenzentwicklungen der Lernenden sowie entsprechende Assessments.

Während zum Beispiel im Bereich der Mathematik und der Naturwissenschaften bereits über einen längeren Zeitraum insbesondere im Anschluss an die Ergebnisse der TIMSS- und PISA-Untersuchungen - Forschungen und Entwicklungsarbeiten durchgeführt wurden und werden, besteht im Bereich der Geographiedidaktik und dabei insbesondere auch zum raumund geographiebezogenen Lernen in der Primarstufe ein Mangel an Grundlagenarbeit und an Untersuchungen.

Im Projekt stehen Fragen der Kompetenzmodellierung, der Entwicklung von Kompetenzen und dabei auch der Unterschiedlichkeit von Entwicklungsverläufen von Lernenden zur räumlichen Orientierung in der Primarstufe im Vordergrund.

In der explorativ angelegten Studie werden, basierend auf einer theoretisch abgestützten Kompetenzmodellierung, eine Querschnitt- und eine Längsschnittuntersuchung zur Ausprägung und Entwicklung von Kompetenzen zur räumlichen Orientierung und zu räumlichen Vorstellungen von Schülerinnen und Schülern in der Primarstufe (3.-6. Schuljahr) durchgeführt. Es wird untersucht, welche Aspekte in welcher Form Einfluss auf die Kompetenzentwicklung haben. Zudem werden Fragen der Methodik und der Instrumentenentwicklung für die Erschliessung und Erhebung von Kompetenzentwicklungen bei jüngeren Schülerinnen und Schülern aufgenommen und entsprechende Verfahren erprobt.

Dazu wurden Testsituationen und -aufgaben entwickelt, getestet und nach einer weiteren Überarbeitung in sieben Klassen am Ende des 4. Schuljahres (n 142) und in sechs Klassen des 6. Schuljahres (n 122) im Rahmen der Querschnittuntersuchung eingesetzt. Parallel dazu wurden in einem Fragebogen Aspekte der schulischen und ausserschulischen Erfahrungen, des Interesses, der Selbsteinschätzung u.a. der Lernenden erhoben und ein Test zu Aufgaben zum räumlichen Denken und zur räumlichen Orientierung (aus dem Bereich Form und Raum in der Mathematik) durchgeführt. Die Erhebungen erfolgten im Rahmen von insgesamt fünf Unterrichtssequenzen à 2 Lektionen an den jeweiligen Schulen. Eine Sequenz wurde in Kleingruppen im Realraum absolviert.

Mit dem gleichen Setting – allerdings mit einer Erhebungssequenz weniger - wurde die Längsschnittuntersuchung im Sommer/Herbst in 9 Klassen des 3. Schuljahres (n 189) begonnen (Zeitpunkt 1 Anfang des 3. Schuljahres, gleichzeitig auch Querschnittuntersuchung 3.-6. Schuljahr 2011, Zeitpunkt 2 Ende des 4. Schuljahres im Frühling/Sommer 2013 und 3. Zeitpunkt Ende des 6. Schuljahres im Frühling/Sommer 2015)

Auf der Grundlage der ersten Auswertungsarbeiten wurden 39 Schülerinnen und Schüler der Klassen im Längsschnitt für ein fokussierendes Interview ausgewählt. Ziel dieser vertiefenden Erhebung ist es, noch näher an den Lernenden ergänzende Angaben, Aussagen und Kommentare zu erschliessen zur Kompetenzentwicklung, zu den Einflussfaktoren und zu den Rahmenbedingungen, welche die Ausprägung und Entwicklung von Kompetenzen beeinflussen. Die Interviews wurden im Februar/März 2012 geführt und werden momentan ausgewertet.

Bis im Spätherbst 2012 liegen erste Ergebnisse aus der Querschnittuntersuchung vor, welche Aussagen zu Kompetenzausprägungen insgesamt, zu Unterschieden zwischen den Ausprägungen bei einzelnen Schülerinnen und Schülern, Klassen und Schulstufen erlauben. Auf dieser Grundlage ist es auch möglich, eine erste Validierung der Kompetenzmodellierung und -erfassung (Struktur- und Entwicklungsmodell) im Bereich der räumlichen Orientierung auf der Primarstufe vorzunehmen. Die Ergebnisse dienen insbesondere auch dazu, Fragen und Aspekte der Kompetenzdiagnostik und -förderung im Hinblick auf die Unterrichtsentwicklung zu erörtern.

Im Vortrag werden insbesondere Fragen der Kompetenzmodellierung, methodologische Aspekte des Untersuchungsdesigns vorgestellt und zur Diskussion unterbreitet.

Zudem werden erste Ergebnisse aus der Querschnittuntersuchung dargelegt und Fragen dazu erörtert.

Schlagwörter: Kompetenzmodellierung, Kompetenzerwartungen, -ausprägungen, -entwicklungen; raum- und geographiebezogenes Lernen, räumliche Orientierung, Längsschnittuntersuchung Primarstufe

Practical teaching of geography at high school level - experiences from own teaching practice.

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1.3

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Starting a high school geography class, one faces various levels of students' previous knowledge and their ideas about what geography is and how it should be taught are no less variable. Initial developing of common basics would be time consuming and an important ingredient of the geographical competence would be missing anyway: the sense of geographical processes carrying on around. Aiming at developing just this very specific ability of sensing complex natural and social processes in the geographical space, I often use the vehicle of the applied geosciences and foster students' practical contribution to the lessons. This being aware that far less geographic scientific theory may be imparted to the students, but based on repeated experience, that sustainable interest on geoscientific topics may be supported this way.

Two projects, selected from among the topics of physical geography and realised in 2000-2012 during my teaching contract at the Atelierschule in Zürich, are presented in following. All photos and figures are originally made by the students or by me. Both projects include extended field trips completing thematically the teaching in the classroom.

Geology project with a field trip of two days.

The geology may be a topic in the "Quarta", the starting gymnasium class. The initial instruction takes ca. two weeks' time in the classroom (15 lessons a week) and includes a) elements of geology and geomorphology of the region where the school is located, b) sedimentary processes and the construction of rocks, c) geotectonics, development of oceans and mountains, petrology, d) influence of geological processes on human societies, e.g. volcanoes, earthquakes, or selected deposits, e) field trip illustrating geotectonic processes and landscape evolution in a selected region. The last field trip, which will be reported here, was carried out in the Albulapass area.

Interdisciplinary project in surveying and mapping, in collaboration with mathematics.

Surveying is usually carried out on demand of a local authority, so the students know that their project is useful and will contribute to sustainable development of a municipality. It takes usually 1.5 weeks of fieldwork with surveying devises and final construction of a map. Following a student's report from such a project:

"Die Vermessung der Doline

Die Doline liegt oberhalb des Lai da Palpuogna am Hang zwischen zwei Geröllhalden. Das Wasser hat unter der Erde im Kalkgestein eine Höhle ausgewaschen bis die Decke der Höhle so dünn wurde, dass sie einstürzte und die Doline bildete.

Wir hatten die Aufgabe, die Doline zu vermessen. Um die Grösse der Doline zu bestimmen, steckten wir ein Polygon um sie herum ab. So konnten wir mit dem Theodolit die Winkel des Polygons und den Rand der Doline bestimmen. Mit dem Nivelliergerät massen wir die Steigung des Hanges. Das steile, schwierige Gelände erschwerte uns die Arbeit beträchtlich.

Um die Tiefe der Doline zu bestimmen, spannten wir ein Seil von oben bis unten. An diesem befestigten wir alle vier Meter eine Senkrecht hängende Schnur. Diese schnitten wir direkt über dem Boden ab. Die Schnüre wurden ausgemessen und mit diesen Massen konnten wir ein Höhenprofil zeichnen. Dasselbe machten wir für ein Querprofil. Aus diesen Profilen konnten wir die tiefste Stelle in der Doline errechnen.

Unsere genaue Vermessung wird in Zukunft sehr wichtig sein, um festzustellen, ob sich der Boden noch weiter bewegt. Der Albula-Tunnel ist sehr sanierungsbedürftig und um ihn während der Sanierungszeit nicht schliessen zu müssen steht die Frage, einen zweiten Tunnel zu bauen. Um aber bohren zu können, ohne dass die Doline weiter einstürzt (oder der See ausläuft), muss beobachtet werden können, ob sich die Doline bewegt.

Trotz des Regens und mit der Hilfe von Frau Heer konnten wir die Vermessung genau und ordentlich zu Ende bringen. Unsere Gruppe war motiviert und ehrgeizig. Es war uns ein Trost, zu wissen, dass wir nicht ohne guten Grund in Kälte und Nässe ausgeharrt haben um zu vermessen."



Fig. 1 Zusammenfassung der Vermessung der Doline SW⁴ Lai da Palpuogna. Monitoring Punkte (L1, N, J, K, D, Q, T, O, P, R und S) sind eingemessen und dienen der Beobachtung von Hangbewegungen.

Exploring secondary school students' conceptual understanding of hillslope springs through learning process analyses

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The relevance of teaching hydrological concepts in compulsory education is given by the fact that it has become a sociopolitical and future-orientated necessity to constitute an understanding of "water knowledge" (UNESCO-IHE, 2007). However, prior research has indicated that students of all ages show little understanding of hydrological processes (e.g. Reinfried, 2006). To better understand students' learning processes concerning hydrological issues and the difficulties related to them an analysis of 13-year old lower secondary school students' learning pathways when trying to understand the concept of hillslope springs and spring water pollution was conducted. Freshwater springs play an important role in the context of "water knowledge" because they are at the intersection of subsurface and surface water.

To better understand students' learning processes an explanatory in-depth investigation based on the case study method was employed (Reinfried et al., 2012). Based on the principles of constructivist learning theory and conceptual change theory (e.g. Vosniadou, 2008) we developed a learning environment aimed at deep understanding and mental model building of the hillslope spring concept. To better understand (1) how students construct their knowledge and (2) what their difficulties are in understanding the complex concept of hillslope springs, we subsequently conducted a learning process study in which we explored students' learning pathways when studying with our constructivist learning environment. The following research questions were addressed:

- In which way do lower secondary school students construct their mental models of hillslope springs when learning with our learning environment?
- Does in-depth learning and conceptual change occur and on what does it depend?
- What role does the pre-instructional knowledge play in the students' mental model building process?

Ten students of the 7th grade (M_{age} = 12.4 years, 5 boys, 5 girls) from a Swiss suburban middle school were selected for the analysis of their learning pathways. The study employed an instructional sequence embedded in a pre-/post-test design, providing quantitative and qualitative data. The students' knowledge and mental models of hillslope springs before and after the instruction were explored using a questionnaire that included 30 knowledge questions and a request to draw an annotated sketch of how they understand freshwater springs. During an instructional session, which took 60 minutes, two students, working in pairs, were guided through the learning process by a tutor. The students worked with worksheets, experiments and two physical models of freshwater springs. After the instructional session they were questioned about their learning difficulties in a one-on-one tutoring interview with each learner. The entire session was videotaped. The transcripts of the videotaped instructional session, students' annotated drawings, their answers to the questions in the questionnaires and the transcripts of the interview served as database. Following the different steps of qualitative content analysis (Mayring, 2008), the video and interview transcripts, the drawings and texts were interpreted, systematically categorized, generalized and contrasted.

The synopsis of the data allowed an analysis of each student's learning process in relation to his or her pre-instructional knowledge. The analysis of the learning pathways showed that the pre-instructional knowledge had the most significant influence on mental model building and conceptual change. Students' who had no or only little prior knowledge about freshwater springs and who could only resort to general naïve ideas constructed new mental models that were very similar to the scientific model used in the learning environment. Their conceptual change concerned the change or adaption of their pre-instructional cognitive schemata. Students who showed elaborated but false mental models that were based on personal experiences with freshwater springs showed great difficulties in changing their personal mental models and adapting them to the scientific model. Apparently, their initial but false mental models, constructed through real world experience in social contexts and thus emotionally charged offered a greater subjective plausibility to them than did our teaching materials.

The results of this study are of great significance for instructors on all levels. Even if an appropriate, theory-based and effective learning environment is available to teach a certain topic, teaching for deep understanding involves:

- 1. analysing students' conceptions developed both before, during and after instruction using formative assessments,
- 2. finding and coordinating analogies and dissonance producing events that take the students' alternative conceptions into account and
- 3. integrating metacognitive sequences in the lessons in which the students' explain how they understand the topic in question and reflect about similarities and differences between their personal mental models and the scientific model. If instructors learn how to make use of mental model evolution strategies, their teaching for meaningful conceptual change will be more effective.

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P 1.1

Seismo at School – introducing seismology to the classroom in Switzerland

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"Seismo at School" (www.seismoatschool.ethz.ch) is an educational program that aims to promote awareness of earthquake hazard and risk, and at the same time develops and provides material to use topics from earthquake science in school education, in a close collaboration between scientists and teachers.

As one part of the project, seismic stations are installed at schools and used to record real-time seismic activity. These stations meet, to a large extent, the technical standards of the national seismological monitoring networks operated by the Swiss Seismological Service (SED). Earthquake databases for classroom use are generated by compounding event data recorded at the school stations with data from broadband stations of the national network, and, for large global events, also with data from global scientific and school seismic networks. The installation of seismic stations in schools, and further operation of the stations by the schools, requires dedicated involvement and training of teachers. This is achieved by working directly with the involved teachers at schools in the form of workshops, and by offering seminar days at ETH Zurich in collaboration with the *focus*Terra earth science information center (www.focusterra.ethz.ch).

As a second part of the project, educational materials and concepts are developed in close collaboration with involved teachers, which can be used by all schools, irrespectively of whether they host a seismic station.

The rich collection of earthquake data together with tools & software for data analysis, online courses, movies, bibliographies, and the various educational materials are openly available on a web platform, thus creating a extensive resource center for educational activities.

Having been launched in 2010, the Seismo at School network today involves eight schools with their own seismic station, with the aim of installing a total of 26 stations in as many schools over the next years.

Seismo at School is also integrated in European and global school seismology activities and actively engages in collaborations to develop new materials, exchange data, and to foster connections among participating schools.

The Seismo at School project is partially sponsored by the Swiss Federal Office of the Environment (BAFU).



P 1.2

Fehlvorstellungen zum Thema Jahreszeiten und deren Änderungen durch den Unterricht

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Sommer, Winter, Frühling und Herbst sind vertraute Begriffe seit der Kindheit. Sie bezeichnen die Jahreszeiten, die das Jahr bei uns in verschiedene Perioden unterteilen. Jedoch nicht überhall auf der Erde gibt es vier Jahreszeiten. An den Polen unterscheidet man nur das Sommer- und das Winterhalbjahr; innerhalb der tropischen Zone findet man hingegen nur Trocken- und Regenzeiten.

In Spontansituationen, wenn Leute die Entstehung der Jahreszeiten erklären sollen, wird häufig wie folgt argumentiert "Im Sommer ist es wärmer, weil die Erde näher an der Sonne ist" (Alean 2009).

Diese Antwort stammt aus der intuitiven Überlegung, dass die Wärme zunimmt je mehr man sich einer Wärmequelle nähert. Alltagsvorstellungen sind mentale Konstrukte, welche das Vorstellungsbild aus Ausschnitten der Realität zusammensetzen (Reinfried 2006). Sie werden als Fehlvorstellung bezeichnet und sie spielen eine wichtige Rolle für die Wissenserwerbung (Vosniadou et al. 2001).

Im Rahmen meiner Geographielehrerausbildung habe ich das Thema von Fehlvorstellungen im Geographieuntericht am Beispiel von Jahreszeiten untersucht. Das Ziel war es eine Unterrichtstrategie zu entwickeln, die die Fehlvorstellungen zum Thema Jahreszeiten abbauen kann. Als Ausgangspunkt wurde das Vowissen der Schüler und Schülerinnen einer dritten Klasse (neuntes Schuljahr) erhoben. Basierend auf der 4-Phasen Strategie von S. Reinfried (Reinfried, 2006) zum Aufbau von mentalen Modellen im geowissenschaftlichen Unterricht wurde anschliessend eine Unterrichtseinheit geplant

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2. Structural Geology, Tectonics and Geodynamics

Neil Mancktelow, Guido Schreurs, Paul Tackley

Swiss Tectonics Studies Group of the Swiss Geological Society

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Thermo-mechanical model for the finite strain distribution in kilometerscale shear zones

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We present a one-dimensional shear zone model which considers a power-law flow law and a temperature dependent viscosity. The analytical solution for the velocity profile across the shear zone depends on the single dimensionless parameter β . β depends on the activation energy of the applied flow law, the temperature at the base of the shear zone and the temperature difference across it. We then derive the analytical solution of the ellipticity of strain ellipses along the shear zone. We perform a systematic parameter search over 1) the rheological parameter β , 2) the mean finite strain γm of the shear zone and 3) the shear zone thickness. We thus determine the parameters that provide the best fit between sets of strain ellipses measured in natural kilometer scale shear zones and our model (Figure 1). The estimates of β from the fitting are consistent with the ones based on temperature estimates from field data and laboratory derived activation energies of crustal rocks. Our simple 1D analytical solution can predict the nonlinear distribution of finite strain across natural kilometer-scale shear zones as a function of temperature increase across shear zones controls to first order the observed nonlinear increase of finite strain towards the base of the shear zone. In the lowermost tens of meters natural shear zones often exhibit a stronger increase of finite strain (often expressed by mylonitic texture) than predicted by our simple model. This deviation from our model is likely caused by processes not considered in the model, such as for example, grain-size reduction, effects of fluids or viscous shear heating.



Figure 1. Model results showing the influence of the parameter β on a) velocity, b) strain rate and c) ellipticity profiles across the shear zone. The influence of the mean finite strain γ m on the finite deformation is illustrated in d). Strain ellipses have been calculated by deforming small initial circles, which have been scaled up, with the analytical velocity profile.

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2.2

Early Mesozoic rift-related sandstones of the Southern Alpine Tethys margin characterised by detrital zircons: U-Pb dating and Hf-isotopes analysis

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Detrital zircons from Triassic and Jurassic rift-related sandstones from the southern margin of the Alpine Tethys (SMAT) were analysed in order to characterise the age of the sources and the origin of the magmas in which the zircons have crystallised. We present results from: (1) The Fuorn Formation in the Upper Austroalpine Silvretta nappe, which represents tidally influenced shallow marine deposits of Early Triassic age (e.g. Furrer et al., 2008). (2) The Middle Jurassic Saluver Fm, which is situated in the Lower Austroalpine Err nappe and represents an example of turbiditic sandstones and breccias deposited during protracted rifting along the SMAT (Finger et al., 1982). (3) Two volcaniclastic layers within the Middle Triassic (Ladinian) carbonates of the Upper Austroalpine Silvretta nappe; the lower layer is interbedded in the Prosanto Fm (called Ducan-I) and the upper one is interbedded in the Altein Fm (Ducan-II) (Furrer et al., 2008). (4) The Carnian Val Sabbia sandstone located in the South Alpine domain, which is considered a continental terrigenous-volcaniclastic sequences with palaeocurrents from the south (Crisci et al., 1984).

The U-Pb zircon ages of the Fuorn Fm show a population spanning from 310 to 260 Ma with a peak at ca 292 Ma. Thus, the Fuorn Fm was mainly sourced in Permian igneous rocks and volcaniclastics, which obviously were exhumed and eroded at the SMAT during the Triassic. Schaltegger and Brack (2007) suggest that Permian magmatism and associated basin formation occurred during major post-Variscan extensional and strike-slip movements between ca 285 - 275 Ma, which is in line with our results. The calculated epsilon-Hf values of the Permian detrital zircons between +5 to -5 indicate contamination of mantellic magmas with crustal material and depict probably two different sources of similar age.

U-Pb ages of detrital zircons from Saluver Fm have a dominant population from ca 320 to 250 Ma with a peak at ca 300 Ma and other minor populations from 460 - 420 Ma and from 1 - 0.95 Ga. The calculated epsilon-Hf values of the eroded Variscan and late-Variscan (Permian and Carboniferous) zircons lie between -3 to +7, indicating contamination of the magma source with crustal material. The present Saluver Fm sandstone was mainly sourced in Variscan and post-Variscan magmatic and volcaniclastic rocks, whereas no Triassic magmatic rocks were exposed in the source areas.

Detrital zircons from the volcaniclastic layer Ducan-I show a U-Pb age spectrum spanning from 268 to 228 Ma with a peak at ca 252 Ma. The calculated epsilon-Hf values range between -1 to +8, indicating magmas with high contribution of juvenile mantle sources with slight contamination by crustal material. The U-Pb ages of detrital zircons from the second volcaniclastic layer Ducan-II shows a range from 264 to 238 Ma with a peak at ca 247 Ma. The calculated epsilon-Hf values range between -4 to +4, which point to contamination of mantellic magmas by crustal material. The differences of the measured Hf - isotope ratios between these two volcaniclastic layers can be explained by two scenarios: (i) The two volcaniclastic layers were sourced by two different magma reservoirs; one more contaminated by crustal material sourced Ducan-II and the other one with more influence of juvenile material sourced Ducan-I. (ii) The evolution of a single source where the reservoir first was dominated by juvenile mantle material (Ducan-I) and subsequently more contaminated by crustal material (Ducan-II).

The U-Pb age population of detrital zircons from the Val Sabbia sandstone covers the time span from 257 to 220 Ma with a peak at ca 240 Ma. The younger age spectrum (240-220 Ma) correlates with other Ladinian and Carnian volcanic and volcaniclastic formations in the Austroalpine domain. The epsilon-Hf values (-6 to -3) suggest a mantle source highly mixed with crustal material.

There are contrasting models proposed to explain the Triassic Alpine magmatism, either within an extensional environment (e.g. Crisci et al., 1984) or in a subduction-related setting (e.g. Castellarin, 1988). The results from Triassic detrital zircons corroborate the model of Crisci et al. (1984). These authors suggest the origin of the magmas through partial melting of an upper mantle, which was deeply modified during the previous Variscan orogeny. The rising melts included crustal material during early stages of rifting along the SMAT.

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2.3

Early Cretaceous Triassic salt extrusion rates at Jebel Ech Cheid (N. Tunisia, southern Tethyan passive marge)

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We apply the logic of (Talbot and Jarvis, 1984) to calculate the extrusion rates and likely heights reached by Triassic salt at Jebel Ech Cheid during Barremian-Aptian, Late Aptian, Late Cenomanian and middle Turonian times (Ben Slama, 2011; Ben Slama et al., 2012). The results allow us to reconstruct the movements of the Triassic salt during its Early Mesozoic history. The extrusion rate may have exceeded 55mm year-1 and the salt fountain reached higher than 600 m in the Early Cretaceous sea if its vent was then narrower than its current maximum width.

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2.4

Oblique normal faulting in carbonates at different crustal levels: examples from the SW Helvetics and Central Apennines

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For the same general boundary conditions, oblique normal faults can generate crustal earthquakes of larger magnitude than those generated on dip-slip normal faults of similar size (Ranalli, 1987). In order to provide constraints on the processes involved in fault slip accumulation on oblique normal faults, the current study describes the fault architecture in field exposure of such faults exhumed from different crustal levels. Fault length (12-20 km), accumulated displacement (1-2 km) and lithology (carbonate rich passive margin sequences) are comparable for the examples from the SW Helvetics and the Gran Sasso (Central Apennines). However faults from the SW Helvetics show an interplay between brittle and ductile structures whereas those from Gran Sasso were entirely brittle during seismic faulting. Most large crustal earthquakes are triggered on faults at the brittle-ductile transition, which in the continental crust commonly occurs in sedimentary rocks buried to depths of 8 to 13 km, depending on the geothermal gradient and the tectonic regime (in particular, whether faults are dominantly normal, thrust or strike-slip). In the SW Helvetics, oblique normal faults that developed during Neogene time under very low metamorphic grade and cross-cut the Alpine nappe-stack are currently exposed at the surface. Some of these faults were probably seismogenic when active at depth and represent exhumed "fossil" structures comparable to currently active faults in this active seismic area north of the Rhône Valley. The fossil fault structures developed at the brittle-ductile transition and experienced little significant late brittle overprint during exhumation. Locally, it is possible to establish a transition from mylonitic to cataclasitic fabrics (e.g. on the Rezli fault), with a complex interplay of processes including pressure solution, veining, mineralization on fault planes and repeated brecciation. Generally, the fault architecture, as well as the vein distribution and composition, changes with the lithology, and therefore varies both along and across major faults. Where fault displacement is large and different formations are juxtaposed across a fault, the fault core and damage zones develop a complex architecture involving more important fluid circulation, veining and fluid-rock interaction, whereas faults with minor displacement (a few metres) are generally simpler and narrower, with veining concentrated close to the fault. This implies that the damage zone tends to broaden with increased displacement, rather than the fault increasingly localizing on a narrower zone. However, there are also many examples of fault localization on a late discrete surface. Veining and pressure solution are apparently always related to the initial stages of faulting. Mode 1 extensional veins, commonly developed in an en-echelon pattern, are locally dissolved by stylolites, which are themselves later crosscut by later veins and, finally, also by discrete fault planes. This implies multiple and interrelated processes of dissolution, crack opening, and mineralization during intermittent and repeated faulting. In the Gran Sasso, the outcropping faults were exhumed from depths of < 2 km and therefore provide information on the near-surface development. The faultcore is characterized by fault gouge and crusts of ultracataclasite preserved in the hanging wall of the main oblique normal WNW-ESE- and E-W-striking fault planes of Gran Sasso. Such faults displace Quaternary breccias and soils, showing recent activity. Ultracataclasite and very rare deformed veins infill cracks with an opening direction parallel to fault slip. Coarse grained porous cataclasites are cross-cut by Riedel planes defining book-shelf domino-type structures. This indicates fluidization of the fine grained cataclastic material and preferential slip on the main fault surface and gouge. The damage zone ranges from 5-10 m in the foot wall and up to 20 m in the hanging wall, whereas the fault-core is concentrated within a few metres of the fault plane. Repeated brecciation is also shown by reworking of cataclasites and the truncation of faulted breccias, suggesting a continuous rejuvenation of the fault plane and fault zone thickening. Between the fault-core and the damage zone, lenses of cataclasites are cross-cut by NW-striking normal faults which terminate on the cataclasites belonging to the main oblique slip planes. This geometry suggests that internal fragmentation of the fault structure was related to the regional stress orientation (i.e., SW-directed extension) whereas the main oblique faults remained preferential surfaces for reactivation and slip accumulation. The NW-striking normal faults can be interpreted as having formed in foreshock sequences of very low magnitude within the WNW-ESE striking fault zones, before the final activation of the main fault plane during the main shock. During the L'Aquila earthquake of 2009 (Mw = 6.3), purely normal faults were activated whereas contiguous oblique normal main faults in the Gran Sasso (e.g. Assergi and Campo Imperatore Faults) were not, despite their well established Quaternary activity. Considering that fault structures and boundary conditions of the Gran Sasso faults are similar to the ones involved during the L'Aquila earthquake, the termination of epicentres on NW-striking normal faults at the western tip of the Assergi Fault suggests that this fault could be seismically activated in the future. Generally, the fault damage zone is narrower in the SW Helvetics compared to the Apennines, implying that near the brittle-ductile transition there is less damage zone broadening with increasing displacement, possibly due to higher confining stress and pore pressure. In conclusion, fluid circulation, pressure-solution and veining are the most important processes that contribute to fault localization near the brittle-ductile transition. Closer to the surface, grain size reduction, fluidization and gouge formation become the most important factors promoting slip.

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Symposium 2: Structural Geology, Tectonics and Geodynamics

Self-consistent modelling of planetary differentiation and onset of mantle convection on Mars. A comparative study in 2D and 3D

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The exact mechanism of core-mantle differentiation and the formation of the crustal dichotomy and the Tharsis rise on Mars, are still unresolved problems. I, therefore, investigate a hypothesis which numerically combines both exogenic and endogenic processes, where a giant impact event and subsequent vigorous mantle convection are building the southern highland crust. I focus on the effect, various initial factors have on core and crustal formation. Key factors of interest are the impactor core temperature, the initial planetary iron and silicate temperature, as well as the initial setup and the impactor size.

A hemispherical magma ocean can be observed at the impact site which spreads over the planet's surface and finally builds one large patch of thicker crust. In the special case of very hot iron diapirs or a hot protocore, an additional magma ocean at the depth of the core-mantle boundary develops. In the case of a very hot impactor and cool protocore, the impactor core will form a hot liquid outer core, surrounding a solid inner core and enable dynamo generation.

2.6

Mechanical versus kinematical shortening reconstructions of the Zagros High Folded Zone (Kurdistan Region of Iraq)

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This work (Frehner et al., 2012) compares kinematical and mechanical techniques for the palinspastic reconstruction of folded cross sections in collision orogens. The studied area and the reconstructed NE–SW trending, 55.5 km long cross section is located in the High Folded Zone of the Zagros fold-and-thrust belt in the Kurdistan region of Iraq. The present-day geometry of the cross section has been constructed from field as well as remote sensing data (Figure 1a). In a first step, the structures and the stratigraphy are simplified and summarized in eight units trying to identify the main geometric and mechanical parameters. In a second step, the shortening is kinematically estimated using the dip domain method to 11%–15%. Then the same cross section is used in a numerical finite element model (Figure 1b) to perform dynamical unfolding simulations (Schmalholz, 2008; Lechmann et al., 2010) taking various rheological parameters into account.

The main factor allowing for an efficient dynamic unfolding is the presence of interfacial slip conditions between the mechanically strong units (Figure 2a). Other factors, such as Newtonian versus power law viscous rheology (Figure 2a) or the presence of a basement (Figure 2b), affect the numerical simulations much less strongly. If interfacial slip is accounted for, fold amplitudes are reduced efficiently during the dynamical unfolding simulations, while welded layer interfaces lead to unrealistic shortening estimates (Figure 2). It is suggested that interfacial slip and decoupling of the deformation along detachment horizons is an important mechanical parameter that controlled the folding processes in the Zagros High Folded Zone (Frehner et al., 2012). A similar conclusion has recently been found by Yamato et al. (2011) for the Iranian part of the Zagros fold-and-thrust belt using numerical forward modeling.



Unit 5

Unit 7

Unit 2

Figure 1. a) Geological cross-section through the Zagros Simply Folded Belt in NE Iraq constructed from field- and remote sensing data. b) Finite-element mesh of the SW part of the same cross-section used for numerical unfolding simulations.



Figure 2. Mean amplitude decrease during the different progressive dynamical unfolding simulations without basement (a) and including a basement at depth d (b). The thick black line is the same in both subfigures. The legend in the top left corner in b) corresponds to simulations using a Newtonian rheology. The second legend corresponds to simulations using power law viscous rheologies. Kinematical pure shear is equivalent to a dynamical unfolding simulation with no mechanical difference between the layers (MAD = s).

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NE

2.7

Tectono-magmatic crustal convection produces novae and coronae on Venus

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Novae and coronae are characteristic surface features on Venus but their origin and relationship remain enigmatic. Several competing hypotheses were proposed for both coronae and novae based on variability of their sizes, shapes, internal structures and topography, yet little work has been done for quantitative testing of these hypotheses.

Here we demonstrate based on new high-resolution three-dimensional thermomechanical numerical model that formation of medium sized (50-300 km) novae and coronae can be explained by tectono-magmatic interaction of mantle plume with hot and thin lithosphere, which has thick low-viscosity lower-middle crust and thin brittle upper crust characterized by elevated surface temperature. According to this model, decompression melting of hot plume material produces large amount of magma, which intrude into the ductile lower crust, and triggers crustal melting and convection.

The crustal convection cell exists for up to several tens of millions years where plume magma and partially molten lowermiddle crustal rocks interact and mechanically mix causing gradual thinning of the brittle upper crustal lid. The long time span of the convection cell is maintained by the plume heat, which causes gradual warming and melting of crustal rocks. Novae forms at the initial stage of the process by radial fracturing of the uplifted region above the convection cell center.

At the later stage, such novae can be converted into coronae by concentric fracturing of thinned upper crustal lid and subsequent overthrusting of partially molten lower-middle crustal rocks over the surface of the down-bending brittle upper crust. Concentric normal faults form in the extensional outer rise region of the bending crust. In contrast, concentric thrust faults form in the advancing front of the advancing overriding crustal wedge. Deep trench-like depression forms in between these two contrasting tectonic regions.

The process resembles subduction with important difference been that no slab is formed and subducted cold upper-crustal lid warms up rapidly and recycles into the convection cell. Model further suggests that coronae and novae fracture pattern and topography evolve with time with different stages been corresponding to various types of these patterns observed on Venus.

Symposium 2: Structural Geology, Tectonics and Geodynamics

Structure and evolution of the Central Andes of Peru

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Based on fieldwork the structural style and the kinematic evolution of the Peruvian Andes are analyzed. A quantitative estimate of the shortening of the orogeny was obtained from the construction of two transects that run from the Pacific coast to the undeformed Amazon foreland. The Coastal Belt consists of a Late Jurassic – Early Cretaceous volcanic arc sequence that was accreted to the South American craton. The volcaniclastic deposits are characterized by relatively open folds which were intruded by the Coastal Batholith in Late Cretaceous times. The Mesozoic strata of the adjacent Western Cordillera represent an ENE-verging fold-and-thrust belt.

Tight symmetrical folds developed above a detachment horizon. In contrast, steeply dipping reverse faults and open folds are observed in the Neoproterozoic crystalline basement and the Paleozoic sediments of the Eastern Cordillera. The reverse faults are in part of transpressive nature and uplifted large blocks of basement rocks.

The Central Highlands between the two cordilleras forms a transition zone. Here, late Paleozoic and, restricted to the western part, Mesozoic strata display open folds. In the Subandean Zone, Paleozoic and Cenozoic strata are affected by mainly NE-verging imbricate thrusting. Total shortening of the two transects is 120 - 150 km (24 –27%), most of which is taken up by the Western and Eastern Cordilleras.

Three major deformation phases can be recognized in the study area. The earliest, the Mochica Phase corresponds to the open folding of the Coastal Belt and is sealed by the Coastal Batholith. The tight folding and thrusting in the Western Cordillera and the neighboring Central Highlands and Eastern Cordillera is attributed to the Inca Phase. This phase is sealed by the unconformity at the base of the Paleogene volcanics. The last phase, called Quechua Phase, can be subdivided into several episodes and accounts for the imbricate thrusting in the Subandean zone involving Neogene and even Pliocene sediments. The Central Highlands were uplifted as a block in the process. Post-Eocene thrusting in the Western Cordillera uplifted this mountain range relative to the Central Highlands. The most recent episode can be correlated with unconsolidated Pleistocene sediments that are folded in the Central Highlands and cut by a steep reverse fault bordering the Cordillera Blanca.

Highlights:

- \bullet Two balanced sections yield a total shortening of 120 150 km across the Andes of Peru.
- The structural style is governed by NE-verging thrusts and various detachment horizons.
- Neogene deformation was responsible for the uplift of the entire orogen.
- A late fault system raised the Western Cordillera relative to the Central Highlands.



Figure 1. Cross-section showing the geometry of the subduction zone and the general structure of the Central Andes of Peru.

2.9

The St.Gallen Fault Zone (NE Switzerland): A long-lived, multiphase structure in the North Alpine Foreland - Insights from high-resolution 3D seismic data

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Surface geology and reflection seismic data in NE Switzerland show that the Mesozoic and Cenozoic formations of the North Alpine Foreland are widely lacking large extensional faults (Nagra 2008). The only existing large structures are represented by either the NW-SE striking normal faults of the Freiburg-Bonndorf-Hegau-Bodensee half graben or by the WSW-ENE striking Baden-Irchel-Herdern lineament. Furthermore, there is a NNE-SSW striking fault zone, cross-cutting almost the entire Molasse Basin between the Bodensee and the city of St.Gallen (Nagra 2008; Sommaruga 2011). This zone, termed here St.Gallen Fault Zone (SFZ), is more than 30 km long and consists of normal faults interpreted from 2D seismic data. It offsets the complete Mesozoic sedimentary cover by several decametres up to approximately 200 m. Offsets of the Tertiary Molasse units are known from a few seismic sections in the northernmost part of the SFZ near the Bodensee. There, the uppermost Tertiary unit, the Upper Freshwater Molasse (OSM) seems to be faulted up to the Base Quaternary. However, the SFZs topmost (Tertiary to Quaternary) extent is vastly unknown as faults are difficult to seismically identify due to the laterally very variable Molasse lithologies and because the fault's potential surface expression is obliterated by young glacigenic landforms.

To precisely locate the individual faults of the SFZ and the target aquifers (Upper Malm, Upper Muschelkalk) for the St.Gallen Geothermal Power Plant Project, a 270 km² 3D seismic survey was performed in 2010. Here we present first results of the stratigraphic and structural interpretation of this new 3D seismic data set. The SFZ is defined by an up to 1 km wide zone mainly comprising 70-80° ESE-dipping normal faults and local reverse faults. The northern part strikes N-S to NNE-SSW and delimits a Late Paleozoic to Tertiary graben to its east. The eastern edge of this graben is represented by the Roggwil Fault Zone (RFZ) consisting of NW-dipping normal faults. The southern part of the SFZ strikes NNE-SSW and exhibits significantly less faults throw. Here, the SFZ rather represents a flexure zone with only small segments of normal faults offsetting mainly the lower Mesozoic units.

Seismic stratigraphy analyses indicate at least three synsedimentary normal faulting events during the Mesozoic. Furthermore, faulted OSM marker horizons indicate continued normal faulting until at least the mid-Miocene. Additionally, the SFZ and the RFZ seem to root in extensional pre-Mesozoic basement structures that may border comparatively small Permo-Carboniferous troughs. Although a detailed seismic stratigraphy analysis on the Mesozoic and Permo-Carboniferous has not yet been performed we are able to postulate a multiphase tectonic activity along the SFZ.

Geological mapping along the Sitter valley in the area of Bernhardzell revealed indications of normal faults in the OSM (e.g. Hofmann 1951) that might be genetically linked to the faults of the SFZ. Schrader (1988) analysed deformed pebbles in conglomeratic Molasse (mainly OSM) units in the North Alpine Foreland Basin. He postulated for the St.Gallen-Bodensee region that this post-OSM deformation must have taken place in a strike-slip to normal faulting regime with compression in NNW-SSE direction and extension in WSW-ENE direction. The same principal stress directions were derived from fault plane solutions of recent seismic events in NE Switzerland (Kastrup et al. 2004). Thus, the overall stress field does not seem to have changed significantly since the Late Miocene. With this stress field it is obvious that the faults of the SFZ are ideally oriented (at an angle of about 30°) to have been reactivated in a transtensional mode. From a geothermal exploration point of view, this is an important finding indicating that these faults might exhibit an increased permeability.

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2.10

Thin- vs. Thick-skinned tectonics in the Alpine foreland of central northern Switzerland: New perspectives based on reprocessed and new reflection seismic data

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The question whether the Late Miocene propagation of the Central Alpine deformation front far into the northern foreland of the collision zone was thin-skinned, thick-skinned or something in between (compare Pfiffner, 2006) is the matter of a long lasting scientific debate. It is considered of fundamental importance for a better understanding of the late stage and future evolution of the Alpine orogen (Rosenberg and Berger 2009) and for seismic hazard assessment in the Northern Alpine Foreland (e.g. Schmid & Slejko, 2009).

One of the key investigation areas in this regard is the Alpine foreland of central northern Switzerland (Laubscher, 1986). In this region, the Late Miocene to Early Pliocene Jura fold- belt - widely accepted to have been formed by thin-skinned distant push -was thrusted onto a Permo-Carboniferous trough. The latter has been considered to be potentially reactivated in a thick-skinned manner by many authors ever since its identification.

As part of its exploration program of potential siting regions for deep geological repositories Nagra recently re-processed existing 2D- reflection seismic data across the eastern-most Jura fold-belt and the adjacent parts of the Swiss Molasse Basin. In addition, an extensive new dataset of more than 300km high resolution seismic profiles was acquired during the winter of 2011/12. We will present an overview and first insights into the ongoing interpretation of these new datasets. Critical aspects concerning the seismic interpretation of a thin-skinned, thick-skinned or combined tectonic scenario will be discussed.

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2.11

New time-constraints on the prograde metamorphism in the High Himalaya of NW Lahul (NW India)

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In the central parts of the Himalayas, the High Himalayan Crystalline (HHC) high-grade rocks are mainly exhumed in the frontal part of the range as a consequence of a tectonic exhumation controlled by combined thrusting along the Main Central Thrust (MCT) and extension along the South Tibetan Detachment System (STDS). In the NW Himalaya, however, the hanging wall of the MCT, in the frontal part of the range, consists mainly of low- to medium grade metasediments, whereas most of the amphibolite facies to migmatitic paragneisses of the HHC of Zanskar are exposed in a more internal part of the orogen as a large scale dome structure referred to as the Gianbul dome.

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This Gianbul dome is cored by migmatitic paragneisses symmetrically surrounded by rocks of the sillimanite, kyanite ± staurolite, garnet, biotite, and chlorite mineral zones. The structural data from the Miyar-Gianbul Valley section reveal that the Gianbul dome is bounded by two major converging thrust zones, the Miyar Shear Zone (MSZ) and the Zanskar Shear Zone (ZSZ), which were reactivated as ductile zones of extension during early Miocene (Dèzes et al., 1999;).

Structural and metamorphic data indicate that the Barrovian metamorphism observed in the northern limb of the dome results from the northwestward underthrusting of the HHC of Zanskar beneath the sediments of the Tethyan Himalayan that occurred between 35 and 28 Ma (Vance and Harris 1999; Walker et al 1999). In contrast with the tight constraints on the timing of the tectonometamorphic evolution of the NE half of the Gianbul dome, the timing of the crustal thickening and subsequent extension on the southern limb of the dome is poorly constrained. On the southern limb of the dome, the Miyar Valley represents a natural cross-section through the southern half of the HHCZ of Zanskar. Moving northward along the valley, the metapelites of the HHCZ preserve a typical Barrovian metamorphism characterized by the succession of chlorite, biotite, garnet, kyanite + staurolite, sillimanite and migmatite zones.

The main tectonic structure in the Miyar valley corresponds to the SW-dipping Miyar Shear Zone. Sheath folds testify to an intense ductile deformation in this shear zone, and a clear top-to-the-NE shear sense is indicated by sigma clasts and shear bands. Sigmoidal inclusion trails in syntectonic garnets in the amphibolite facies paragneiss support a syntectonic growth associated with NE-directed movements. Across the Miyar Shear Zone, the contractional structures are superposed by SW-dipping extensional shear bands and sigma clasts indicating a top-to-the SW sense of shear. These observations reveal that the Miyar Shear Zone was reactivated as a ductile zone of extension (Steck et al., 1999).

One of the major features of the tectonometamorphic evolution of the HHC in the southern limb of the Gianbul dome is that the metamorphism and tectonism in this portion of the Himalaya relates to NE-directed thrusting. In order to bring geochronological constraints on the regional metamorphism observed on the southern limb of the dome, the prograde sequence of allanite and monazite has been investigated in detail.

Along the Miyar Valley, allanite appears to be the LREE-stable accessory phase at greenschist facies conditions. Its first occurrence coincides with the stability field of biotite suggesting a temperature of 430–450 °C for its growth. Moving upsection, the first metamorphic monazite forms at amphibolite facies conditions at the staurolite- in isograd. At these P-T conditions, allanite is preserved only as inclusion in garnet and staurolite indicating that allanite is replaced by monazite at ca.610-640°C.

In situ LA-ICPMS U-Th-Pb dating of the first metamorphic monazite occurring within the upper structural level of the staurolite-kyanite zone gives ages ranging between 42 and 37 Ma. These data indicate that the upper structural level of the staurolite-kyanite zone realized temperature conditions of 610-640°C during the middle Eocene. In contrast dating of monazites collected in the lower structural level of the staurolite-kyanite as well as in the structurally lower sillimanite zone provides ages ranging from 27-30 Ma. Coexisting allanite and monazite preserved in garnet porphyroblasts of the sillimanite zone give ages between 35 and 39 Ma for the allanites and between 29 and 30 Ma for the monazites. These data reveal a leap of about ten million years between monazite growth across the Miyar shear zone indicating that the contractional movements along the MSZ were active between 40 and 30 Ma. Furthermore these new data constrain the time elapsed between of 430–450 °C and 610-640°C which implies an average heating rate of ca 20-25 °C/m.y.

Combined with geochronological data from the migmatite zone (monazite, 26 Ma; Robyr et al., 2006) and from undeformed leucogranitic dykes in the centre of the dome, (monazite, 22-19 Ma; Dèzes et al., 1999; Robyr et al., 2006) the new data provided by this study allow the entire reconstruction of the tectonometamorphic evolution of the Gianbul dome.

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2.12

Towards 4D modeling of transpressional fold-and-thrust belts

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Latest developments in computer power and computational solutions open new ways to envision complex natural systems. Advances in high-resolution 3D geodynamic modeling, in particular, allow investigating complex tectonic processes like the evolution of non-cylindrical fold-and-thrust belts. We demonstrate that implementing the 4 dimensions (space and time) provides and constrains new answers to long lasting discussions. Numerically simulating fold-and-thrust belts needs accurate treatment of brittle/plastic rheology with high resolution to produce spontaneously localizing narrow high strain rate shear bands. Thrusts and flats occur where stresses overcome the material yield stress. Therefore, a numerical approach must allow very high strain rates within the décollement and the "thrusts" while respecting the rigidity of the modelled wedge sediments. Effective viscosity variations across narrow shear bands often range six orders of magnitude. This poses a strong challenge for numerically solving the Stokes and continuity equations. For this purpose, we developed a three-dimensional, high-resolution, fully staggered grid, finite difference, marker in cell model with a visco-brittle/plastic rheology and an efficient OpenMP-parallelized multigrid solver.

As a case study, we chose the Zagros Simply Folded Belt in Iran. There, the recent shortening direction is oblique to the Main Zagros Thrust, which represents the suture between the Arabian and Central Iranian continental plates. This obliquity impels lateral backstop variations that can only be introduced in a three dimensional setup. Furthermore, along-strike structural variations are observed between the the Fars domain, in the SE, towards the Izeh domain, in the NW.

Results shows how a low-viscosity décollement becoming frictional towards the Dezful embayment influences the exposed fold patterns (Figure 1). They also emphasize the importance of an oblique backstop geometry to produce en-échelon arranged folds, where convergence-related and backstop-controlled folds are mingled in the transpressional orogen.



Figure 1. Profiles y = 5, 40, 75, 110 and 145 km after a simulation time of 3.4 Ma. a) Illustration of the rock type defined on markers. Profiles 1 and 2: Pinch-out of salt towards frictional decollement. b) Second invariant of strain rate tensor.

Symposium 2: Structural Geology, Tectonics and Geodynamics

Alpine fold and thrust structures: a 3-D model of the Säntis area (Switzerland)

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The Säntis area offers one of the most spectacular insights into the fold-and-thrust belt of the Helvetic nappes. The nearly perfect outcrop conditions, combined with the exemplary intersection of formation boundaries with topography, make it a natural laboratory for structural geology. Since the pioneering work of Heim (1905) at the beginning of 20th century, the area was mapped in detail (Eugster et al., 1982) and investigated in terms of deformation mechanisms (e.g. Groshong et al., 1984), structural evolution and fold-thrust interaction (Funk et al. 2000; Pfiffner 1982, 1993 & 2011). The proposed restorations are mostly 2 dimensional palinspastic reconstructions, either in map or in cross sectional view.

The main goal of this research is to better understand the geometrical relationships between folding and thrust faulting, investigating for example fault-propagation folds and analyzing the lateral changes of folds and thrust structures along strike. A three-dimensional model of the area is built using 3D MOVE, combining cross-sections from Schlatter (1941), Kempf (1966), Pfiffner (in Funk et al., 2000; 2011), the geological map 1:25.000 by Eugster et al (1982) and a digital elevation model (DEM) with a regular grid of 20X20 m.

Six main horizons are reconstructed, corresponding to the base of the Öhrli and Betlis Limestones, the Helvetic Kieselkalk, Schrattenkalk and Garschella Fm and the Seewen Limestone. The main structural elements in the Säntis area, such as the Säntis Thrust or the Sax-Schwende Fault, are also implemented in the model. The 3-D model obtained highlights the shape of the main anticline-syncline pairs (e.g. Altmann-Wildseeli, Schafberg-Moor, Roslenfirst-Mutschen, Gulmen etc...); such fold trains vary in amplitude and wavelength along strike. The model also shows clearly the lateral extension, the trends and the variations in displacements of the principal faults. The reconstruction of 3-D horizons allows the geologists to investigate cross sections along any given directions. The 3-D model is useful to understand how the changes of the internal nappe structures, namely folds and thrust faults, change along strike. Such changes occur either across transverse faults or in a more gradual manner.

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2.14

The nature of the "Frilihorn nappe" (Valais, Switzerland)

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The Penninic nappe system of western Switzerland comprises a stack of Briançon-derived basement and cover units, known collectively as the Bernard nappe complex. It is sandwiched between relics of N- and S- Penninic basin domains. The S- Penninic Tsaté nappe tectonically overlies the Bernard nappe complex and is mainly composed of Late Jurassic to Cretaceous metasedimentary rocks such as calcschists and black shales ("schistes lustrés"), and prasinites. Predominantly at the base of the Tsatè nappe, thin slices of metasedimentary continental constituents occur, which are attributed to the Frilihorn and Cimes Blanches nappes (Escher, 1997). Their internal stratigraphy resembles the one found in typical Briançonnais cover, but the paleogeographic origin of these fragments is still controversial.

In the model of Pleuger et al. (2007), for example, the Cimes Blanches and Frilihorn nappes are derived from the sedimentary cover of the Sesia-Dent Blanche nappe. They were emplaced along a major thrust zone and were themselves overthrust by the Tsaté nappe. In contrast, Marthaler et al. (2008) suggest that the Cime Blanches and Frilihorn nappes originate from the Briançonnais continental margin and represent possibly olistoliths, which slid into the S-Penninic oceanic basin. Subsequently, the development of an accretionary prism during subduction led to the incorporation of these margin sediments into a "tectono-sedimentary mélange zone".

In this contribution we present field observations that support a tectonic model for the evolution of the Bernhard nappe complex, where stages of top-to-the N(NW) thrusting (Anniviers Phase) are followed by a phase of backfolding (Mischabel Phase). In the upper part of the Bernard nappe complex, where remnants of the Permo-Mesozoic and younger sedimentary cover sequence still rest on top of their crystalline substratum (parautochthonous Toûno and Barrhorn series after Sartori, 1987), backfolding is accompanied by strong top-to-the-S shearing. In the Le Boudri area (Figure 1) shear zones are localized in phyllitic calcschists of the Tsaté nappe. The footwall carbonates are folded into S-facing folds and disrupted fragments are incorporated into the shear zone. In the same area distinct shear planes cut through and detach several decameter-sized blocks of competent lithologies (carbonates and quartzites). Deformation in this tectonic mélange zone is highly complex. We propose that these blocks and lenses traditionally ascribed to the Frilihorn nappe are nothing else but fragments of the Toûno and Barrhorn series that were detached during strong top-to-the-S shearing along the upper limit of the Bernard nappe complex, a process which was severely underestimated so far.

The sequence and style of deformation is similar to the one observed in the Middle- and South-Penninic nappes of eastern Switzerland (i.e. Suretta and Avers nappes, Scheiber et al., 2012).



Figure 1. W-face of Le Boudri. S-vergent folding is accompanied by top-to-the S shearing, localized in minor competent lithologies. Fragments of both footwall and hangingwall carbonates are detached and incorporated into the (C'-type) shearband network (note scale!).

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2.15

The Tauern Window (Eastern Alps, Austria) – A new tectonic map, cross-sections and tectonometamorphic synthesis

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We present a tectonic map of the Tauern Window and surrounding units, combined with a series of crustal-scale crosssections parallel and perpendicular to the Alpine orogen. This compilation, largely based on literature data and completed by own investigations, reveals that the present-day structure of the Tauern Window is primarily characterized by a crustalscale duplex, the Venediger Duplex (Venediger Nappe System), formed during the Oligocene, and overprinted by doming and lateral extrusion during the Miocene. This severe Miocene overprint was most probably triggered by the indentation of the Southalpine Units east of the Giudicarie Belt initiating at around 20 Ma and linked to a lithosphere-scale reorganization of the geometry of mantle slabs. A kinematic reconstruction shows that accretion of European lithosphere and oceanic domains to the Adriatic (Austroalpine) upper plate, accompanied by high-pressure overprint of some of the units of the Tauern Window has a long history, starting in Turonian times (around 90 Ma) and culminating in Lutetian to Bartonian time (45-37 Ma).



Figure 1. Tectonic Map of the Tauern Window



Fig. 2: Profiles across the Tauern Window. Cross sections 1,10 and 11 are orogen-parallel; cross sections 2 to 9 are orogen-perpendicular, arranged going from west to east. Sections 1bis and 2bis are alternative versions of 1 & 2.

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Coupling of landscape evolution and rheologically layered thermomechanical models in three dimensions

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Surface topography and drainage topology can contain copious information about tectonic deformation. Distinguishing a possible tectonic contribution from climate factors is however controversial, and limits the potential reconstruction of deformation histories from a first grade data set. From a different perspective on surface-lithosphere interaction, recent geodynamic studies have elucidated the strong dynamic influence of erosion and sedimentation on the evolution of convergent plate margins. In studying the interplay between tectonics and surface processes, various types of numerical models have been so far capable of providing valuable yet partial insights.

Landscape evolution models (LEM) capture the operation of an excerpt, according to scale and climate, of fluvial, glacial and hillslope processes. They are well suited to specific problems with simple, feedback-free kinematics to study the response of landscape to tectonics. In contrast, large-scale thermomechanical models incorporate simplified continuous surface functions that do not respect the scale-dependency of surface processes, and that do not reproduce landscape characteristics other than gross elevation. The coupled models that have been brought forward so far, aiming at combining each side's capabilities, have been subjected to limitations like two-dimensionality, lack of rheological layering, and computationally limited resolution, exacerbating the inaccuracy of discretized divide location. These models have successfully explored the sensitivity of topography and strain partitioning, on the efficiency of surface processes, but have not advanced to addressing the evolution of drainage patterns. Such research objectives are becoming more feasible as recent developments move towards coupling LEMs to three-dimensional, rheologically layered thermomechanical models at increasing resolution. In this contribution, we present results from coupling a scale-robust LEM with a full thermomechanical model.

The new LEM code DAC combines numerical-analytical modelling of fluvial and hillslope processes, and is capable of treating large model domains at feasible numerical resolution without loss of accuracy. First, location and migration of divides is not confined to the network discretization, and the channelization threshold can be honored on sub-grid scale. Second, the analytical accuracy of divide calculations and capture events provides a balance between dynamic reorganisation, and preservation of deformed river channels and drainage basins that do not adhere to instantaneous steepest-descent assumptions. These capabilities make the LEM suited to study the transient evolution of drainage patterns with full thermomechanical feedback. The LEM is coupled to a visco-plastic code - I3VIS - that models a rheologically layered lithosphere, and accounts for phase changes, melting, and hydration processes. The thermomechanical code employs a large number of markers, a component which is useful for prediction of Lagrangian (P-)T-t paths.

We present results from our coupled models applied to set-ups with isostatic compensation as well as convergent settings and indentation. We compare convergent, fully layered lithospheric plates to basally driven critical-wedge formulations. Using established scaling relationships, we compare characteristic measures of the fluvial network (spacing, length, drainage area) to natural analogues. Coupled models show a strong dynamical feedback between the maxima of fluvial erosion and tectonic uplift.

Swiss 4D: Determination of strain rates from GNSS campaign and levelling data

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In 2010 the federal office of topography, swisstopo, carried out a GNSS campaign for the CHTRF 2010. The measurements cover whole Switzerland and lead, in combination with former campaigns (1988-2010), to a set of velocity data at more than 230 points in the horizontal plane. Vertical velocities, derived from levelling data and covering a time span of more than 100 years, are an important additional data set because vertical velocities are not available from GNSS campaign data. The combination of both measuring methods allows to extract a velocity field consisting of East, North, and Up direction.

The provided velocities show only a very weak signal – in average 0.6 mm/yr in the horizontal and a little more significant in the vertical velocity (e.g. in the alpine areas). It is a major issue, to extract the deformation field. Therefore, an adaptive least-square collocation method (ALSC) (Egli et al. 2007) is developed assuming that tectonic deformations are affecting a wide region. The correlation between the points is based on their distance. During the iterative process the weighting is adapted to the magnitude of strain rates. In mathematical terms, this is realized by deforming the metric for the correlation length determination. This decorrelates points in areas with high strain rates.

The results are a velocity and strain field for the covered area. It can be seen that the collocation technique allows to separate a regional deformation from local effects and noise. The data shows, for some areas, similar trends as derived from seismic information (Kastrup et al. 2004).

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2.18

Deformational evolution of the Aar Massif (Central Alps): From macro- to micro-scale

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The Aar massif belongs to the external massifs of the Alps and is mainly composed of granitoids and gneisses. Despite numerous detailed studies in the past decades, the overall exhumation history and the associated massif internal deformation (internal strain distribution and its evolution in time, kinematics etc.) are largely unknown at present. In this project, we aim to investigate the role of shear zones in the deformation history at a variety of scales. In this context it is important to understand their microstructural evolution, the involved deformation processes, kinematics and relative ages as well as the associated changes in rheology.

A GIS-based remote-sensing structural map, verified by fieldwork, (see Baumberger et al., this session) served as base for our investigations. Localization of strain takes place along lithological contacts between the units (Central Aare granite, ZAGr; Grimsel granodiorte, GrGr and gneisses). Furthermore, the initial magmatic differentiation in the granitoids locally controls the Alpine deformational overprint because of differences in effective viscosity during solid-state deformation. This behavior is illustrated by the increase of foliation intensity and the number of shear zones per rock volume from ZAGr to GrGr.

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2.17
Preliminary results show that deformation at the N boundary of the Aar massif has to be distinguished from the central and the southern part. In the North steep NE-SW trending foliations and shear zones with subvertical lineations represent the major structures. The shear zones acted both as normal faults and as reverse faults, which mostly used pre-existing lithological boundaries between the different gneiss units. In a later stage, E-W trending shear zones and shear bands with moderate dipping angles cross cut the earlier structures. They always show a top to the North component and might be related to the late north directed movements of the Aar massif. Yet, no absolute age dating has been performed on such structures.

In the central and southern part strain localizes along aplitic dykes and inside lamprophyre dykes as well as in discrete zones in the Granitoid rocks. This region has NE-SW (dip azimuth 130°-180°) and NW-SE trending shear zones dissecting the Central Aar granite (ZAGr). The shear zones, mostly with steep lineations, are of ductile origin sometimes overprinted in a brittle manner. Again shear sense indicators of NE-SW structures show south block up and down movements for individual shear zones. In addition some of these shear zones have both subhorizontal and subvertical lineations. They may represent a late strike-slip reactivation of earlier vertical movements.

Crosscutting relationships indicate that the NW-SE shear zones are younger than the NE-SW ones, and acted as dextral strike slip zones (subhorizontal lineations).

2.19

4-D Numerical Modeling of Crustal Growth at Active Continental Margins

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Crustal growth and topography development in subduction-related arcs are intimately related to magmatic processes and melt production above subducting slabs. Lateral and temporal variations in crust thickness and composition have been observed in nature, but until now no integrated approach is developed to comprehensively understand magmatic activities in subduction-related arcs. Here we aim at investigating the 4-D spatial, temporal and compositional character of continental crustal growth at active margins by using new 4-D (space-time) petrological-thermomechanical numerical model of a subduction-related magmatic arc.

Based on a series of numerical experiments we demonstrate that crustal growth inside the arc is inherently clustered in both space and time. The characteristic wavelength of crust thickness and topography variation along the arc is mainly defined by plate convergence velocity: faster subduction favors longer wavelength. The clusters of new crust are mainly contributed by basaltic composition episodically extracted from partially molten peridotite due to lateral variation of water release and movement in the mantle wedge. Melts derived from subducted oceanic crust and sediments could contribute up to 15-50 vol% to the arc crust growth and their relative proportion is maximal at the onset of subduction. Total amount of the newly formed crust correlates mainly with the amount of convergence since the beginning of subduction and is not strongly influenced by the plate convergence velocity. Indeed, slower subduction and lower melt extraction efficiency helps partially molten sediments and oceanic crust to be transported into the mantle wedge by hydrated, partially molten diapiric structures. Maximum of crust additional rate (25-40 km³/km/Myr) occurs when convergent amount reaches around 700 km. Mantle wedge structures developed in our models correlates well with available geophysical observations for Alaska subduction zone. In particular, partially molten mantle plumes found in our models could explain low seismic anomalies in the mantle wedge, whereas mobile water and water release patterns could reflect paths and sources for magmatic activities evidenced by seismic b-value analysis. Symposium 2: Structural Geology, Tectonics and Geodynamics

P 2.1

Dynamic recrystallization and shear heating in numerical models of lithospheric-scale shear zones

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Shear zones are usually defined as regions inhomogeneous and localized deformation. Strain softening has been demonstrated to be a necessary prerequisite for localization. However, it is not clear which physical mechanisms are responsible for this weakening. In this study, we investigate the interplay between two mechanisms that have been proposed to govern the formation of lithospheric-scale shear zones: shear heating and grain size reduction.

Shear heating has been suggested to play an important role in i) creating deep focus as well as intermediate-depth earthquakes (Ogawa (1987), Kelemen and Hirth (2007)) and ii) creating lithospheric-scale shear zones (Kaus and Podlatchikov (2006), Crameri and Kaus (2010)).

Natural shear zones are typically characterized by a significantly reduced grain size. Dynamic recrystallization has therefore been put forward as a mechanism to provide the needed strain softening to localize deformation. With reducing grain size, the dominant deformation mechanism is thought to switch from dislocation to diffusion creep, thus requiring less stress to deform the rock. Recent work (Austin and Evans (2007), Rozel et al. (2011)) suggests that the amount of dynamic recrystallization is not – as previously suggested - only dependent on stress, but on deformational work.

In this study, we employ the grain size evolution law of Rozel et al. and use 1D viscoelastic numerical models of simple shear deformation to investigate the influence of both weakening mechanisms and their interaction. We find that grain size reduction in pure olivine does not localize very efficiently, as grain size very rapidly reaches a steady state and does not allow for further localization. Even when grain size reduction processes use a fraction of the deformational work, shear heating is the dominant weakening mechanism. Inside the shear zone, grain size is significantly increased due to the high temperature. This is not compatible with field observations and indicates that different mechanisms are required to create mylonitic shear zones and/or to reduce the temperature increase due to shear heating.

P 2.2

Dynamic origin of Wilson cycles in mantle convection with self-consistent plate tectonics and continental drift

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The alternation of dispersed continent configuration and supercontinent assembly is part of the Wilson cycle. More and more evidence exist that continents have formed a supercontinent several times since the late Archaean. However, plate reconstruction techniques allow for looking back into Earth's tectonic history, but geologic evidence is hardly preserved for times prior to 200 Ma ago, such that only the existence of the last supercontinent, Pangaea, is well documented. Especially for the first supercontinents only poor constraints exist; among them is the episodic production rate of continental crust derived from analyzing the osmium decay system [1]. The peaks of crustal growth correlate with the proposed assembly times of some older supercontinents, which are derived from the argument that almost all cratons that stabilized at a certain time were located next to each other in Pangaea. This is very unlikely if they have not formed in a single continental block [2].

Supercontinents are thought to generate a large-scale thermal anomaly by insulation beneath them, which enhances melting processes and with that the growth of continental crust.

However, although the effects of supercontinents on tectonic history, head budget or climate have been debated, the dynamic origin of the Wilson cycle remains somewhat enigmatic. What causes the alternation of assembled and dispersed configuration?

Here we use fully dynamic models of mantle convection featuring self-consistently generated plate tectonics and buoyant, rheologically-distinct continents that eventually collide or split during their drift. In contrast to our previous models [3] the continents in this study consist of a strong core (representing Archaean cratons) surrounded by weaker belts (representing Proterozoic-Phanerozoic mobile belts). Using 2D and 3D models we investigate the key controls on the generation of a Wilson cycle and its period, in particular the rheological properties of the mobile belts and the properties of mantle flow (mode of heating, yield strength of the lithosphere). In order to generate a Wilson cycle a long-wavelength convection pattern is needed to assemble the continental fragments. During supercontinent break-up this long-wavelength pattern is disturbed due to the formation of new plate boundaries that cause the dispersal of continental fragments.

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P 2.3

3D numerical modeling of continental extension to seafloor spreading

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The process of continental rifting to oceanic spreading is one of the most significant plate tectonics on the earth. There are many questions remained related to this whole process, most of which are poorly understood, such as how continental extension transforms into seafloor spreading? How the curved oceanic ridge developed from a straight continental rift? How the pre-existing weakness in either crust or lithospheric mantle individually influences the continental rifting and oceanic spreading? By employing the state-of-the-art three-dimensional thermomechanical-coupled numerical code (using Eulerian-Lagrangian finite-difference method and marker-in-cell technic)(Gerya and Yuen, 2007), which can model long-term plate extension and large strains, we investigated the continental extension to oceanic spreading based on two questions: (1) how the curved continental breakup/oceanic ridge formed? (2) Pre-existing lithospheric structure affects the continental rifting and oceanic spreading patterns, but where is the inheritance from, crust or lithospheric mantle?

We found that the continental rifting initiated geologically synchronous along the pre-existing weak zone, but the seafloor spreading develops in a propagation way. Curved ridge can form during the ridge propagation, and this process is related to the extension history, as the spreading ridge goes through the weakest spots in different places generated in the earlier extension stage.

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Implications of single-sided subduction in global self-consistent models of mantle convection

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Previous global dynamical models using a visco-plastic rheology are able to reproduce some aspects of plate tectonics and mantle convection. However, these models still fail to reproduce some first-order features of plate tectonics, for example Earth-like one-sided subduction. The usual assumption these models make inhibits development of surface topography.

[1] and [2] showed that it is necessary to include a proper free surface in numerical models in order to reproduce laboratory results and to guarantee a physically accurate topographic evolution, respectively. According to these benchmark studies, mimicking a free surface by inserting a weak, zero density layer on top of the crust is an adequate approach if (a) it is sufficiently thick and (b) has a sufficiently low viscosity. As shown in [3], this model extension directly leads to singlesided subduction (Figure 1).

We here study the effect of the mode of subduction on Earth's interior dynamics using Cartesian 2-D to spherical 3-D global, fully dynamic mantle convection models with self-consistent plate tectonics. For this we use the finite volume multi-grid code STAGYY [4]. While in the mobile lid (plate tectonic like) regime, our model shows that single-sided subduction has strong implications on Earth's interior such as its rms. velocity and mantle flow distribution. Another feature caused by nature-like asymmetric subduction is the toroidal flow around the slab edges. This flow of mantle material is responsible for forming the slabs in the mantle and subsequently also the subduction trenches at the surface towards an arcuate shape.



Figure 1. Single-sided subduction in a 3-D spherical, dynamically self-consistent global model of mantle convection and plate tectonics. Shown are temperature (left) and viscosity fields (right).

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Exhumation of HP to UHP-HT rocks during delamination in orogenic settings - distribution of P-T paths from numerical modelling

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Geological exposures of HP and UHP rocks in collisional orogens worldwide indicate subduction of continental material to considerable depths before its separation from mantle lithosphere. Numerical models produce exhumation, after continental subduction to depths as large as 200 km, by a variety of mechanisms, but tend to predict cooler P-T paths than observed in geological analogues. In this contribution, we explore the exhumation record predicted from recent thermomechanical models of self-consistent subduction-collision-delamination cycles.

UHP/HP exposures are mainly associated with Phanerozoic orogenies operating with lower Moho-temperatures than during the Precambrian. The potential of delamination for exposing deeper subduction-channel rocks and for superimposing HT/LP metamorphism has been principally demonstrated. In addition to the uniformitarian, geodynamic role in accompanying recent subduction-collision tectonics, delamination is also a potential mechanism permitting, protracting, and stabilizing long-lasting sub-crustal vertical tectonics in and after hotter, accretionary orogens during the Precambrian.

Synthetic P-T-t results are presented with a novel perspective: making use of the marker-in-cell technique, markers in surface positions are identified for each time step and then tracked back individually through the evolving temperature and dynamic pressure fields. The approach honors (i) the volatility of the observation reference frame, the surface, through time; (ii) lateral variability in exposed records; (iii) a spread of P-T paths, sampled in large numbers on the marker distribution rather than at isolated arbitrary points. A P-T evolution envelope can be established from the set of predicted P-T paths. In addition, this approach allows better to probe the sensitivity of the predicted range of exhumation records to factors like surface processes or lithostatic pressure assumptions.

Retreating, syn-collisional delamination in orogens, in absence of external forcing, is characterised by three contributions to P-T exposure. In an early stage, HP rocks that originate from the subduction channel are exposed in proximal positions to the suture. They record moderate (<=600°C) temperatures, and produce simple and prolate initial P-T loops. Subsequently, an increasing HT overprint results in more complex loops with pronounced near-isobaric heating after isothermal decompression. The respective peak conditions of the separate HP; HT contributions amount to pressures of ca. 3 GPa, and temperatures of ca. 800 °C. A third component becomes apparent in late model stages as the exhumation level becomes deeper. Contemporaneous UHP-HT conditions of > 4 GPa and ca. 1000°C reduce to 1 GPa at ca. 800°C on the retrograde path. The appearance of the last component is limited to the region close to the suture in which lower crust reaches the surface late in the evolving model, demonstrating the sensitivity of exposure to the surface evolution of the model.

The conditions and complexity of observed P-T paths are compatible with thermobarometric data from the Mediterranean, in particular the Aegean.

Towards combined modelling of planetary accretion and differentiation

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Results of current 1D models on planetesimal accretion yield an onion-like thermal structure with very high internal temperatures due to powerful short-lived radiogenic heating in the planetesimals. These lead to extensive silicate melting in the parent bodies. Yet, magma ocean and impact processes are not considered in these models and core formation is, if taken into account, assumed to be instantaneous with no feedback on the mantle evolution.

It was pointed out that impacts can not only deposit heat deep into the target body, which is later buried by ejecta of further impacts, but also that impacts expose in the crater region originally deep-seated layers, thus cooling the interior. This combination of impact effects becomes even more important when we consider that planetesimals of all masses contribute to planetary accretion. This leads occasionally to collisions between bodies with large ratios between impactor and target mass.

Thus, all these processes can be expected to have a profound effect on the thermal evolution during the epoch of planetary accretion and may have implications for the onset of mantle convection and cannot be described properly in 1D geometry.

Here we present a new methodology, which can be used to simulate the internal evolution of a planetary body during accretion and differentiation: Using the N-body code PKDGRAV we simulate the accretion of planetary embryos from an initial annulus of several thousand planetesimals. The growth history of the largest resulting planetary embryo is used as an input for the thermomechanical 2D code I2ELVIS. The thermomechanical model takes recent parametrizations of impact processes like impact heating and crater excavation into account. The model also includes both long- and short-lived radiogenic isotopes and a more realistic treatment of largely molten silicates.

Results show that late-formed planetesimals do not experience silicate melting and avoid thermal alteration, whereas in early-formed bodies accretion and iron core growth occur almost simultaneously and magma oceans develop in the interior of these bodies. These tend to form first close to the core-mantle boundary and migrate upwards with growing internal pressure.

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3D Marker-In-Cell Finite Element based Discretisation for Lithospheric Scale Geodynamics: Theory and Applications

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Developing numerical methods to study long term, 3D lithospheric scale processes requires specialized techniques. Of most importance is that the numerical method should provide the ability to (i) resolve the large deformation of viscoelastic-plastic materials and (ii) robustly solve the inherently non-linear equations describing the evolution of the material and its rheology.

The use of a mixed finite element formulation to discretise Stokes equations, coupled with a particle based Lagrangian representation of the material lithology is a common numerical technique employed within geodynamics to study large deformation processes. The extension of this methodology to enable high-resolution, three-dimensional simulations represents a number of challenges. From a theoretical point of view, there is currently little mathematical analysis to define the accuracy and support the robustness of the numerical solution obtained from such methods. From the computational side, traditional FE implementations are memory intentsive. The development of efficient FE methods which are 'light-weight' and can accuratley and robustly solve linear and non-linear problems, and furthermore are performant on multicore, massively parallel computational hardware is an on going research challenge.

Here I describe the developments of a hybrid finite element (FE) discretisation, coupled with a particle based Lagrangian representation of the material lithology to study geodynamic processes. The development of the method includes both a theoretical analysis of the discretisation errors, and a computationally 'cheap' and efficient numerical implementation utilizing the mixed element Q2-P1. With this new methodology, we intend to study 3D geodynamic processes associated with subduction, rifting and folding.

The key to the efficient implementation is as follows: 1) Always pose the discrete problem in defect-correction form; 2) Utilise a mixture of assembled and matrix-free operations to evaluate the non-linear residual and apply the operators and smoothers required to define the multi-level preconditioner for the Jacobian.

The performance characteristics of the matrix-free, multi-level preconditioning strategy is demonstrated by considering several 3D visco-plastic models. The robustness of the preconditioner and non-linear solver with respect to the viscosity contrast and the topology of the viscosity field, together with the parallel scalability is demonstrated.

3D FEM modeling of fold nappe formation in the Western Swiss Alps

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Fold nappes are recumbent folds with amplitudes usually exceeding 10 km and they have been presumably formed by ductile shearing. They often exhibit a constant sense of shearing and a non-linear increase of shear strain towards their overturned limb.

The fold axes of the Morcles fold nappe in western Switzerland plunges to the ENE whereas the fold axes in the more eastern Doldenhorn nappe plunges to the WSW. These opposite plunge directions characterize the Wildstrubel depression (Rawil depression, Ramsay, 1981). The Morcles nappe is mainly the result of layer parallel contraction and shearing (Ramsay, 1981).

During the compression the massive limestones were more competent than the surrounding marls and shales, which led to the buckling characteristics of the Morcles nappe, especially in the north-dipping normal limb. The Doldenhorn nappe exhibits only a minor overturned fold limb.

There are still no 3D numerical studies which investigate the fundamental dynamics of the formation of the large-scale 3D structure including the Morcles and Doldenhorn nappes and the related Wildstrubel depression. Such studies require a numerical algorithm that can accurately track material interfaces for large differences in material properties (e.g. between limestone and shale) and for large deformations.

The applied numerical algorithm is based on the finite element method (FEM) and can simulate 3D fluid flow for a powerlaw viscous rheology. Our FEM code combines a numerical marker technique and a deformable Lagrangian mesh with re-meshing (Poliakov and Podladchikov, 1992). With this combined method it is possible to follow the initial material contours with the FEM mesh to accurately resolve the initial buckling instabilities.

Two 2D models represent simple end-member scenarios for the Morcles and the Doldenhorn domain (Fig. 1 and 2). The models consider a sediment filled half graben within a basement block. Within the sediments are two layers with a 50 times larger reference viscosity than the surrounding sediments. These layers are sheared over the basement due to overall pure shear shortening and form a fold nappe with an overturned limb (Fig. 1 and 2).

The two models differ in the initial sedimentary thickness below the stiff layers representing the general situation of the pre-shortening Morcles (thicker) and Doldenhorn (thinner) domain. Thicker sediments yield a larger amplitude fold nappe with a significant overturned limb (Fig. 2) whereas thinner sediments yield a smaller amplitude fold with a minor overturned limb. For both models a cusp (mullion) forms at the basement-sediment contact.

The two end-member models are combined in a full 3D model where the sedimentary thickness is laterally increasing (Fig. 3). The 3D model is used to study the 3D deformation and the geometry resulting from the laterally varying style of folding and shearing due to laterally varying sediments thickness.



Figure 1: 2D results for an initial graben depth of 30% of the total basement thickness before (left) and after 55% (right) shortening.



Figure 2: 2D results for an initial graben depth of 60% of the total basement thickness before (left) and after 55% (right) shortening.



Figure 3: Geometry of the initial 3D model for the basement (top left) and for the whole geometry before (bottom left) and after 25% shortening (right, first results for low resolution). The basement depth is laterally increasing. Color plot represent the topography.

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Do foliation refraction patterns around buckle folds represent finite strain?

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Axial plane foliation associated with geological folds may exhibit a divergent or convergent fan. To test the hypothesis that the foliation orientation coincides with the major principal finite strain, numerical finite-element (FE) simulations of single-layer buckle folding are performed (Figure 1; Frehner & Exner, subm.). Four different strain measures are considered: (1) finite strain (recording the entire strain history), (2) infinitesimal strain (current strain), (3) incremental strain (recording the strain history from a certain shortening value until the end of a simulation), and (4) initially layer-perpendicular passive marker lines.



Figure 1: Snapshots of a FE simulation of a single-layer buckle fold with a viscosity ratio of 100 between the folding layer and the surrounding matrix. Top to bottom represents increasing shortening. Lines represent the orientation and magnitude (indicated by line length) of the major principal strain for the infinitesimal (a, e, and k), finite (c, h, and o) and incremental strain measures (b, f, g, l, m, and n). The amount of strain recorded by the later strain measure is indicated above the respective snapshots. d), i) and p) show the orientation of initially vertical passive marker lines.

Since all strain measures result in similar divergent fan patterns in the matrix at the outer arc of the fold (Figure 2), these patterns do not necessarily reflect the finite strain. In the stronger layer differences of the convergent fans between the different strain measures are identified. The main difference is associated with a 90° major principal strain rotation from a layer-perpendicular to a layer-parallel orientation at the outer arc, which was also observed in one of the studied natural folds (Figure 3). However, because in natural folds a bedding-parallel foliation is challenging to identify as it may coincide with sedimentary structures, also the convergent foliation fan pattern in natural folds is not very well suited for strain estimates.



Figure 2. Strain and fold interface orientation data for the simulation in Figure 1. Line gray levels represent different strain measures (black: finite strain, lightest gray: infinitesimal strain, intermediate gray: different incremental strains). Positive values indicate a convergent fan; negative values a divergent fan. IP: Inflection point. a), c), e) Angle between major principal strains and fold axial plane (FAP) plotted versus normalized distance from FAP. b), d), f) Angle between major principal strains and FAP plotted versus angle between pole to fold interface and FAP. Arrows indicate the direction from antiform to synform.



Figure 3. a) Outcrop at Portizuelo, NW Spain. Orientation of bedding, foliation, and extension gashes (b and c) were measured at the positions indicated by numbers in a) within the sandstone and plotted in the same way (b and c) as in Figure 2.

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Modeling interactions between tectonic and surface processes in the Zagros Mountain, Iran.

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Introduction

Fold and thrust belts record a variety of landscape forms (e.g. wind/water gaps, diverted rivers), and sedimentary features (e.g. alluvial fans, growth strata), reflecting the competition between tectonics and surface processes. Moreover, this competition plays a key role in the distribution and behavior of fluvial systems and thus affects both the transport and the deposition of sediments from mountains to basins.

Over the past decades, numerous models have been developed to study interactions between tectonics erosion, sedimentation and deformation. However, only a few models are using a fully 3D mechanical representation of the deformation and many issues remain unsolved. For instance, what control does an array of growing folds exert on drainage network development and, conversely, how does river incision influences growing structures? Which physical parameters are essential in predicting and interpreting wind gaps and diverted river features?

Landscape evolution model

The approach taken here is based on Simpsons and Schlunegger (2003) and uses a nonlinear diffusion formulation, which is the simplest mathematical formulation to model erosional processes taking both hillslope and channel processes into account by assuming that the sediment discharge qs is given by

$$qs = k_0 S + cq^n S (1)$$

where k0 is the hillslope diffusivity, c the fluvial transport coefficient, and n a power law exponent relating the sediment transport to the fluid discharge. qs, and q are the sediment and surface water discharges, respectively, and S (= $|\nabla h|$) is the local slope.

Governing equations:

The model is governed by a system of two equations with the two unknowns h(x,y,t) and q(x,y,t), the topography and the magnitude of surface fluid discharge, respectively. The masses of moving sediments and surface water are conserved, which yields:

 $\partial h/\partial t = -\nabla .(nqs)$ (2) and $\nabla .(nq) = \alpha$ (3)

where $\mathbf{n} = -\nabla \mathbf{h}/\mathbf{S}$ is a unit vector directed down the surface, and a the effective rainfall. Substituting equation (1) into equation (2), the system can be written as

 $\partial h/\partial t = \nabla .((k_0 + cq^n) \nabla h) (4)$, where $k_0 + cq^n$ has the dimensions of a diffusion coefficient and $\nabla .(\nabla h / |\nabla h|) = -\alpha$ (5)

The system is solved by the finite element method on an irregular triangle mesh. Equation (4) is discretized on 3 nodes triangle using linear shape functions, and equation (5) is solved using a discrete water flow routing algorithm (also called D8 method). This method consists on routing progressively both sediment and fluid down the computed drainage area between discrete neighbors from the highest to the lowest elevation. This algorithm is computationally efficient but suffers from significant grid dependency.

Preliminary results

Velocities in z-direction, obtained from a 3D multilayer folding simulation of the thermo-mechanical code LaMEM were used as uplift rates in the landscape evolution model (Figure 1), to simulate the effect of more realistic uplift rates on erosion, without feedback of erosion to deformation.

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Figure1

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P 2.11

Kinematic Investigation of the Central Alborz Mountain belt

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The compressional faults and overturned anticlines with East-West trend are the most important structural features in the Alborz Mountain belt. One of the major reverse faults which plays an important role in the evolution of the Alborz is the Mosha fault. It locates in the southern part of the Alborz mountain belt. The Mosha fault separates Paleozoic successions in the North from the southern Cenozoic deposits. The Kinematic history of the Mosha fault is investigated as a representative of the central part of the Alborz. More than 200 fault planes included striations are measured over of the Mosha fault along two transverse river valleys and one parallel outcrop (figure 1). These field observations are used to obtain the occurred stress fields by using inversion method. The field observations are processed all at once and also separately for each measured sections. The result of both ways of investigations implies two distinct stress fields with different trends (NW-SE and NE-SW) (figure 2). Furthermore, the spatial direction of stress vectors (δ 1 and δ 3) are obtained for each stress fields. On the basis of the result, the southern part of the Alborz Mountain belt experienced two major stress fields which probably driven by different tectonic events. Indeed, the spatial location of the $\delta 1$ is rotated clock wise through the geological time. The Mosha fault displacement mechanism is changed from right-lateral reverse (dextral) fault to left-lateral reverse (sinistral). These stress directions appear in transpiration tectonic, and they overcome compression regime to strike slip regime. The ages of stress changes are determined by using the cross cutting relations of individual fault planes. The dextral system is occurred as a result of the movement of the Arabian plate toward the North. This age is determined to be Miocene and probably older. The sinistral system originates from structural transition of Alborz Mountain because of the progressive deformation in Alborz. At present, most of the movements on the Mosha fault show a contribution of sinistral and reverse faulting.



Figure 1: The digital elevation map combined with major faults. The Mosha fault is shown in red, the studied area and three investigated sections are shown in pink.



Figure 2: Two distinct stress fields with different trends

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Cenozoic deformation of Mount Birk: A key to restoring of Iranian Baluchestan tectonic history

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Mount Birk is a continental ribbon composed of platform deposits mainly late Cretaceous in age is situated through the Eocene deep-water silisiclastic turbidites, the eastern flysch, about 100 km in the north-west direction in Iranian Baluchestan (Fig. 1). There is not any consensus on the origin of Mount Birk. A group of researchers considers this outcrop as the deeper parts of the flysch basin, another group consider as the eastern continuation of the Sanandaj-Sirjan Zone, others believe in a separate microcontinent (McCall, 2002), and finally, the rest attributes to a suspect terrane. Here, we try to use some of structural evidences inside and around of Mount Birk to restoring its previous position may be helping to shed light on the tectonic history of the southeastern Iran. Our structural studies including field works as well as satellite image observations show that the northwestern continuation of Mount Birk discontinuously exposes again in Kuh-e Pich, where its trend completely turns back toward south and makes a closed upright to inclined plunging anticlinorium. The same and parallel curved structures can be observed both toward south of Kuh-e Pich in the ophiolitic mélange of east of Iranshahr, and in direction of northwest near west of Khash in the crystallized limestone with probable age of Permian. This huge curved structure was geometrically appeared such as a similar macrofold which at its axial surface there are several mesofolds and refolding structures confined to the west by the Karvandar right-lateral strike-slip shear zone and from east to the Saravan fault. We think such huge structure could not have been constructed by simple folding during closure of the eastern flysch basin. The dome-and-basin structures distributed in this zone demonstrates at least two periods of folding with perpendicular axial surfaces have occurred since the late Cretaceous time. Exploration of Middle Eocene fossilliferous shallow-water limestone exotic blocks inside a serpentine matrix at slopes of Mount Birk yields a late Eocene to Oligocene age for the most robust episode of mélange generation. We propose this curved structure which occupied more than half of the Eastern Iranian Range wideness could have been formed during the anti-clockwise rotation of the Central-East Iranian Microplate around a vertical axis relative to preliminary position of the subduction zone south of the Eurasian margin. This rotation which is confirmed by few old paleomagnetic reports (e.g. Conrad et al., 1982) was happened synchronous with the India-Eurasia collision event (Bagheri, 2008) when the Central Afghanistan Block westwardly escaped



and pushed the accretionary prisms away toward the margin of the Lut Block and rotated them in a wedge-shaped basin with a sharp nose toward north probably in a clockwise direction. Since the stratigraphy of the Mount Birk is similar to the Lut Block at the Nehbandan area, few hundred kilometers toward north, we suggest during this amalgamation incident it may narrow ribbons of the Lut Block were detached from its eastern edge along the right lateral strike-slip faults such as the West Neh Fault, incorporated into the accretionary prisms and squeezed and folded between two large blocks of Lut and Central Afghanistan. By this model we may be able to explain why the wideness of the Eastern Iranian Range gets larger toward south. Afterwards, the effects of Iran-Arabia plate collision in this area were reactivity of the Karvandar shear zone and shaving of the southwestern limb of the mentioned curved structure as well as distribution of minor conjugate strikeslip faults and folding of continental Neogene beds.

Figure 1: Satellite image of Mount Birk and distribution of the structural trends around it.

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Sandstone detrital mode and heavy mineral study in the Makran accretionary wedge, southeast Iran: implication for the tectonic setting

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The Makran accretionary prism results from the convergence between the Arabian and Eurasian plates, which was initiated during the Late Cretaceous. Today, the system is characterized by great sediment thickness (> 7 km) in the foreland of the Oman Sea and a wedge width of > 500 km, > 300 km of which are exposed onshore. The clastic sedimentary record is useful for monitoring the long lasting history of the supplying Makran chain. Provenance analysis of sediments is aimed at reconstructing the parent-rock assemblages of sediments and the tectonic setting conditions under which sediments formed.

Samples collected from different units span the regional stratigraphy from Upper Cretaceous to Miocene. Point counts of 25 sandstone thin sections were performed following the Gazzi-Dikinson method (e.g. Dickinson & Suzek 1979). 300-400 points were counted in each thin section. For heavy mineral study we selected 17 samples. 200-300 grain were identified and counted in each sample.

The sandstones are classified as feldspathic litharenites and litharenites. In majority feldspar is plagioclase (> 90%) with minor amounts of K-feldspar. Most quartz grains (75%) are mono-crystalline but poly-crystalline quartz (maximum 25%) and minor amounts of foliated tectonic quartz occur. Rock fragments are represented by sedimentary, volcanic and meta-morphic grains. Volcanic grains mostly are andesites and glasses. Extrabasinal sedimentary lithic grains are mostly sandstone, siltstone, limestone and dolomite. Metamorphic lithic grains are generally low-grade schists and phyllite. In various compositional ternary diagrams, the sources of the sandstones plot in the transitional to dissected arc and recycled orogenic fields. These preliminary detrital mode analysis show that the Makran sandstones were supplied from mixed source terranes including older orogenic basement and presumable continental arc rock series.

Heavy mineral suites show a highly variable composition (Fig. 1) including (1) a group of ultrastable minerals (zircon, monazite, tourmaline, rutile, brookite, anatas and sphene) deriveable from shallow granitic continental crust, (2) metastable minerals delivered from variable metamorphic-grade source rocks (epidote group, garnet, staurolite, chloritoid, kyanite, andalusite, blue amphibole), (3) chromian spinel from ultrabasic (serpentinite) rock sources, (4) common hornblende either supplied from metamorphic or igneous series, and (5) a local pyroxene-rich source in the basal sandstone formation overlying pillow lavas (Fig. 2). It is worth noting that in several samples 5-20% of blue amphiboles occur, which indicate the presence of high-p/low-T metamorphic rocks in the detrital source areas.

The Makran area is critical with regard to the Himalayan orogeny. Earlier works (e.g. Critelli et al. 1990) suggested that pre-Miocene sediments in the Pakistanian Makran were supplied from the Himalaya, whereas Miocene to Recent deposits were formed by reworking (canibalism) of older sediments of the accretionary wedge. Our present data would not support this idea. We instead find subduction-related detrital sources in older orogenic basement and a continental volcanic arc (U-Pb dating of detrital zircons in progress). In addition, an other portion of the clastic material most-likely has been derived from the blueschist-bearing Makran ophiolitic belt.

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Fig. 1: Heavy minerals distribution in Eocene to Miocene units of Makran accretionary wedge. The work is supported by the Swiss National Science Foundation project no.2-77644-09.

The Cretaceous-Palaeogene (K/Pg) boundary: cyclostratigraphic and U-Pb zircon geochronological constraints

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The boundary between the uppermost Maastrichtian and lowermost Danian has been in constant debate. This is because its closest relation to a large asteroid impact at Chicxulub, Mexico, which may be the cause for the latest mass extinction. However, since the impact discovery and subsequent definition at the base of the boundary clay at El Kef, Tunisia, several attempts have been made to constraint its age. Uncertainties in the computation of Earth's orbital parameters beyond 40 Ma (including a gap in the astronomical tuning for the Eocene) and radiometric age constraints by Ar-Ar dating (and its limited accuracy) have led to a widespread of studies with geochronological tie-points and derivative age models that are different and of variable quality.

We have here derived with an unprecedented study combining independent numerical dating techniques for the boundary, aiming to contribute with the tuning of such an important event in Earth's history.

The uppermost part of the Horseshoe Canyon Formation in southern Canada, shows well-preserved cyclic alternations of organic material, silt and sandy horizons, in which altered volcanic ash-layers are abundant. Rationale is that if the deposition of these alternations was controlled by sea-level changes, it will be possible to "pin-down" the astronomical imprint and we would be able to tie it in with radiometric age constraints. After decomposing the stratigraphy into the time-frequency space by wavelet analysis, it has been observed that the section has a strong precession-frequency signal, matching the observations in the field. A thick volcanic ash-layer containing zircon grains was found ~30 cm above the K-Pg boundary, which in the area is placed at the bottom of a thick coal seam (Coal nr. 13 or Nevis Coal). 11 zircon grains have been dated from this ash-layer using isotope dilution-thermal ionisation mass spectrometry (ID-TIMS). Single grains and grain fragments $^{206}Pb/^{238}U$ dates range from 65.69 to 66.27 Myr with 2σ uncertainties of 0.16 to 0.3%. 6 analyses have a weighted mean of 65.74 ± 0.03 Ma with a mean square of the weighted deviates (MSWD) that satisfies the null-hypothesis, when analysing the distribution of ages by weighted mean statistics. We therefore suggest this age as the age for the boundary.

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The breccias of Sambosan Accretionary Complex (southwestern Japan): tectonic vs depositional origin

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The Sambosan Accretionary Complex (SAC) is a Late Jurassic to Early Cretaceous subduction-generated accretionary complex that crops out in southwestern Japan (Honshu, Shikoku and Kyushu) and in the Ryukyu Islands. In Shikoku and Kyushu the SAC is composed of several units of limestone, basalt, breccia, chert, and mudstone. These units are interpreted as atoll-type limestones, intra oceanic seamount basalts, seamount flank deposits, pelagic siliceous sediments and trench-fill sediments respectively. According to the Ocean Plate Stratigraphy concept (Wakita & Metcalfe 2005), most of these units represent accreted remains of panthalassic seamounts capped by Upper Triassic atoll-type carbonates.

In March 2012, we visited 9 localities along the Sambosan Accretionary Complex in Shikoku and Kyushu. In each locality various polygenic breccias composed of clasts of basalt and/or limestone and/or chert in a volcaniclastic or chert matrix occur.

Several studies provide a theoretical frame for description and interpretation of SAC breccias. For example, according to the size and distribution of clasts, some breccias are considered to be debris flows (granule to pebble size clasts) or debris avalanches (pebble to boulder size) deposited at the toe of seamount flanks.

Although origin of some breccias is quite well known, more particularly in Kyushu (Onoue & Stanley 2008, Chablais et al. 2010), others breccia features remain puzzling. Indeed, in the Wajiki area (eastern Shikoku), a breccia complex exhibiting reefal limestone clasts floating in a microbrecciated chert matrix lacks reliable interpretation.

To explain breccia formation two hypotheses are generally considered: (1) a tectonic origin, related to the subduction/accretion of the seamount (Okamura 1991, Sano & Kanmera 1991); (2) collapse of the atoll-type carbonate platform, including predominantly reefal limestones on the seamount flanks before the subduction event (Onoue & Stanley 2008). The former correspond to non-depositional breccias, the second to depositional breccias.

In the SAC, geological units are often chaotically associated due to accretional processes. Therefore, this geological frame makes difficult the recognition of depositional or tectonic breccias.

To improve our understanding of seamounts history, we want to test these two hypotheses for the breccias found in Shikoku. In order to achieve this objective, a detailed classification of the different kinds of breccia based on fabrics, clast facies and matrix composition is needed. Therefore, field observations, mapping and thin section analysis will be performed on breccia outcrops including samples on both the matrix and clasts.

The first observations show that clasts exhibit similar facies and fauna in different breccia outcrops, today located hundred kilometers from each other (e.g. typical Peronidella sponge reefal clasts).

It is important to be noticed that in the SAC, limestones are often strongly recrystallized. However, in breccias, limestone clasts are relatively well preserved. This enhanced preservation improves facies analysis and thereby, could allow more accurate reconstruction of the paleoenvironments of panthalassic seamounts during the Triassic.

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Investigation of deep geological structures in the north-west part of Canton of Neuchatel using a combination of gravity and 3D geological model

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Pioneer work on the Atlas of gravimetry (Klingelé & Olivier, 1980) has allowed the scientific community to discover that the underground structure of Switzerland was affected by significant gravity variation within the Jura Mountain, and in the Molassic plateau. While some of the gravity decreases are clearly associated to sedimentary deposit during the post-Mesozoïc period, source of decrease of gravity in other part cannot be explained using the existent knowledge on current geophysical and geological information. More recent work on reinterpretation of seismic profiles within the frame of the Seismic Atlas of Switzerland (Sommaruga et al., 2012) has shown the existence in some area of permo-carboniferous graben below the Mesozoïc sedimentary pile. These grabens are also highlighted using gravity exploration in the 80-ties by Klingelé and Schwendener (1984), in the northern part of Switzerland.

The study presented here investigates the possibility of permo-carboniferous graben within the Jura Mountain in the north-west part of canton of Neuchâtel. The investigated area go from the French border in the west, to west of La Chauxde-Fonds. To better understand the origin of deep geological structures, a new gravity data set has been collected along a profile overlapping one of the seismic profiles, which come from the Seismic atlas of Switzerland.

Gravity has been collected with a sampling step of 200 m and the data set has been combined with the gravity database of the gravimetry Atlas of Switzerland. A gravity data set from the BRGM was also used to cover the French area. Special considerations were taken in account to merge both Swiss and the French database. Two techniques were used to validate this compilation; i) using a geostatistical approach, and ii) using the means value of the neighboring measurements within a specified radius. In the end, a complete Bouguer anomaly computed at the same ellipsoid is obtained for the whole studied area. As this Bouguer anomaly is strongly dominated by the regional trend, caused by the sedimentary layer and by the deepening of the cristallin basement, a Betterworth filter (Abdelfettah and Schill, 2012) using different wavelength is applied to get a residual anomalies which are ready to be interpreted.

In order to explain the large negative anomaly observed in the center of the interesting area, a 3D geological model has been build using available information (e.g. Sammaruga, 1997). However, due to limited information in this area, uncertainties remain on the depth of the deep structure. In order to investigate the crystalline basement and determine the possibility of a permo-carboniferous graben, a simplification of the sedimentary formation of the Mesozoic period has been done by grouping them into a fewer number of units. This simplification is justified by the important size of the geological model which reach ~65x50 km. The obtained 3D geological model has then been used to calculate the theoretical gravity response by doing a 3D forward modeling.

Gravity survey results confirm the existence of decrease of ~8 mGal in the south of Le Locle (NE), which was previously highlighted in the gravimetry Atlas of Switzerland. The general regional trend is well recovered by the geological model, although that the dynamic of the computed Bouguer anomaly remain smaller than the observed Bouguer anomaly. A constrained inversion is achieved on the basis of the geological model and a density values, which minimize the misfit between the observed and the computed Bouguer anomalies, is recovered. This misfit remains important especially in the center of the model. A stripping of the known structures is achieved and the gravity effect for each unit is removed. In the end, we show that the observed residual anomaly cannot be explained without using a permo-carboniferous graben in the basement, where this negative anomaly remains unresolved.

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The Born Engelberg Anticline (Eastern Jura Mountains): New insights from balanced cross sections and 3D modelling

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The Born-Engelberg-Anticline is one of the most distinctive structures of the Eastern Jura-fold-and-thrust belt, characterized by an isolated location in the Molasse basin to the south of the main Jura Mountain range (Fig.1). The internal structure of the anticline and its kinematic significance during the formation of the Jura fold-and-thrust belt has been discussed controversially (e.g. Bitterli 1979; Ziegler et al. 1995) and is still unrevealed (Jordan et al. 2011).

The wide anticlinal arch of the Born-Engelberg is built up by Upper Jurassic limestones. In the hinge zone it reaches an elevation of more than 1000m above the lateral projection of the presumed decollement level within Mid-Triassic evaporites. A straight forward depth extrapolation of the structure based on outcrop data thus leads to volumetric problems in the core of the anticline. Ziegler et al. (1995) suggested a crystalline horst structure to solve this problem and as consequence argued against the distant-push hypothesis (Laubscher 1961). Bitterli (1979) postulated Muschelkalk imbrications in combination with a moderate basement high.

Another important aspect regards the formation timing of the Born-Engelberg Anticline. The watergap of the Aare-Klus and several higher located and hence presumably older windgaps are antecedent with respect to the anticline's axis. Considering the regional drainage system evolution this could possibly point toward a comparatively young formation age



Fig. 1: Geologicaltectonic setting (left) and shaded relief elevation model (right) of the Born Engelberg Anticline (DTM-Av copyright of SWISSTOPO).

The open scientific questions outlined above and the close vicinity of the Born-Engelberg Anticline to one of the potential siting regions for a deep geological repository proposed by Nagra led to a tectonic re-investigation of the structure applying state of the art structural geological analysis tools. Based on newly available high resolution geological maps (Jordan et al. 2011) and reprocessed, depth migrated reflection seismic data balanced cross sections were constructed using the Move-software suite (Midland Valley). Together with additional geological information from boreholes, structural geological 3D model of this area, using the GOCAD software (Paradigm). The 3D-compilation of these different data was then used to check the 2D- cross sections on coherence and revise them if necessary.

The 3D model provides a coherent big picture for the Born-Engelberg-Anticline avoiding isolated 2D-interpretations that often lack lateral coherency. As a next step, it is anticipated to perform forward modelling of the lateral coherent cross sections to learn more about the kinematics of the Born-Engelberg structure. Together, the results make a significant contribution for a better understanding of the kinematic processes in this area during the orogenesis of the Jura fold-and-thrust belt.

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To what extent have inherited normal faults influenced thrust propagation at the front of the easternmost Jura fold-and-thrust belt?

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The formation of the Jura fold-and-thrust belt in the foreland of the Central Alps is widely accepted to been caused by thin-skinned deformation (Laubscher, 1961). The major structures of the range are considered to have been formed in Late Miocene times as in-sequence thrust faults over a subhorizontal basal detachment (décollement) located within evaporites of the Middle Muschelkalk Formation (Lower Triassic) while the basement underneath the basal detachment was not involved in deformation. In northern Switzerland the basement underlying the easternmost Jura fold-and-thrust belt is dissected by a deep trough system of Carboniferous to Permian age that is documented by several deep wells and seismic reflection data. The Oligocene to Early Miocene reactivation of normal faults bounding the trough system is clearly documented by normal offsets within the Tertiary Molasse sediments (Laubscher, 1986). It is suspected that the deep trough system could also have been reactivated in a compressional/transpressional manner in the course of the later formation of the Jura fold-and-thrust belt, which would mark a change from thin-skinned to thick-skinned tectonics (e.g. Ustaszewski and Schmid, 2007).

Here we present selected new interpretations of recently reprocessed and depth migrated seismic reflection profiles, which are verified by classical balancing methods of equal bed length and constant area and conceptual kinematic considerations. A focus was laid on the reinterpretation of the most external structures north of the Jura main thrust that interfere with the Permocarboniferous trough system and are thus ideal to test thin-vs. thick-skinned interpretation approaches.

Our results confirm the hypothesis that the deformation of the easternmost Jura fold-and-thrust belt is mostly thinskinned. The interpretation of thick-skinned deformation is possible in some areas but is most often more ambiguous. Key issues to clarify before a thin- or thick-skinned interpretation are the seismic identification of the décollement and the precise picking of the base Mesozoic reflector. Despite the availability of high quality seismic reflection data both tasks are often very difficult to accomplish. For this reason the development of conceptual models for pre-Jura folding scenarios are essential. The models developed out of our balanced cross sections constrain Mesozoic and Cenozoic normal fault reactivation along the Permocarboniferous trough boundaries resulting in stratigraphic thickness variations. Moreover, the analyses indicate that an offset of the main décollement by pre-existing normal faults potentially favours the presence of basement thrusts in the eastern Jura fold-and-thrust belt. We conclude that even if thin-skinned deformation explains the overall structure, the possibility of thick-skinned thrusting cannot be disregarded as a component of Jura deformation.

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Deep geothermal exploration of low enthalpy reservoir in the Neuchâtel Jura (GeoNE project) – Use of gravity survey to validate and improve 3D geological models.

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Within the frame of the GeoNE project, different areas of Neuchâtel canton have been explored to investigate the geothermal potential of deep aquifer. The aim of the GeoNE project is to determine, which areas are more suitable for deep geothermal district heating in the main populated areas of the canton. Supported by the authorities of the canton of Neuchâtel, three regions in the canton have been investigated; the work presented here focus, on the region of Neuchâtel – St-Blaise and the Region of Boudry - Auvernier, which are both along the Lake of Neuchâtel in the southern part of Neuchâtel canton.

In context of sedimentary mountain range, like the Jura mountains, deep geothermal exploration is traditionally done through a combination of geological model and seismic reflection survey, however, this geophysical method is still very expensive and require a heavy organization plan. In order to obtain reliable information on the geology structure at depth with a limited budget, the GeoNE project use extensive gravity surveys combined with geological model based on available data.

The study presented here focusses along the north shore of the lake Neuchâtel, where the geology characterizes the south border to the Jura Range and present relatively complex structures. The structure of the Neuchâtel Jura is composed of thrust-related folds which are crosscut by several strike-slip fault systems. These folds are composed of Mesozoic to Cenozoic cover rocks detached from their pre-Triassic basement Bedrocks are mainly composed of limestones and marls, which can reach a thickness of several hundred meters. The three main deep aquifers investigated in this area, from the shallowest (< 400 m below surface) to deepest (< 2000 m), are the upper Malm, the Dogger and the Muschelkalk.

The present study is based on gravimetry surveys, 3D geological models and 3D gravimetry models to best characterize the underground structures and to find areas where the rock properties would be favourable to geothermal exploitation. This means targets are geological structures (i.e., fault and fractured zone) where permeability and porosity are high in the potential aquifers, allowing a significant flow at the future production wells.

The results indicate that 3D geological models are able to reproduce the expected geological structures with thrust-related folds and which are overcut by strike-slip fault systems and secondary faulting events.

Validation of the 3D geological models has been done through the comparison of forward gravity models with the residual gravity anomaly maps. The comparison indicate that the forward gravity model reproduce quiet well the main measured gravity structures, which allow us to validate the 3D geological model.

Exploration of deep low enthalpy geothermal reservoirs in the Neuchâtel Jura (GeoNE project) – 3D geological and thermal modeling of potential aquifers.

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Within the frame of the GeoNE project, different zones of Neuchâtel canton have been explored to investigate the geothermal potential of deep aquifers using a multi-disciplinary approach. In this context, 3D geological and thermal modeling has been performed in order to select potential drilling sites for geothermal exploitation in the canton.

The canton of Neuchâtel is located in the central part of the Jura fold and thrust belt at the north-western limit of the Molasse basin. The structure of this part of the Jura is a succession of thrust-related folds, composed of Mesozoic to Cenozoic cover rocks detached from their pre-Triassic basement, and limited by several major tear faults. Three main aquifers, representing potential geothermal reservoirs, are recognised within the cover series in this area. These are from top to bottom: the upper Malm, the Dogger and the upper Muschelkalk.

In order to constrain the geometry of these three aquifers at depth, 3D geological modelling has been performed using 3D Geomodeller software (BRGM, Intrepid Geophysics). Two large models have been realised, a first one in the lake Neuchâtel area, between Neuchâtel and Saint-Blaise, and a second one, in the northern part of the canton, between Le Locle and la Chaux de Fonds. More detailed models have also been realised with further details on the geology and tectonic features, in the zones of potential exploitation of deep geothermal energy. These models have then been used to perform 3D thermal modelling and estimate temperatures in the different aquifers, taking into account the possible effect of cold water circulations in karstic aquifers.

We present the different 3D models and discuss the implications for the potential exploitation of geothermal energy in the Neuchâtel Jura.

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Permeable Fault Detection in Deep Geothermal Aquifer Exploration by Soil Gas Measurement

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The two key focus points in the exploration for deep geothermal fluids are the inferred temperature and productivity. These two parameters define whether the resource will be economic or not. The productivity is dependent on the permeability of the reservoir, and turns out to be the main factor limiting the number of fully successful geothermal projects in deep aquifers of Switzerland. To improve the capacity to exploit the resources available under our feet, the exploration campaigns aim at localizing fault zones, in which the fracture density naturally enhances the circulation of water. However, traditional methods used to detect fractured zones, either geological or geophysical, give no information on the permeability of the fractures.

The measurement of volatile species in soils has been widely used for detection of ore deposits, and contaminants monitoring, but also for active fault detection and geothermal reservoir localization. Some of the main soil gases used in exploration are CO_2 , He and Rn, which all have a specific source. Carbon dioxide is a major gas in soils and groundwater, and is mainly produced by biologic activity and equilibrium with carbonate minerals. However, part of the CO_2 can also originate from mantle degassing or metamorphic processes. Sources of He are the mantle, radiogenic decay in the crust, and the atmosphere, were its concentration is considered homogenous, at 5.24 ppm.

High He fluxes are often found in tectonically active zones, where seismic activity tends to maintain a high permeability in active fractures. These fractures act as preferential conduits for gases trapped in the mantle or the crust, leading to gas concentration anomalies in soils close to the intersection of the fractures with the surface (Baubron et al., 2002). In the framework of an exploration campaign for heat production from deep geothermal aquifers in the canton of Neuchâtel, numerous faults have been detected and localized by geological and geophysical methods. Helium and CO_2 were measured in soil gases along two ~ 800 m long profiles across the fault of St-Blaise, which is one of the major known faults in the prospected area. The gases were sampled through a 10 mm diameter copper tube inserted at ~ 90 cm depth in the soil. The gas was pumped and analyzed for CO_2 , together with O_2 and CH_4 , by a portable gas analyzer, and gas samples were taken to the lab to be analyzed for He on a mass-spectrometer (leak-detector) on a semi-daily basis. Radon was not considered in this study.

Soil gas concentrations are highly sensitive to meteorological conditions and environmental factors like soil moisture and biological activity (Hinkle, 1994). During the sampling campaign of this study, the meteorological conditions varied from very humid spring weather to dry and warm summer weather.

Along the two profiles, CO_2 and O_2 values showed important variations depending on the type of soil, and a strong negative correlation between the two gases suggesting a biological origin of these variations. Methane was never detected during this campaign. Helium data show a positive correlation with CO_2 in most measuring stations, but still remain mostly within \pm 0.2 ppm of the concentration in the atmosphere. On the first profile, a small positive anomaly was observed in three to four stations located above one of the main outcropping fractures. On the second profile, a large anomaly of small amplitude (about 0.2 ppm) was observed at the beginning of July just a few meters east of the main branch of the St-Blaise fault. However, this anomaly was not observed after a second sampling three weeks later. Between the two sampling trips the soil moisture had dramatically decreased, from near saturated to dry and cracked. The possible explanation of this discrepancy is the trapping of deep sourced He under the humid clay-rich soil, and its release after some weeks of dry weather.

The use of soil gases for the detection of permeable faults in geothermal exploration is well established in some geological settings. At the Jura mountain foothills, this study shows that more measurements are needed to better understand, and account for, variations due to meteorological conditions.

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Cross-correlation and location error assessment of nano-earthquakes on the Fribourg Lineament - Switzerland

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As part of two joint PhD projects, we study the low-magnitude seismicity in the Fribourg area (Switzerland) with special focus on the Fribourg Lineament (KASTRUP et al., 2007) (Figure 1). Since the beginning of 2010, the Fribourg Lineament has been monitored by two seismic navigating systems (SNS), consisting each of one central 3D sensor surrounded by three 1D sensors in a tripartite array of about 100 m radius (JOSWIG, 2008). The two SNS complement recordings of the three permanent stations of the Swiss Seismological Service (SED) in the area (SCOU, STAF and TORNY in Figure 1).

Event detection is done daily with SonoView (GeophysSuite software – nano.geophys.uni-stuttgart.de) for the two SNS and the three SED stations. Sonoview displays seismic traces in form of sonograms which are spectrograms based on power spectral density (PSD) matrix, noise adapted, muted and prewhitened (SICK, 2012). Special features of sonograms allow extraction and recognition of earthquake signals near to 0 dB SNR by visual pattern recognition. Detected events are then located using HypoLine, a software especially suited for SNS records but applicable to all kinds of networks. Event location in HypoLine is done interactively in a sense that every onset change induces immediate simulation updates in the affected parameter space. This conveniently takes into account geological knowledge of the area in the manifold of possible location choices (JOSWIG, 2008). Depending on data quality and solution consistency, a location quality factor is assigned to each event. Densification of the seismic network in the Fribourg area together with event detection on SonoView permitted to lower the detection threshold relative to that of the Earthquake Catalog of Switzerland (ECOS) by one order of magnitude on the Fribourg Lineament, and thus multiplied by about a factor of ten the earthquakes detected on the Lineament after 2010. However, a large part of the detected events with local magnitude lower than 1-1.5 were recorded only by a few stations and/or SNS (sometimes only by one). Accurate location of such events remains a difficult task. Moreover, signal to noise ratios can be very low, rendering phase picking and hence the location more imprecise.

Signal cross-correlation has shown that most of the recorded earthquakes detected only by one station and/or SNS show good correlation (cc>0.7) with other well-located higher magnitude events. Several families of events have been identified in this manner on the Lineament. In order to corroborate location solutions of master events obtained with HypoLine, the location software (NonLinLoc) and 3-D velocity model routinely employed by SED are used for event relocations (with same phase picking data). NonLinLoc gives hypocenter solutions in the form of a probability density function that holds information on X, Y, Z hypocenter uncertainties (LOMAX et al., 2009). First results show that HypoLine locations are consistent with NonLinLoc solutions (HypoLine location are situated in NonLinLoc X,Y,Z error bars of the respective event). Quantitative errors on location need now to be determined with more accuracy by defining phase picking error consistently (DIEHL et al., 2009) and the influence of the station distribution relative to the Lineament must be evaluated (LOMAX et al, 2009).

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Figure 1: Tectonic Map of the Fribourg Zone showing location of detected earthquakes

The application of titanium-in-quartz geothermometry in recrystallized quartz - a methodological discussion

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In rocks deformed under intermediate-grade metamorphic conditions, the precise determination of deformation temperatures (and pressures) becomes particularly challenging due to the absence of neocrystallized phases in the case of quartz mylonites. The characterization of distinctive deformation processes in rock-forming minerals, such as the three dislocation creep regimes for dynamically recrystallized Qtz, only yields qualitative temperature estimates, for instance. In contrast, direct temperature measurements based on geothermometry promise more accurate temperature estimations. Recently, the titanium-in-quartz geothermometer (TitaniQ) was applied to dynamically recrystallized Qtz (Kohn & Northrup, 2009) and exercised in various studies.

In this study, TitaniQ measurements were performed in dynamically recrystallized Qtz from (i) weakly deformed host rocks and (ii) monomineralic Qtz veins in granitic or mylonitic rocks of the Aar massif (Swiss external massif). Ti concentrations measured by means of laser-ablation ICP-MS reveal low Ti concentrations in dynamically recrystallized Qtz (subµg/g to µg/g-range).

(i) The TitaniQ temperatures of weakly deformed and mylonitic samples show a temperature range between ca. 160°C to 585°C. This range in temperatures indicates leaching of Ti, caused by pervasive fluid activity, which has modified igneous Ti concentrations, but did not lead to Ti re-equilibration in Qtz during subgrain rotation recrystallization.

(ii) In contrast, synkinematically recrystallized Qtz (SGR) veins in weakly deformed host rocks reveal temperatures between around 450°C and 350°C in ultramylonites. High-temperature recrystallized veins are interpreted as veins that initially formed during the cooling of the pluton, which later recrystallized under peak-greenschist metamorphic conditions (450°C). Samples from ultramylonitic shear zones indicate latest stage strain localization in ductile shear zones at lower temperatures at around 350°C in the Aar massif. Both recrystallized vein generations indicate synkinematic reequilibration of Ti from pervasively penetrating (Ti-oversaturated) fluids during subgrain rotation recrystallization, which lead to a readjustment of the Ti concentrations.

Furthermore, a comparison of three different available TitaniQ calibrations (Wark & Watson, 2006; Thomas et al., 2011; Huang & Audétat, 2012) was performed by student's t-tests. The limitations of TitaniQ calculations in a rutile-absent system were taken into consideration by consistently propagating the error on the activity of Ti in Qtz as a(TiO₂)=0.8±0.2 (Ghent & Stout, 1984; Kohn & Northrup, 2009).

The two-tailed t-test distributions indicate that TitaniQ calculations gained by the calibrations of Wark & Watson (2006) and Huang & Audétat (2012) do not significantly differ (within the 2s confidence interval). Moreover, TitaniQ temperatures calculated by the calibration of Thomas et al. (2011) significantly differ from the above-mentioned calibrations, which apparently result in lower temperatures. Temperatures obtained by the Thomas et al. (2011) calibration are not in line with the microstructural record, emphasizing the importance of good constraints on the pressure conditions during deformation and the activity of Ti in Qtz in rutile-absent rocks.

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Role of brittle deformation and fluid-rock interactions on the formation of ductile shear zones under blueschist facies metamorphic conditions: example in the Roffna metarhyolite (Suretta nappe, eastern central Alps).

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Although ductile shear zones are known to be preferential pathways for fluid and therefore the loci of metamorphic and metasomatic reactions, the impact of fluid-rock interactions on shear zone formation is still poorly understood. The formation of shear zones in a homogeneous granitic host-rock may be subdivided into two distinct stages; (1) nucleation on a new or pre-existing brittle structure and (2) lateral widening during ductile deformation (e.g. Mancktelow & Pennacchioni, 2005). The aim of this study is to describe and identify the consequence of fluid-rock interactions in both stages.

The studied shear zones are located in the Roffna metarhyolite from the Suretta nappe (Penninic domain, eastern central Alps). This early Permian massif intruded a Variscan basement at ca 268 Ma (Marquer et al., 1998) and was affected by Alpine tectonics under blueschist facies conditions (450 °C, 1 GPa) at ca 45 Ma (Challandes et al., 2003). The ductile deformation is characterized by a network of precursor brittle fractures and shear zones from millimetric to plurimetric scale. The symmetrical development of angular micrometric quartz crystals without any crystallographic preferred <c> axes orientations to either side of the shear fracture is interpreted as a cataclastic flow. Epidote, biotite and phengite nucleate in the intracrystalline porosity of the cataclastic quartz layer. The mineralogical assemblage and the highly substituted white micas (Si = 3.6 cations p.f.u.) suggest that the initiation of this shear zone occurred during a stage of brittle deformation (shear fracture and cataclastic flow) already under blueschist facies conditions. High resolution X-ray mapping of the brittle precursor indicates that the brittle deformation is accompanied with a gain of MgO and a total loss of Na₂O.

With increasing strain, the discrete zone broadens and new quartz grains become plastically deformed simultaneously with crystallization of metamorphic epidote, biotite and phengite at the expense of magmatic K-feldspar and plagioclase. More developed strain gradient, from centimeter to meter scale, shows the same large mass transfers that consists of MgO gains (up to 500%) and complete leaching of Na₂O.

It appears that fluid-rock interactions (chemical mass transfer and metamorphic reactions) are identical from the nucleation stage to the widening stage of the shear zone, which is consistent with the development of the shear (initial fracturing and ductile widening) at the same P-T-fluid conditions (i.e. blueschist facies conditions). This isobaric/isothermal coeval development of brittle and ductile structures challenges the temperature-dependent concept of brittle-ductile transition. We also suggest that the widening of the shear zone is driven and controlled by the kinetics of the equilibration of the metastable host-rock at the P-T-fluid conditions of the deformation. Using a suite of PT and chemical potential computed phase diagrams, we are able to model the reaction path involved during the equilibration process from the host rock to the highest strained zone.

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Transient Temperature and Pressure variations in crustal shear zones – numerical modelling using local-thermodynamic equilibrium and a conservative approach

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Crustal shear zones can accumulate considerable displacements, therefore the mechanical energy released in shear zones is an important factor that contributes to significant and transient perturbations of the temperature and the pressure (P-T) fields. The P-T estimates from metamorphic phase equilibria is the main source of information available on the conditions of the middle and lower crust. Interpretations of these estimates commonly assume spatial homogeneity and steady-state conditions.

Direct numerical simulations assuming only local-thermodynamic equilibrium are free of the aforementioned assumptions. More specifically, we develop a non-Boussinesq (compressible) approach, to be used for the investigation of geodynamic scenarios, assuming local thermodynamic equilibrium, conservation of mass, energy and momentum. This allows the investigation of problems where density changes are important without violating the conservation of mass. In addition, our approach considers the conservation of total energy of which, mechanical energy is an important contributor. In this formulation, shear heating follows as a natural consequence of the conservation of energy rather being an additional fitting parameter.

P 2.26

Chemical zoning and ductility of natural garnet at lower crustal conditions: An example from the Rhodope Massif

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The Kesebir-Kardamos gneiss dome in the Rhodope Massif (northern Greece – southern Bulgaria) is a late orogenic extensional structure that deformed an Alpine, synmetamorphic nappe complex containing high-pressure (HP) metamorphic rocks. Microdiamond inclusions in garnet of quartzofeldspathic rocks from one of the thrust sheets suggests equilibration at ultrahigh-pressure metamorphic conditions (P>2.5GPa). This study aims at delimiting the P-T conditions of the metamorphic evolution experienced by these rocks.

Garnets (10-15% vol, pyrope: 15% grossular:10% almandine:65%) from the aforementioned quartzofeldspathic rocks are chemically zoned. Biotite and kyanite are other major phases of the rock paragenesis. Garnet-biotite-plagioclase-quartz geobarometry and garnet-biotite geothermometry confine the recorded peak conditions at ca 1.0 ± 0.1 GPa and 690 ± 50 °C in the stability field of kyanite. The consistency of these results with the metamorphic overprint of HP-metapelites from central Rhodope indicates that the low-pressure (1GPa) metamorphic overprinting event has a regional significance. The lensoid shapes of the chemically zoned garnet crystals place recrystallisation of this mineral phase before the extensional evolution of the Kesebir-Kardamos gneiss dome. Furthermore, the shapes of garnet grains indicate that the ductile deformation of natural garnet crystals is not restricted to ultrahigh-temperature conditions.

P 2.27

Fission-track constraints on the thermal evolution of the Serbo-Macedonian Massif (south Serbia, southwest Bulgaria and east Macedonia)

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Serbo-Macedonian massif (SMM) is a crystalline terrane situated between the two diverging branches of the Eastern Mediterranean Alpine orogenic system, the northeast-vergent Carpatho-Balkanides and the southwest-vergent Dinarides and the Hellenides. It is outcropping from the Pannonian basin to the Aegean Sea in central and southeastern Serbia, southwestern Bulgaria, eastern Macedonia and central Greece. It's affiliation to European or African plate basement is still questionable due to the lack of reliable geochronological dating and detailed structural investigation along its boundaries. The massif is also a key area to understand the bipolarity of the Alpine orogenic system, as well as the interaction of the Pannonian and Aegean back-arc extension during the Cenozoic time.

SMM is generally considered to be comprised of an Upper (low-grade) and a Lower (medium to high-grade) complex (Dimitrijević 1959). The protoliths of both units are reported as volcano-sedimentary successions, which have later been intruded by magmatic rocks during several pulses.

We have applied fission-track analysis on both, apatites and zircons from the rocks of the SMM in order to reveal its lowtemperature evolution. Two distinct phases of cooling have been discerned in the study area. The region west of Južna Morava river experienced relatively fast cooling through zircon and apatite closure temperatures (300° - 60°C) during the late Cretaceous (100 - 67 Ma). This event is interpreted as a post-orogenic collapse following the regional nappe-stacking event ("Austrian" phase). In the rest of the study area, same late Cretaceous cooling was recorded by the zircon data, whereas the apatite suggests a heating event at temperatures higher than 120°C (but lower than 200°C) prior to the late Eocene (43 - 32 Ma) extension and post-magmatic cooling. Within the Crnook dome however, both zircon and apatite fission-track data reveal a late Eocene (45 - 33 Ma) cooling event related to the extension and the exhumation of the dome itself. For the first time the Crnook dome was recognised as continuation of the Osogovo-Lisets extensional complex in Serbia.

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The Eastern Pelagonian metamorphic core complex: insight from the ⁴⁰Ar/³⁹Ar dating of white micas

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The Pelagonian Zone in continental Greece constitutes a pre-alpine gneissic block trending approximately NNW-SSE between two domains with oceanic affinity: the Pindos in the west and the Vardar zone in the east. In the eastern Pelagonian zone we recognized a denuded metamorphic dome extending about 20 x 15 km with the long axis trending NNW-SSE. The main lithologies (gneiss, marbles and amphibolites) display a shallow-dipping foliation whose up-arch defines the structural dome. The metamorphic conditions decrease from upper-amphibolite in the core to greenschist metamorphic conditions in the flanks of the dome. Aligned micas and amphiboles and elongated quartz and feldspar grains define a prominent lineation trending SW-NE. Asymmetric structures in the XZ plane of finite strain record two regional senses of shear: (i) everywhere, top-to-the-SW sense of shear (direction: 252°±30; plunge: 8°±25) is associated with strain gradients from protomylonite to ultramylonite and recumbent, isoclinal and occasional sheath folds; (ii) top-to-the-E sense of shear (direction: 88°±24; plunge: 11°±12) is localized into narrow (0.1 to 100 m), low-angle shear zones on the eastern flanks of subdomes.

The ⁴⁰Ar/³⁹Ar step-heating dating technique has been applied to micas from orthogneisses sampled from the core to the flanks of the dome. The micas have been separated with acoustical shockwaves produced in the SELFRAG apparatus, with the advantage to liberate morphologically intact grains. The liberated grains were sieved at different grain-sizes (between 100 and 300 µm) according to the microstructures recognized in thin-sections. Results show "plateau"-ages at ca. 100-120 Ma, 80 Ma and 50 Ma. The 100-160 µm fraction of white micas in mylonitic orthogneisses yielded slightly younger ages than the 160-300 µm fraction. This difference sets the discussion between neo-crystallization age of the smaller grain fraction and cooling age with multiple diffusion domains of the larger fraction. The latter hypothesis is tested with modeling of Ar-diffusion along Pressure-Temperature-time histories using the MacArgon program. These new ages are consistent with ages published on the southern Pelagonian, demonstrating major tectonic and metamorphic activity during early Cretaceous and Eocene times.

P 2.29

Inversion tectonique d'une zone de relais extensive adjacente à un diapir salifère: terminaison orientale du Dj. Chambi (Atlas central tunisien).

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Actuellement, dans les travaux de terrain, de sismique réflexion ou encore expérimentaux l'inversion tectonique d'un relais de failles normales à un relais transpresif demeure peu documentée. Ce processus au quelle peut être associé une tectonique salifère est mis en évidence à partir des données de terrain de la terminaison E du Chambi (Tunisie centrale). Ainsi à l'Aptien, cette terminaison apparait comme une zone de relais en extension correspondant à une rampe de relais de direction ENE-WSW affectée par deux structures monoclinales de même direction et à vergence S. Cette rampe de relais est limitée par deux failles de transfert (NW-SE) : faille de la laverie E et W dont la dernière relie la faille de Kasserine à celle du Chambi (faille normale probable à vergence N). Au droit de cette dernière (partie haute de la rampe) se développe un diapir salifère asymétrique. L'inversion de cette zone de relais extensive en zone de relais transpressive lors de l'orogène alpin (fin crétacé-oligocène), s'effectue par la concentration de la déformation au niveau de ce diapir qui facilite la formation des failles en short cut et favorise la propagation de la déformation sur la rampe de relais au niveau de la quelle se développe une mégastructure en fleur positive d'inversion. Cette dernière est associée aux décrochevauchements en short-cut et des rétrochevauchements qui s'incurvent ensemble vers la surface dans la couverture.

⁴⁰Ar/³⁹Ar dating of Alpine shear zones in the Mont Blanc area

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Timing of deformation in the Mont Blanc area is crucial for the understanding of its structural evolution, especially with regard to its recent exhumation and the tectonic evolution of this area, where the major bend of the western occurs. Ductile deformation in the Mont Blanc region lasted from Oligocene to Upper Miocene, resulting in the development of the Helvetic nappe stack, with the Mont Blanc massif (MB) forming the core of its lowermost structural unit, the Morcles nappe. The general NW-directed kinematics interacts with dextral transcurrent movements along the Rhône-Simplon fault, which finds its continuation both in the Chamonix valley and the Val Ferret on the internal side of MB. Shearing along the nappe contacts (e.g. Diablerets thrust, Morcles thrust) lasted over a timespan of ~15 Ma and is supposed to end in mid-Miocene times (Kirschner et al., 1996), possibly related to increased influence of movements on the Rhône-Simplon fault. However, ongoing NW-SE compression as well as dextral transcurrent movements promoted localized shearing on either side of the massif. This study presents ⁴⁰Ar/³⁹Ar age data of white micas from shear zones in key areas of the Mont Blanc region. The sampled shear zones are low-grade mylonites and phyllonites and the ages obtained are interpreted to reflect neocrystallization of synkinematically grown minerals. In the Mont Chétif basement slice on the eastern side of Mont Blanc, dextral + E-side up oblique-slip to transcurrent movements dominate, with a tendency toward a stronger strike-slip component with time. The youngest sample from the Mont Chétif yields an Upper Miocene age, suggesting that subsequent folding that overprints the shear zone must have taken place after 9.5 Ma. Samples from the eastern margin of the Aiguilles Rouges massif (AR) in the Chamonix zone indicate top-NW directed shear around 20 Ma and subsequent uplift of AR relative to MB at ~15 Ma subsequent to shear along the Morcles thrust. This suggests a NW-migration of the deformation zone and possible tectonic extrusion of AR after ~16 Ma. One age spectrum from Col de la Seigne of 28-35 Ma fits well with Oligocene activity along the Penninic Front. A NW-verging shear zone between the MB granite and MB paragneiss, close to Champex-Lac and coinciding with the Faille du Midi, yields ages between 15-20 Ma. The age results are used to provide time constraints on a model for the structural and temporal evolution of the Mont Blanc area in Neogene times.

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P 2.31

Structural and ⁴⁰Ar/³⁹Ar geochronological data from different mylonite belts along the Canavese Fault

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The Canavese Fault (CF), i.e. the Insubric Fault west of Lago Maggiore, accounts for the uplift of the relatively high-grade Penninic Alps with respect to the Southern Alps and a poorly constrained amount of dextral displacement.

Between Lago Maggiore and Valle d'Ossola, the CF comprises two several hundred metres thick, partly overlapping greenschist-facies mylonite belts. N(W)-side-up mylonites (Belt 1) are developed mostly within the Sesia Zone (SZ) immediately N(W) of the CF. Dextral mylonites, locally with a considerable S(E)-side-up component (Belt 2), are developed mostly within the Southern Alpine rocks (see also Schmid et al. 1987). The foliation of Belt 1 is the axial planar foliation S_{n+1} of generally NW-vergent F_{n+1} folds which overprint the "pre-Insubric" foliation S_n . In moderately sheared domains, F_{n+1} folds are open and L_{n+1} is a generally subhorizontal intersection lineation of S_{n+1} and S_n parallel to F_{n+1} axes. In highly sheared domains, F_{n+1} folds are tight to nearly isoclinal with axes parallel to the steeply plunging stretching lineation L_{n+1} . Close to the boundary between the SZ and the Southern Alps, the Belt 1 mylonites are locally refolded by F_{n+2} folds. F_{n+2} folds developed during shearing and ongoing mylonitisation of Belt 2.

Belt 2 can be traced toward the W until Valle Strona where it finally ends in a brittle fault. Belt 1 also becomes thinner toward the W, being restricted in Valle Mastallone to a few hundred metres of the SZ. Outside Belt 1, the shear sense in the SZ is SE-side-up. 40Ar/39Ar data obtained from recrystallised white mica from these SE-side-up mylonites (UTM32 5084144/436441) yield a weighted plateau age of 37.45 ± 0.61 Ma which we interpret as the time of the mylonitisation. These mylonites are thus considerably older than shearing in Belt 1 which started at ca. 32 Ma. 40Ar/39Ar weighted plateau ages of 34.07 ± 0.43 Ma and 33.70 ± 0.59 Ma obtained from pseudotachylyte samples (5084356/437405 and 5084360/437415) collected immediately S of the protolith boundary in the Ivrea Zone (IZ) probably date brittle faulting at the onset of the N(W)-side-up shearing.

A second belt of dextral plus SE-side-up mylonites (Belt 3) parallels the CF inside the IZ in Valle Sermenza and Valle Sesia. In a section along the Dolca river, the same shear sense is observed in augengneiss mylonites occurring between the SZ and basic rocks of the IZ. The mylonites are crosscut by post-kinematic andesitic dykes which were probably emplaced coevally with the ca. 30-33-Ma-old Biella and Miagliano Plutons (Kapferer et al. 2012; Carraro & Ferrara 1968). Therefore, Belt 3 is older than Belt 2. The SZ rocks are affected by a lower greenschist-facies ductile to brittle belt with a NW-side-up plus sinistral displacement sense (Belt 4). South of Dolca river, Belt 4 is covered by ca. 33-Ma-old (Kapferer et al. 2012) andesitic volcanites. These volcanites often contain xenoliths derived from the SZ and rest on top of Sesia-derived conglome-rates which in turn were deposited onto the SZ basement. In most places, the succession from the SZ basement into the volcanites is not faulted. A largely brittle fault accommodated the relative uplift of the IZ with respect to the volcanites. In Valle Sessera, this fault is represented by kakirites and a fault breccia containing mylonite fragments. 40 Ar/ 39 Ar on white mica from such a fragment (5057936/427188) gave a weighted plateau age of 53.82 ± 0.78 Ma.

South of Valle Sessera, shear zones observed along the protolith boundary between the SZ and the Southern Alps are commonly only a few metres thick and subordinate to fault breccia. Since the displacement sense of these shear zones is variable and the CF is poorly exposed, the observed structures cannot be integrated into a regional pattern.

From the Serra d'Ivrea towards south, the CF splits into two branches, the Internal (ICF) and External Canavese Faults (ECF), which frame the Canavese Zone to the (S)E and (N)W, respectively. The ECF is dominated by brittle fault rocks and only rheologically weak rocks such as serpentinite and calcschist were mylonitised. From a W-side-up calcschist mylonite (5030790/397670), we obtained a 40 Ar 39 Ar white mica weighted plateau age of 28.93 ± 1.50 Ma. The displacement senses of low-grade mylonites at the ICF are mostly dextral plus E-side-up and thus in line with a relative uplift of the IZ postdating the emplacement of the Miagliano Pluton further north.

The distribution and timing of the mylonite belts observed along the CF show that coherent N(W)-side-up (Belt 1) and dextral (Belt 2) mylonite belts of Oligocene age are only present between Lago Maggiore and Valle Sesia. Therefore, large amounts of dextral "Insubric", i.e. Oligocene, displacement in the order of 100 km or more (e.g. Schmid & Kissling 2000) cannot have been accommodated along the CF itself. Either there was a transfer of dextral shearing into the Penninic nappe stack (e.g. Handy et al. 2005) or a smaller amount of dextral displacement must be assumed.

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P 2.32

Basement lithostratigraphy of the Adula nappe: implications for alpine kinematics

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The Adula nappe is the uppermost Alpine basement nappe of the Lower Penninic nappe stack in the Lepontine Dome. The basement consists of strongly folded and sheared gneisses of various types; a minor amount of rocks from the cover series is also present. Based on detailed field investigations, U-Pb zircon geochronology and geochemical analysis, we propose a new lithostratigraphic sequence of the northern Adula nappe basement:

- Cambrian clastic metasediments with abundant carbonate lenses and minor manifestations of bimodal magmatism;
- Cambro-Ordovician metapelites with amphibolite boudins containing abundant eclogite relicts and representing oceanic metabasalts;
- Ordovician metagranites of a peraluminous calc-alkaline affinity related to a continental collision scenario;
- Ordovician metamorphic volcano-sedimentary deposits;
- Lower Permian post-collisional granites recording the Alpine deformation and metamorphism only.

The Adula basement, composed of pre-variscan polyorogenic rocks and post-Variscan intrusions, represents a complete Palaeozoic geodynamic cycle from Cambrian to Permian, also recognized in other Alpine basements. The Alpine cover shows also a coherent and uniform Triassic sedimentary series (Galster et al. 2012). This coherency proves that the Adula nappe was a single entity before the Tertiary collision and was not an accretion of different units related to subduction. This entity was already moulded before the Alpine collision. However, the Adula nappe was not subducted and exhumed as a huge block, the strong internal deformation suggests that the whole nappe operated as a major deformation plane during the Alpine nappe stack emplacement.

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Distribution and inferred ages of exfoliation joints in the Aar Granite (Central Alps, Switzerland)

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Exfoliation joints are well-known natural fractures limited to the near ground surface. Relatively few details, however, are known about their distribution and age in the Swiss Alps. Exfoliation joints follow the landscape surface at the time of their formation. The age of the landscape then provides a minimum age of exfoliation joint formation. While landscape forms can change through time, exfoliation joints may preserve elements of former landscape morphologies by their undisturbed orientations.

The Grimsel region of the Central Swiss Alps is well-suited for analyzing the impact of erosional episodes, and accompanying stress changes, on exfoliation joint formation. Our study area exhibits some of the most well-developed exfoliation joints in granitic rocks in Europe, as well as numerous glacial and fluvial landscape features of different age. In situ and remote mapping above and below ground revealed that exfoliation joints are widespread, and occur over an elevation range of more than 1.5 km within different geomorphological settings: inner and hanging trough valleys, gently-inclined linear slopes above the trough valleys, inner valley gorges, steep V-shaped side gullies, glacial cirques and steep mountain crests. Upper valley slopes are thought to mimic a former landscape surface that developed predominantly by fluvial erosion prior to the glacial incision of the trough valley (Ivy-Ochs 1996). The prominent U-shaped cross-profile of the upper Hasli valley is likely to have been established during the Middle Pleistocene after intensified glacial activity in MIS 22 (0.87 Ma) (e.g. Muttoni et al. 2007; Haeuselmann et al. 2007). Prominent circues and hanging valleys likely formed during the same period. Glacial erosion during the LGM (Last Glacial Maximum) is thought to be relatively minor, not decisively changing the overall shape of the main valley (e.g. Florineth 1998).

Three exfoliation joint types have been distinguished in the study area: joints oriented distinctly parallel to the present-day ground surface (type C), joints that are nearly parallel (< 10° difference in orientation with respect to the today's ground surface) (type B), and joints that are not parallel (type A). These types may represent different generations. Joint orientation, curvature, and spacing indicate that the bulk of mapped type A joints along slopes of the inner U-shaped valley, hanging valleys, and V-shaped gullies most likely belong to one generation. This exfoliation generation reveals areas that likely experienced considerable glacial incision after joint formation. We suggest that these type A joints formed prior to or during an early stage of Middle Pleistocene trough valley erosion. Type B joints, which (nearly) parallel the present-day landscape, are interpreted to have a minimum age dating to about the LGM. Less widespread type C joints occur almost exclusively within the extent of Late Glacial ice margins and are most likely of LGM or post-LGM age.

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P 2.33
Seismic properties and anisotropy in melt-generating metapelites

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Small amounts of melt have a profound influence on mechanical properties and deformation of rocks. However, the understanding of processes by which melt generates and distribute in rocks remains incomplete. We present new experimental findings that track the compaction, partial melting and neo-crystallization of minerals in parent rocks representative of mid-crustal conditions. The samples used consist of a mixture of quartz and muscovite powders, each mineral phase in equal volume proportion. These powders were consolidated to synthetic rocks in two steps, 1) by cold uniaxial compaction (200 MPa differential stress) followed by 2) hot isostatic compaction (580° C, 160 MPa confining pressure). Three specimens were drilled from the synthetic rock, parallel, perpendicular and at 45° to the compaction axis. The initial porosity in the specimens ranged from 24 - 26 %, and initial microstructural images indicated an overall uniform microstructural arrangement (Figure 1a). After specimen preparation we used a Paterson gas-medium apparatus, equipped for ultrasonic wave measurements, in order to observe the dynamic compaction and melting. Static peak experimental conditions were kept at 300 MPa confining pressure and 750 °C for six hours, with measurements of the ultrasonic velocity at regular intervals (Figure 1e). From these measurements we infer that the rock initially becomes elastically stiffer with significant accompanying acoustic anisotropy. This hardening is followed by elastic softening, marking the onset of dehydration melting and formation of semi-connected melt lenses (i.e., Figure 1b). In addition to lowering the overall acoustic velocity (i.e., the mean velocity of the three specimens investigated), the elastic wave anisotropy is significantly reduced and approaches isotropy, because of preferential melting of the highly anisotropic muscovite. The initial microstructural anisotropy of the sample dictates compaction and the geometrical distribution of generated melt. Upon cooling, after six hours at peak experimental conditions, crystallization of new phases and notable development of a foliation are evident, (Figure 1c, d). Crystallization of new minerals, including potassium feldspar, biotite, spinel and sillimanite is accompanied with the reintroduction of strong acoustic anisotropy. Although no active deformation was imposed at peak experimental conditions, the results provide useful insight on the seismic properties and anisotropy in weakly deforming rocks, at the onset of melting and with small volumes of melt. Our results imply that regions in the Earth's crust where dehydration melting takes place, consuming the most anisotropic minerals such as muscovite, biotite and amphibole, may effectively become seismically less anisotropic than regions where these minerals remain intact, or where crystallization of new phases has taken place.



Figure 1. Scanning Electron Microscopy images (BSE mode) illustrating the sequence of compaction, melting and crystallization discussed in this article; (a) starting material of quartz (Q, dark grey) and muscovite (Mu, light gray) with pores (Por, black). Muscovite defines a foliation; (b) compacted sample after ca. 1 hour at 750 °C and 300 MPa. Pores have collapsed; (c) after 6 hours melt (m) and new crystals of k-feldspar (K-f), biotite (Bt), spinel (Sp) and sillimanite (Sil) along with quartz (Q) and muscovite (Mu) as restites; (d) a low magnification image of same stage of figure (c) showing that the pseudo-foliation, in terms of both mechanical and compositional anisotropy, of the initial sample is retained. The composition, and thus the density, of the sample changed due to chemical reaction at 750 °C; (e) Longitudinal wave velocity, measured at 0.1 MHz, as a function of experimental duration (shown in minutes), for three specimen orientations. The line represents the fit of a 3-point running average, to the velocity data points. The shaded area surrounding the three sets of data points represents the uncertainty in velocity, resulting from the error in picking first arrival of the ultrasonic wave.

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AlpArray – the next generation seismology initiative

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AlpArray is a new initiative to study the greater Alpine area with a large-scale broadband seismological network. The interested parties (currently 57 institutes in 16 countries) plan to combine their existing infrastructures into an all-out transnational effort that includes data acquisition, processing, imaging and interpretation. The experiment will encompass the greater Alpine area from the Black Forest and the Bohemian Massif in the north to the Northern Apennines in the south and from the Pannonian Basin in the east to the French Massif Central in the west. We aim to cover this region with a high-quality broadband seismometer backbone by combining the ca. 220 existing permanent stations with additional 300-340 instruments from mobile pools, all of them to be deployed between August 2014 and August 2016. In this way, we plan to achieve homogeneous and high resolution coverage (ca. 40 km average station spacing). Furthermore, we also plan to deploy a few densely spaced targeted networks along swaths across – and in regions of – key parts of the Alpine chain on shorter time scales. These efforts on land will be combined with deployments of ca. 40-45 ocean bottom seismometers in the Mediterranean Sea. We also aim to implement the best practice for synchronizing mobile pool operation procedures and data handling: common data centre and data management procedure, free access to data to participants as soon as possible through EIDA. Data will be open to the public 3 years after the experiment ends.

The main scientific goal of AlpArray is to investigate the structure and evolution of the lithosphere beneath the Alps. A primary target is the geometry and configuration of subducting slabs and their polarity switch beneath the arc. Numerous regional questions such as seismic hazard will be tackled. Targets will be imaged at several depths (e.g., from near-surface structure down to upper mantle anisotropy), scales (e.g., from local seismicity to mantle transition zone thickness variations), using different methodologies in the sub-regions of interest. An overview of these targets and the methodologies intended to be applied in connection with the seismological measurements will be presented. The geodynamic interpretation of the acquired data will be complemented by other Earth Science disciplines such as state-of-the-art numerical and analogue modelling, gravity and magneto-telluric measurements, as well as structural geology. In conclusion, we hope to turn the strong community interest into a truly interdisciplinary and collaborative project in the key region for seismotectonic activity and dynamics of Europe.

At this poster we welcome anybody who is interested to hear more on the project, who would like share their experience with similar large-scale field experiment(s), and/or who has scientific, practical or funding advice, especially in connection to Switzerland.

P 2.36

Deformation of flat areas by using InSAR. Application to the Geneva (CH) and la Faute-sur-mer (FR) areas

Nicolas Houlié

ETG GGL

InSAR is today commonly used to map the surface deformation induced by volcanic or seismic events. However, small deformation detected (less than a fringe) over soft or "changing" areas (ice, sand, rockfalls) is still challenging. Such limitations are due to difficulties in during modeling InSAR phase over complex surface textures. Also, troposhere phase delays affecting accuracy of the surface topography change between two seasons or vegetation coverage that affect coherency of every scene are the most known of these issues. Additionnaly, flat topography challenges also the correlation between scenes. We explore the potential use of InSAR to two areas where the topography is smooth or quasi-flat: Geneve and La Faute-sur-mer. We show in both cases, that InSAR studies can be completed.

Mineralogy, Petrology, Geochemistry & Tracing magmatic systems from the petrological, geochemical and isotopic perspective & Low-Temperature Isotope Geochemistry

Eric Reusser, Bernard Grobéty, Benjamin Heredia, Sebastien Pilet, Thomas Nägler, Elias Samankassou, Andrea R. Voegelin

Swiss Society of Mineralogy and Petrology (SSMP)

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3.1

Extracting accurate high temperature thermal histories from crustal rocks

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Thermochronological studies assume that daughter isotopes (e.g. ^{206,207}Pb and ⁴⁰Ar) are redistributed within minerals and ultimately lost to an infinite reservoir by thermally activated, volume diffusion (Watson & Baxter, 2007). This fundamental assumption is central to hundreds of scientific publications which have focussed on the thermal history of the Earth's crust since the 1970's. However, some studies (Lee, 1995; Villa, 1998) challenge this assumption, suggesting that the physical mechanisms controlling isotope transport in minerals over geological time-scales are dominated by aqueous fluid flow along specific mineral pathways and that volume diffusion is a secondary process. An experimental verification of the role played by Fickian volume diffusion in mechanisms of daughter isotope loss over geological time-scales is therefore vital in validating the accuracy of existing and future thermochronological studies.

We present high precision single and multi-grain isotope-dilution thermal ionization mass spectrometer (ID-TIMS) apatite U-Pb dates (\sim 81 – 137 My) extracted from an early Triassic (\sim 247 Ma) migmatite of southern Ecuador. These data are used to generate theoretical thermal history solutions assuming that Pb was lost by volume diffusion. A comparison of these solutions with i) intra-grain apatite U-Pb date profiles, and ii) independent geological constraints demonstrates that volume diffusion governed the displacement of Pb. Inverse-modelling has permitted the generation of several million time(t)-temperature(T) path iterations. The large quantity of iterations and measured intra-grain U-Pb profiles provide an opportunity to test whether or not Mesozoic (approximately 250 – 65 Ma) apatite U-Pb dates can be used to differentiate between fundamentally contrasting t-T paths, which reflect significantly different high temperature (375 - 570 °C) tectonic processes.

This study has demonstrated that the dispersion of whole grain U-Pb dates and core-rim intra-grain U-Pb variation can be used to differentiate between gradual cooling and reheating with respect to the Pb partial retention zone (PRZ) using only the 206 Pb / 238 U chronometer. This permits the application of this procedure to Mesozoic (approximately 250 – 65 Ma) rocks which have resided at temperatures of ~375-570°C, providing geologists with a unique tool for studying the high-temperature thermal evolution of the Earth's crust.

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Using U-series and beryllium isotopes to reveal the occurrence and relative timing of crustal and mantle processes in the Southern Volcanic Zone of Chile

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Magmas erupted from subduction zone volcanoes represent the end products of multiple magmatic processes occurring in the asthenospheric mantle wedge and overlying lithosphere (i.e., fluid addition, melting, assimilation, and crystal fractionation). To resolve the contributions of diverse processes and components, and the relative timing of these events, we have determined U-series activities (U-Th-Ra-Pa) for 60 and ¹⁰Be compositions for 20 historic or very young lavas carefully chosen on the basis of major and trace element analyses of 625 samples from six volcanoes in the Andean Southern Volcanic Zone of Chile (37.6-41.1°S: Nevados de Chillán, Antuco, Llaima, Lonquimay, Villarrica, and Osorno). Our dataset demonstrates that each of these volcanoes reflects a unique combination and sequence of magmatic processes that are only revealed through analysis of multiple samples spanning the extent of intra-volcano and intra-eruption chemical variation.

Sigmarsson et al. (1990; 2002) identified a regional trend using U-series and Be isotopes from mostly single samples, which they interpreted to represent along-strike variations in the flux of slab-derived fluid into the wedge [from ²³⁰Th-excess plus ²²⁶Ra-deficit plus low ¹⁰Be/⁹Be at Chillán towards progressively higher ²³⁸U- and Ra-excesses and ¹⁰Be/⁹Be at Villarrica and Osorno]. These data fall within the much broader array defined by our results, but we infer the operation of assimilation (e.g., Llaima; Reubi et al., 2011) and aging of subduction zone components with variable compositions and proportions in the mantle prior to partial melting as important factors in generating the highly individualized and complex U-series systematics observed at each of these six volcanoes. All of the volcanoes exhibit evidence of assimilation, with the exception of Lonquimay which has undergone mostly closed-system fractional crystallization. At Llaima and Chillán the assimilant is crustal. At Villarica, flux-related melts that dominate in the main edifice have been mixed with magma compositions similar to those at surrounding minor eruptive centers (Hickey-Vargas et al., 2002). The latter appear to be decompression melts of enriched mantle which manifest moderate U-Th-Ra disequilibrium and substantial ²³¹Pa-excesses, whereas melts from Villarrica have substantial U- and Ra-excesses. Magmas from Osorno reflect a greater influence of sediments originating from the incoming slab. After discounting assimilated samples, all primary melts have uniformly high Pa-excesses (1.7-2.2) coincident with large variations in ²³⁸U-²³⁰Th disequilibria. Fluid addition-aging-melting successions at Antuco and Chillán may have led to compositions near U-Th equilibrium or with Th-excesses, respectively. Primary Radeficits at Chillán, Lonquimay, and Osorno are under investigation and potentially reflect melting of a cumulate body.

Forthcoming ¹⁰Be data for select U-series samples will enable further clarification of the regional trend. Preliminary analyses of nine Llaima samples erupted between 1850 and 2009 confirm the successful elimination of a meteoric ¹⁰Be component and produce a data array consistent with assimilation. The invocation of radioactive decay to produce U-Th equilibrium (duration of at least 380 ky) could also explain the low ¹⁰Be/⁹Be compositions (half-life of ¹⁰Be=1,390 ky). Our comprehensive dataset may shed new light on melting processes in subduction zone systems.

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3.2

Ablation behaviour of titanite and constraints for U–Th–Pb geochronology using LA-ICP-MS

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Titanite (CaTiSiO₅) is a common accessory mineral in magmatic and metamorphic rocks. It is commonly involved in reactions with other Ca- and Ti-bearing phases (e.g. rutile, perovskite), and element substitutions occurring in titanite enhance its stability. Titanite lattice can incorporate significant amounts of U and Th. In-situ age determination of titanite is crucial for metamorphic rocks, since different titanite generations can be assigned to different stages of the metamorphic P–T cycle.

U–Pb geochronology using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) has become a widespread and powerful tool for in-situ U–Pb dating of zircon in the last 10 years. The LA-ICP-MS technique has recently been developed for in-situ U–Th–Pb titanite geochronology and has become a rising technique (e.g. Storey et al. 2006; Simonetti et al. 2006). However, only few titanite standards are currently available for titanite geochronology: Khan, BLR-1, Fish Canyon Tuff and Grenville skarn titanite, and opinions diverge on the possibility of using non matrix-matched standards and samples (e.g. zircon and titanite). In order to understand the behaviour of U, Th and Pb with respect to Ti, Ca and Si in titanite, ablation experiments were carried out on the Khan titanite (522.2 ± 2.2 Ma; Heaman 2009) using a GeoLas Pro 193 nm ArF excimer laser ablation system (Lambda Physik, Germany) coupled to an Elan DRC-e quadrupole ICP-MS (Perkin Elmer, Canada). The ²⁰⁶Pb/²³⁸U, ²⁰⁷Pb/²³⁵U and ²⁰⁸Pb/²³²Th ratios were also measured in the Plešovice zircon (337.13 ± 0.37 Ma; Sláma et al. 2008), as well. All analyses were carried out using a spot ablation mode.

Laser-induced elemental fractionation Si/Th, Si/U, Si/Ca, Pb/Ti and Si/Ti increase when increasing energy density and repetition rate conditions, while the Pb/Si, Ca/Ti, U/Ti, Th/Ti and U/Ca intensity ratios remain relatively constant during ablation. The temporal changes of the intensity ratios indicate a similar behaviour for Ca, Ti, U and Th, while Pb and Si share a similar behaviour to each other. With increasing ablation repetition rate and/or energy density, the fractionation of the $^{206}Pb/^{238}U$, $^{207}Pb/^{235}U$ and $^{208}Pb/^{232}Th$ ratios increases and becomes parabolic for both zircon and titanite. However, the laser-induced fractionation is weaker for titanite than for zircon at the same operating conditions. Matrix effects on the Pb/U and Pb/Th ratios between zircons and titanite can be tested by a comparison of the mass bias coefficients: e.g. for the $^{206}Pb/^{238}U$ system, KPb/U = $^{206}Pb/^{238}U$ known / $^{206}Pb/^{238}U$ measured

The mass bias coefficients calculated for the ²⁰⁶Pb/²³⁸U, ²⁰⁷Pb/²³⁵U, and ²⁰⁸Pb/²³²Th ratios in Khan titanite and Plešovice zircon generally decrease when decreasing the spot size from 44 to 32 µm, and when increasing the repetition rate and/or the energy density. The mass bias coefficients are higher for Khan titanite than for Plešovice zircon, at similar laser operating conditions. The ²⁰⁸Pb/²³²Th ratio in Plešovice zircon is more sensitive to fractionation than in Khan titanite due to the low Th/U content in Plešovice. The comparison of the mass bias coefficients between zircon and titanite indicates that comparable mass bias values are obtained between the two matrices, if Plešovice zircon is analysed at a larger spot size than Khan titanite with a similar repetition rate and energy density conditions.

A Khan titanite age was determined using Plešovice zircon as an external standard at a repetition rate of 4 Hz, and an energy density of 4.5 J/cm². The beam size for Plešovice zircon was fixed to 44 µm. At a beam size of 32 µm, the weighted average ²⁰⁶Pb/²³⁸U and ²⁰⁸Pb/²³²Th ages calculated for Khan titanite are within error to the reference ID-TIMS from Heaman (2009). At a beam size of 44 µm, the ²⁰⁶Pb/²³⁸U and ²⁰⁸Pb/²³²Th ages are c. 35–40 Ma younger than the reference value. The increase of the repetition rate for titanite has only a small effect on age accuracy. Still, the ²⁰⁶Pb/²³⁸U and ²⁰⁸Pb/²³²Th ages obtained for Khan are closer to the reference age, when using a spot size of 32 µm instead of 44 µm.

Even if matrix-matched standardisation is preferred for titanite dating, this various series of ablation experiments has shown that matrix effects can be minimised using a varying spot size for zircon standard and titanite samples.

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3.4

The pioneer work of Bernard Kübler and Martin Frey in very low-grademetamorphic terranes: Paleo-geothermal potential of variation in Kübler-Index/organic matter reflectance correlations – a review

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Abstract Low-temperature metamorphic petrology occupies theP-T field between sedimentary and metamorphic petrology. Two important pillars of low-temperature metamorphism are coal petrology and clay mineralogy. When low temperature petrology was established bridging a hiatus between the two classical geological disciplines of sedimentary geology and metamorphic petrology, geologists faced a need for the usage of different terminology tenets. Martin Frey and Bernard Kübler were two pioneers in low-grade metamorphic petrology. They focused their research on clarifying the relationships of clay mineralogy and organic petrology to metamorphic pressure (P) and temperature (T) conditions.. The ultimate aim of M. Frey and B. Kübler was to establish a correlation between clay indices and organic parameters for different geodynamic setting and therefore for various pressure-temperature (P–T) conditions occurring in low grade metamorphic terranes. For this purpose, a special attention was addressed to the correlation between the Kübler-Index (KI) and vitrinite reflectance (VR). All these efforts are dedicated to estimate the P–T conditions and thus to gain insight into the geodynamic evolution of low-grade metamorphic terranes.

B. Kübler and M. Frey honored here concentrated their studies to the Helvetic Central Alps area. The very low-grade Helvetic domain is therefore of basic interest of this paper. Ensuing the extensive compilation of data from the Helvetic domain, a reinterpretation of Kübler and Frey's research is presented in the light of last decade's scientific progress. A comprehensive dataset available enables to discriminate many factors influencing the Kübler-Index and organic-matter reflectance alongside to time, temperature and pressure. The correlation is restricted to the KI and organic matter reflectance (mostly VR) because most of the studies used both methods. Organic matter reflectance (OMR) includes data from vitrinite reflectance and bituminite reflectance measurements.

Geodynamics has important control on the KI/VR (OMR) correlation. Tectonic units having a similar geodynamic evolution are featured by the comparable KI/OMR trends, related to the particular paleo-geothermal conditions. Obviously the KI/ OMRcorrelations provide a mean to characterise geothermal gradients and metamorphic very-low-grade pressure–temperature conditions. In terranes where high deformations rates are reported, exceeding the high anchizone conditions, strain promotes the kinetic effects of temperature and pressure on the KI versus OMR ratio.

3.5

Do Mo isotope fractionation processes accompany the dissolution of molybdenites? Studying the interface of water, molybdenite and their weathering products.

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The element molybdenum (Mo) is redox sensitive and the most abundant transition metal in the ocean. In todays oxidized surface waters, Mo is predominantly present as molybdate anion $(MoO_4^{-2}; Mo^{6+})$. Its isotope ratios in marine sediment records are used as proxy to reconstruct the redox history of the ocean. However, the knowledge about the sources of the ocean Mo cycle is limited. It is known, that changes in the Mo-complex (coordination number) or the redox state of Mo may lead to isotope fractionation. Molybdenite $(MoS_2; Mo^{4+})$ is not only an ore mineral, it is also quite common as an ac-

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cessory mineral phase in granites and pegmatites (Audétat et al. 2011), making it even more important to investigate. In addition, earlier studies have shown that sulfide melt inclusions play a crucial role during the weathering of Mo (Voegelin et al. 2012). Its dissolution comes along with a change in the redox state of Mo from 4+ to 6+, which bears the potential of Mo isotope fractionation. Therefore, the dissolution of molybdenite has been investigated at the Alpjahorn, where different molybdenite weathering products and the access to water samples flowing through a talus with molybdenite bearing handspecimens produces a perfect natural laboratory to investigate small scale Mo dissolution and accompanying isotope fractionation processes.

A heavy (centered around 1.1‰) and a light (centered around 0.2‰) molybdenite group can be identified based on their δ^{98} Mo isotope composition. The mean Mo isotope composition of all measured molybdenites is around 0.42‰. The secondary Mo minerals powellite (CaMoO₄) and ferrimolybdite (Fe₄(MoO₄)₃·8H₂O) are very common. Both incorporating Mo as the oxidized molybdate anion complex. Powellite and ferrimolybdite are either grown directly on top of molybdenite or a bit farther away covering the granite or pegmatite. In addition, also amorphous Fe-hydroxide crusts exist. Their Mo content is very high, resulting in a low Fe:Mo ratio of ~5:1. Water was collected directly inside the talus, outside the mineralized area and below the enriched zone.

The water samples have different δ^{98} Mo values and Mo concentrations. The sample outside the molybdenite-mineralized zone has a low concentration (0.2ppb) and a δ^{98} Mo value of 0.75‰. The one below the talus has an intermediate concentration (5ppb) and the highest Mo isotope composition of 0.83‰. The sample deriving from the mineralized zone has by far the highest concentration (380ppb) but with 0.63‰ the lowest δ^{98} Mo.

The isotopic signatures of the molybdate weathering products (ferrimolybdite and powellite) show two different signatures. Either, the Mo isotope composition is very close to the one of the molybdenite from the same sample, or they lie very close to the water deriving from the talus. A closer look reveals that all the molybdate minerals with a similar composition to the water sample are situated on the surrounding rock and not on top of molybdenites. On the other hand, molybdate minerals always show values identical δ^{98} Mo to those of associated molybdenites, if they crystallized on top of these. In contrast, the Mo isotope composition of the Fe-Hydroxides is always lighter than of the corresponding molybdate mineral or molybdenite, indicating the expected preferential adsorption of light Mo isotopes onto Fe-hydroxide phases.

This results lead to the following three conclusions.

- 1. During the precipitation of molybdate minerals from a water source, no Mo isotope fractionation is observed and the mineral keeps the signature of the water. This can be explained, as no change in the Mo-complex (coordination number) occurs during the precipitation process.
- 2. Fe-Hydroxides adsorb light Mo isotopes, an actually well known fact. Combining those two results is a further argument that a change of the Mo-complex (tetrahedral to octahedral) is the reason for the isotope fractionation during the adsorption of Mo on Fe-Hydroxides.
- 3. No net Mo isotope fractionation is observed in the case of a direct transformation and recapture of Mo4+ to Mo6+ (the case when molybdate minerals are on top of molybdenite). This is considered to indicate a batch process, i.e. that no significant amount of Mo is removed from the system.

The δ^{98} Mo value of 0.63‰ of the creek water sample deriving from the talus fan is 0.21‰ higher than the mean Mo isotope composition of the molybdenites. This difference may derive from a non-representative sampling, or it is the effect of the adsorption of light isotopes on Fe-hydroxides. Another explanation may be that it results from a Mo isotope fractionation during molybdenite dissolution. A Bachelor Thesis at our Institute will experimentally investigate this latter hypothesis.

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3.6

The geochemistry of aqueous fluids and hydrous melts in subduction zones

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Aqueous fluids and silicate melts released from dehydrating slabs play a crucial role in mass transfer in subduction zones. Therefore, it is important to quantify the nature and composition of these mobile phases in order to understand elemental transport from the slab to the mantle wedge and the consequences for arc magmatism. We performed experiments at 2 and 3 GPa and temperatures between 700 and 1100°C on a K-free, H_2O -saturated and trace element-doped basaltic composition representing altered, oceanic crust. This pressure-temperature range corresponds to a depth in subduction zones where hydrous phases, most prominently epidote group minerals and amphibole, are stable and constitute hosts for a number of trace elements like REE, HFSE, some LILE as well as U and Th.

Due to experimental and analytical difficulties in measuring the composition of fluids and melts directly and quantitatively, a "freezing stage" (Kessel et al., 2004, Aerts et al., 2010) is employed to determine compositions of frozen liquids and fluids by Laser ablation ICP-MS. By applying this method, the loss of any potential precipitates and unquenchable solutes upon preparation for subsequent analyses is prevented. We employed diamond traps in the experiments which allow mobile phases to be collected in the trap and being analysed by Laser ablation ICP-MS. Coexisting eclogitic residual mineral assemblages are likewise measured by EMPA and LA-ICP-MS in order to obtain partition coefficients between fluids/melts and solid residual phases.

At 2 GPa preliminary results show hydrous phase assemblages with amphibole and epidote stable at lower temperatures (700 and 800°C), that are replaced by dominantly anhydrous phase assemblages with omphacitic clinopyroxene and garnet coexisting with trondhjemitic melt at higher temperatures. Accessory minerals are titanite (at 700°C) and rutile, the latter stable up to 1000°C. We observe the hydrous phase staurolite at 3 GPa and 700°C coexisting with garnet, clinopyroxene and rutile, additionally, kyanite is stable at 800°C. H_2O contents of the liquid phase indicate an aqueous fluid being stable up to 800°C and hydrous melts coexisting with eclogite above 850°C at 2 GPa. At 3 GPa we observe aqueous fluids up to 900°C. Liquids show (strongly) peralkaline character at lower temperatures and evolve towards metaluminous compositions with increasing temperature.

Partition coefficients between hydrous mobile phases and the solid residue indicate epidote controlling (Light) REE, as well as Th and U, below 800°C. Garnet is the principal control for Heavy REE; its composition is temperature dependent. Titanite and rutile are the principal hosts for HFSE.

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3.7

Ascent and fragmentation in volcanic eruptions involving CO₂-rich silicate magmas

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A common feature of many volcanic eruptions involving CO_2 -rich silicate magmas is the formation of landforms normally attributed to explosive interactions between the rising magma and an external water source (i.e., phreatomagmatic fragmentation building maar volcanoes and tuff cones). However, on closer inspection, many of these landforms lack the typical features diagnostic of phreatomagmatism and instead produce fine-grained and well-rounded pyroclasts (Fig. 1). The mechanisms driving the ascent and fragmentation of CO_2 -rich silicate magmas thus need to be revised.

It is generally accepted that melilititic magmas form by small degrees of partial melting at mantle depths and that the magmas can hold a significant amount of CO_2 dissolved within the melt structure (15-18.5 wt.% at 1.2-2.0 GPa; Brooker et al., 2001). The high CO_2 solubility in melilititic magmas can thus have a significant effect on the ascent and fragmentation of such magmas. It has previously been shown that the melilities ascend rapidly from the source region to the surface (i.e., at 10-30 m s⁻¹; Mattsson, 2012), exsolving volatiles and frequently carrying abundant mantle debris intermixed with the juvenile material. In the East African Rift of northern Tanzania melilititic eruptions form maar-diatreme volcanoes, while the less volatile-rich nephelinitic magmas predominantly form scoria cones. This region is arid with evaporation greatly exceeding rainfall on an annual basis, and thus a potential water source required to drive the postulated phreatomagmatic fragmentation is not obvious.

Analyzes of pyroclast shapes, vesicle size distributions (VSD), vesicle density numbers (VDN) were carried out on pyroclasts from the Loolmurwak maar. These pyroclasts are representative of the different depositional facies and show considerable differences. Stereologically corrected 2D-vesicularities range from 15.3 to 43.0 vol. %. It appears that larger pyroclasts (cm-sized) have higher overall vesicularities (up to 43 vol. %), while pelletal lapilli (>0.5 cm) have considerably lower vesicularities (typically <20 vol.%). The spread in VDN's is surprisingly small, only varying from 1.48 x103 to 1.52x103 mm⁻³, which is overlapping with values previously reported from both phreatomagmatic eruptions as well as Hawaiian-style fountaining. Therefore it is difficult to distinguish between different fragmentation mechanisms solely based on textural analyses.

However, when combined there are many indications suggesting that the CO_2 -rich melilititic eruptions in Tanzania were dry and only involve magmatic fragmentation. These include: (1) absence of features typically found in phreatomagmatic deposits (such as accretionary lapilli, plastering and vesiculated tuffs), (2) the strong similarities between the fluidal-shaped melilititic pyroclasts and those produced in Hawaiian-type fountaining, (3) the arid climate, in combination with the fact that the maar-diatreme volcanoes occur on top of horst-structures and not in the lake basins, (4) only melilititic magmas form maar-diatreme volcanoes while nephelinites predominantly form scoria cones. In addition to this, the fast ascent rates of the melilititic magmas would leave very little time for magma-water interactions to occur, especially considering the lack of a obvious water source in the vicinity. Moreover, the dominance of near-spherical pelletal lapilli in the deposits suggest that most of the fragmentation was driven by gas-exsolution, and that if water was at all involved in the eruptions this could only have had a minor effect on the fragmentation process.



Figure 1. Typical morphologies of melilititic pyroclasts. (a) Moderately vesicular pelletal lapilli with clinopyroxene cores from the Loolmurwak maar volcano. (b) Close-up of small pelletal lapilli from the Mianmoja Hill tuff cone. Note that the small lapilli in (b) have cores of melilite-laths similar to the structure seen in (a).

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Fe stable isotope fractionation in modern and ancient hydrothermal Fe-Si deposits

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The possible role of microorganisms in the formation of ancient siliceous Fe deposits, such as banded iron formations (BIF), has been under debate over the past decades. Here, we compare Fe isotope variations in microbial Fe-Si precipitates from the Jan Mayen vent fields, North Atlantic, with those of Ordovician jasper beds from the Løkken ophiolite complex, Norway. Both deposits precipitated in the proximity of white smoker type hydrothermal vent fields and exhibit similar macro- and microscopic features. The modern deposits consist of individual stratified, laminated layers which are largely composed of branching, twisted filaments. DNA analyses confirmed the occurrence of the Fe-oxidising bacterium *Mariprofundus ferrooxydans*. The Ordovician jaspers are the recrystallisation product of an Fe-Si precursor gel, which formed as fall out sediment in a hydrothermal plume and cumulated around the venting site [1]. Micron-scale filamentous structures, concentrated in red hematite-rich laminea, are thought to be formed by Fe-oxidising bacteria, thus giving evidence for biological activity during formation of the Fe-Si gel [2].

Fe isotope variations from -2.09 to -0.66 ‰ in δ^{56} Fe were determined for the modern biological precipitates. A similar scatter in δ^{56} Fe values (-0.38 to +0.89 ‰) was also measured for the Ordovician jaspers. The data suggest that Fe isotope fractionation was caused by partial oxidation of hydrothermally derived Fe(II)_{aq} and precipitation of siliceous ferrihydrite particles in both systems. The oxidation mechanism, i.e., inorganic or microbially induced, however, cannot be derived from the Fe isotope variations.

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Symposium 3: Mineralogy, Petrology, Geochemistry

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Trace element partitioning along the liquid line of descent from olivinetholeiite to granite

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In this experimental study, the isobaric fractional crystallization history of a cooling hydrous, primitive basaltic magma at intermediate to shallow crustal levels has been investigated. An end-loaded piston cylinder apparatus was used at 7kbar. The synthetic compositional equivalent of an olivine-tholeiitic dyke from the Adamello batholith (Northern Italy) was used as a starting material adding 3wt% of H₂O. This composition was prepared with oxides and hydroxides and 32 trace elements at 40ppm level. The experiments were conducted at NNO and cover a temperature range of 1170-700°C. Phases were analyzed by EPMA. The following crystallization sequence has been determined: olivine (ol) => clinopyroxene (cpx) => plagioclase (plg), spinel (sp) => orthopyroxene (opx), amphibole (amph), magnetite (mag) => apatite (ap) => quartz (qtz), biotite (bt). Over the last 200°C of fractionation, per-aluminous granitic liquids were produced. Trace element compositions were analyzed with an New Wave 193nm Excimer Laser coupled to a Sector field ICP-MS (Thermo Element XR) with a small spot size (5-10 µm), low frequencies (5Hz) and low energies 35-45%. Despite of the high sensitivity of the mass spectrometer and the low intensity of the laser, only short signals (~5sec) have been obtained. Due to the small grain size and to avoid mixed analyses, the measuring technique was changed in a way that several crystals (4-5) of the same mineral were analyzed in one sequence. The obtained signals within this sequence were cut together, resulting in a longer integration interval. Amphibole and plagioclase are stable phases from 1010-700°C allowing for a systematic assessment of trace element partitioning between mineral phase and the corresponding melt over a wide temperature range. Amphibole compositions vary from pargasite to magnesio-hornblende to cummingtonite. The compositions of feldspars are less variable at An84-80 over 150°C. However, at 860°C the An content starts to decrease to more albitic compositions finishing at An27 at the lowest temperature runs. Partition coefficients of REE's for both minerals display a ~10 fold increase with decreasing temperature. The higher compatibility of trace elements in the fractionating amphiboles and plagioclases play a major role in determining trace element patterns of calc-alkaline granitoids.

Using microphenocrysts of amphibole and the bulk compositions of chilled margin of mafic dikes in the Adamello, the experimental partition coefficients of rare earth elements could be used to estimate crystallization temperatures for the amphibole (Hürlimann et al. 2011), suggesting that amphibole was a near-liquidus phase in some evolved dikes of the Adamello.

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3.10

Fluid inclusion study in ore and gangue minerals from Main Stage veins at Butte, Montana.

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In this study, we report new microthermometric measurements on fluid inclusions in ore minerals (enargite, sphalerite) and adjacent quartz from the Leonard mine, Butte district, Montana. At Butte porphyry Cu-Mo ("pre-Main Stage") mineralization is cut by large through-going "Main Stage" base-metal vein lodes. The Main Stage mineralization consists of intergrown sulfides (chalcocite, enargite, pyrite, \pm bornite, covellite, sphalerite) and gangue minerals (quartz, carbonates). Previous fluid inclusion studies in quartz from Main Stage veins describe CO_2 -bearing (0.2 to 1 mol%) liquid-rich fluid inclusions that homogenize to liquid at temperatures between 250° and 300°C, with salinities ranging from 1 to 4 wt% NaCl eq. and some rare vapor-rich fluid inclusions (Rusk et al. 2008).

Four quartz generations have been defined based on cathodoluminescence imaging (SEM-CL) in samples belonging to the Cu-rich zone of the Main Stage mineralization, from the Leonard mine. An early, high-luminescent quartz (quartz-I, Figs. 1a-b) constitutes the crystals' core and precedes a dark, poorly-crystallized quartz generation (quartz-II), which is related to the deposition of the enargite-pyrite assemblage (Fig. 1b). Low luminescent, black quartz (quartz-IV) crosscuts all quartz generations and is coeval to the deposition of a Cu-rich sulfide (covellite, bornite) assemblage.

Primary fluid inclusions in enargite (Fig.1e), studied by near-infrared (NIR) microscopy, are liquid-rich, rectangular to tubelike, trapped along growth zones and show similar T_h and salinity to quartz-II-hosted fluid inclusions (Figs.1c-g). Secondary fluid inclusions in enargite trapped along healed fractures are larger in size, have lower T_h (230-250°C) and distinctly higher salinity (5.1 ± 1.2 wt% NaCl eq.). Three primary fluid inclusion assemblages in the late sphalerite (Fig.1f) contain trapped chalcopyrite and homogenize between 300° and 330°C and have salinity of 4.4 ± 1.3 wt% NaCl eq. Following the deposition of the enargite-pyrite assemblage at temperatures of 260-280°C from a low-salinity fluid (2.4 ± 0.9 wt% NaCl eq.), a slight increase in salinity and homogenization temperature is registered in quartz-IV-hosted inclusions, whereas secondary fluid inclusions in enargite could indicate later mixing with a cooler fluid of even higher salinity (Fig.1g). Primary fluid inclusions in sphalerite, which is late in the paragenetic sequence at Leonard, are witnesses for the incursion of high temperature fluids with similar salinity at the late stage of vein formation. To better understand the fluid evolution and composition within the studied sequence Raman microspectrometry and LA-ICP-MS analyses of fluid inclusions will be performed.

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Figure 1. a-b) SEM-CL images of single quartz crystals. Multiple quartz generations are indicated: quartz-II (light-gray), quartz-II (medium-gray), quartz-III and late black quartz IV; c) Transmitted-light photomicrograph of primary liquid-rich fluid inclusions in quartz-II; d) Transmitted-light photomicrograph of vapor and liquid-rich polyphase fluid inclusions related to quartz-IV; e) Infrared transmittedlight photomicrograph of primary fluid inclusions in enargite; f) Transmitted-light photomicrograph of primary fluid inclusions in sphalerite with trapped chalcopyrite; g) Microthermometric data on 116 single fluid inclusions from 34 FIAs in quartz, enargite and sphalerite. Error bars correspond to the 1s standard deviation within the assemblage; h) Temperature and salinity evolution of fluid inclusion assemblages according to the paragenetic sequence. Abbreviations: PSFI – pseudo-secondary fluid inclusions, PFI – primary fluid inclusions, SFI – secondary fluid inclusions, anh-anhydrite, cp-chalcopyrite, py-pyrite, s-solid, sl-sphalerite, V-vapor.

3.11

Exotic mineralization at Chuquicamata, Chile: focus on the copper wad enigma

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Supergene processes in porphyry copper deposits are important for their economic potential (Sillitoe, 2005). Meteoric fluids oxidize the upper part of the sulfidic deposit; oxidation of certain sulfide minerals, such as pyrite, produces sulphuric acid and lowers the pH, resulting in the mobilization of divalent metal cations like copper. Copper may re-precipitate more at depth, depending on the redox potential and pH conditions, as oxide or sulfide minerals enriching the primary ore. In certain cases, the supergene copper-rich fluids flow laterally and may precipitate downstream to form an exotic deposit.



Figure 1. a. Location of the exotic deposit downstream of the Chuquicamata porphyry deposit. b. Schematic section across the Chuquicamata porphyry and its related exotic deposit. c. Gravels from the exotic deposit cemented with copper wad. d. Chrysocolla, atacamite, copper wad (brown) and copper pitch (black, right part) from the exotic deposit. e. Strongly altered gravels (kaolinite, alunite) from the central part of the exotic deposit.

At Chuquicamata, both in situ supergene enrichment and an exotic deposit are developed (Pinget et al., 2011, 2012). The exotic deposit extends 6 km to the south (Fig 1a), and contains of 3.63 Mt Cu (Ossandón, 2001), with grades typically between 0.7 and 1.5 Cu wt.%, and locally up to 15 wt.%Cu. In the central part of a mineralized paleochannel, the gravels and the bedrock are strongly altered (principally as kaolinite and alunite, Fig 1e), and contain virtually no Cu. Around this altered zone, copper mineralization is present, principally as chrysocolla, atacamite and "copper wad" as well as pseudomalachite, paracoquimbite, lebethenite and sampleite.

Despite its economic importance, copper-wad composition and structure are poorly known. The field term copper- wad includes dark brown to black powdery (in contrast to "copper- pitch" that is black shiny, Fig. 1d) copper-bearing material generally present as patina on fractures and rock surfaces and as cement of porous rocks (Fig. 1c). At Chuquicamata copper-wad occurs mainly in the external part of the exotic mineralization. Under an homogeneous appearance, XRD analyses indicate that copper- wad is a mixture between a poorly crystalline chrysocolla-like phase and other well crystallized minerals, principally atacamite, lebethenite, birnessite and gypsum. SEM backscattered electrons analyses reveal that the microscopic habitus of copper- wad can be very variable (Fig. 2 b-c).

The results achieved so far suggest that copper-wad s. str. is mainly the chrysocolla-like material. The compositional variability (Fig. 2a.) may be explained by the fact that copper-wad covers other minerals (like lebethenite in Fig. 2b) that cannot be discriminated during analysis.



Figure 2. a.) Chemical analyses on copper-wad samples (XRF Uniquant) b-c.) Two examples of SEM backscattered electrons images on copper-wad. b.) copper-wad as flexible fibers covering a lebethenite crystal. c.) copper-wad needles forming a "film" that covers the substratum.

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3.12

First results of Barium isotope fractionation in scleractinian coral skeleton

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Here we present first measurements of barium isotope fractionation in scleractinian coral skeleton. Corals take part in the marine cycle of Ba and the Ba isotopic fractionation in the skeleton can provide informations about Ba cycling in shallow water. Ba in seawater is linked with paleo-productivity, given that Ba reacts like a nutrient in the water column. Prominent Ba sources to shallow marine environments are continental weathering and upwelling, both potentially influencing the oceanic cycle of Ba.

The Ba fractionation of natural (Bahamas/Florida) and cultured corals (CSM, Monaco), are compared to $Ba(NO_3)_2$ standard solution (± 0.1 ‰) and standard natural limestone BSC-CRM 393 (0.05 ± 0.2 ‰) (Bureau of Analysed Samples, Ltd., Middlesborough, England). The chemical method used was developped recently (Pretet et al., 2011). Measurements were performed using a ¹³⁰Ba/¹³⁵Ba double spike on Nu Instruments Multicollector ICP-MS following von Allmen et al. (2010) procedure.

The mean Ba isotopic fractionation in coral skeleton is 0.3 ± 0.2 and 0.6 ± 0.1 ‰ for cultured and natural samples, respectively. Statistic test reveals a significant difference between the sample sets (ANOVA: p<0.01). However, no significant differences were found between different cultured species (*Diploria strigosa*, *Acropora* sp., *Stylophora* sp., *Montipora* sp. and *Porites* sp.) Thus no species-specific fractionation could be found. The origin of the skeletal fractionation relative to standard can be linked to Ba incorporation in coral skeleton, or variations in seawater Ba isotopic composition, given the Ba residence time of 11 kyrs (Chan et al., 1976). The influence of diagenesis on the Ba isotopic composition was checked in 5 natural samples with varying calcite to aragonite ratios (0 to 0.3). No significant effect was observed.

These promising results encourage us to further investigate the Ba cycle and Ba fractionation on marine carbonate material. Currently we are working on the method for measuring Ba isotopic fractionation in seawater.

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3.13

Experimental study of the sensitivity to shrink/swell behaviour of clayey soils in the Paris Basin

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In France since 1976, periods of prolonged drought accompanied by significant water deficits, have revealed a high vulnerability of constructions on clayey soils. This phenomenon is due to the shrink/swell properties of these soils. The mineralogical, microstructural, geotechnical and mechanical characteristics of three clayey formations in the Paris Basin were studied to highlight the contributions of the mineralogical composition and also the microstructure on the sensitivity of these soils to the shrinkage and swelling processes.

In this study, the Plastic clays of Sparnacian age, which exhibit no carbonate content, are compared to the Green clays of Romainville of Rupelian age and to the Blue marls of Argenteuil of Ludian age. Three distinct levels of Plastic clays of Sparnacian age were analyzed: a lower level, a medium level and a higher level. They differ in their clay content (<2µm) and proportion of clay minerals. It is more or less established that the microstructure of clayey soils partly controls the means of access (or withdrawal) of dipolar water molecules to adsorption sites on the surfaces of clay minerals (especially smectites). So, the characterizations of undisturbed samples and remoulded samples permit to identify the importance of the microstructure factors on the sensitivity of clayey soils to shrinkage and swelling processes. In fact, microstructure is partially or totally destroyed by the remoulding process in the laboratory.



Figure 1. Analysis of microstructure of Plastic clays (higher level) by mercury porosimetry and scanning electron microscope. a) Clay matrix of swollen intact sample

- B) Clay matrix of swollen remoulded sample
- C) Porosimetric curve
- D) Derived porosimetric curve

Analyses of potential swelling by oedometer tests, analyses of mineralogical composition by X-ray diffraction, analyses of microstructure by mercury porosimetry and scanning electron microscope are presented. The corresponding results have confirmed the role of two families of factors in the processes of shrinkage and swelling of clayey soils: the mineralogical composition and the microstructure. Smectites and Illite-Smectite interstratified minerals promote swelling, which is not the case of Kaolinite. The swelling is counteracted by the presence of carbonates as well as quartz, the presence of these minerals limit the influence of clayey minerals. In the intact samples, the free swelling depends on the rate of carbonates or the rate of quartz. For a given percentage of carbonates or quartz, the swell sensitivity is greater for the remoulded soil than for the intact soil. In fact, the remoulding process destroys, at least partially, the elements of microstructures that counteract the swelling process. These elements of microstructure can be represented by carbonate bridges between clayey aggregates in carbonated clayey soils or clusters of quartz grains insensitive to swelling.

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3.14

HP metamorphism in the Sesia Zone (Western Alps, Italy): Constraints on subduction dynamics of continental crust from in-situ U-Th-Pb dating of accessory minerals

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The Sesia Zone, in the Western Italian Alps, comprises several continental slices derived from the Apulian margin and accreted to the orogen during the Alpine orogenic cycle. In the easternmost unit of the Sesia Zone, the so called Eclogitic Micaschist Complex (EMC), products of the Alpine high pressure metamorphism are remarkably well preserved; they reflect the oldest high pressure metamorphic overprint in the Western Alps. Geochronological and petrological data indicate that the Alpine high pressure metamorphic history involved several stages and the tectonic evolution for different slices of the EMC was unequal (Regis, 2012). The size, shape, and kinematics of the distinct crustal fragments that make up the Sesia Zone are still poorly constrained. The aim of the study is to delimit the geometry of these different tectonic blocks and to provide PTt-constraints on the early Alpine HP history of the Sesia terrane.

By combining in situ U-Th-Pb dating of accessory phases and detailed petrological and (micro-)structural analysis we can link the data to specific tectonometamorphic stages. Data from the SW part of the EMC are presented here:

- In a fine-grained orthogneiss, allanite shows up to 4 metamorphic growth zones that can be distinguished by texture, trace elements and age. In situ SHRIMP Th-Pb dating of these allanite zones yields two distinct metamorphic stages:

1) Allanite cores coexisting with omphacite are ~76 Ma old,

2) Allanite rims coexisting with albite yield ages around 61 Ma;

Intermediate growth zones, coexisting with phengite (3.5 Si), date between ~72 and 64 Ma. Detailed thermobarometric investigations are in progress to link these ages to specific P-T conditions.

- Zircon rims from a felsic eclogite and a carbonate-bearing mica schist, which can be related to HP assemblages, yield an age of ~ 78 -70 Ma and 74 Ma, respectively.

These new data reveal that a distinct HP stage occurred between ~78 and 74 Ma. Rubatto et al. (2011) demonstrated that the rocks in the central Sesia Zone experienced two HP stages between ~79 and 65 Ma. A first HP stage, dated between ~79 and 75 Ma, was immediately followed by decompression before a second HP stage took place around 65 Ma.

The oldest ages obtained during this study are consistent with the early high pressure ages in the central section indicating that these ages date the first high pressure peak. The allanite data further reflect a prolonged metamorphic evolution at elevated pressure conditions. The youngest age of 61 Ma records the exhumation to lower pressure-conditions. Ongoing petrological and microstructural analysis will link these new ages to the metamorphic evolution of this SW part of the Sesia block, and further constrain subduction and exhumation rates of the continental crust in the Western Alps.

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P 3.1

Accessory Mineral Thermometers at High and Ultra-High Temperatures: a case study from the Ivrea-Verbano Zone.

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Ti-in-Zircon and Zr-in-Rutile are newly established thermometers calibrated both empirically and experimentally (e.g. Zack et al., 2004a; Ferry & Watson, 2007) and have been successfully applied as geothermometers at intermediate temperatures (400-650°C) in various geologic settings. However, the application of these thermometers to high and ultra-high temperatures (700-1100°C) is more problematic since investigations on small areas or even single samples result in a large set of temperatures. The difficulty in applying accessory mineral thermometers to high and ultra-high grade terranes is usually interpreted as related to diffusion during slow cooling after peak metamorphism, or to fluid-induced re-equilibration/recrystallisation during retrograde metamorphism.

We present preliminary data from the Ivrea-Verbano Zone (IVZ). The IVZ is a portion of the Sudalpine basement in northern Italy and southern Switzerland. It is interpreted as a fossil lower crustal section exhumed and tilted to its current position during the Alpine cycle after Variscan high-grade metamorphism and late Carboniferous and Permian magmatism.

The Ivrea zone consists of a heterogeneous metamorphic formation (the so-called kinzigite formation, mostly composed by paragneiss whose metamorphic grade ranges from amphibolite in the southeast to granulite conditions in the northwest) intruded by a Mafic Complex. The Mafic Complex consists essentially of gabbros and diorites with minor pyroxenites and ultramafic intercalations. The lower (northwestern) and the central part of the mafic complex are rich in metric to hectometric paragneiss septa (host-rock) originated from the kinzigite formation.

In Val Sesia, near Varallo, at the roof of the mafic intrusion the kinzigite formation consists of mica bearing (bt ± ms), orthopyroxene-free paragneiss. However, the paragneiss in the mafic complex are orthopyroxene bearing and almost free of mica, and display features of partial melting with a common paragenesis of qtz+fsp+opx+grt+accessory minerals. The amphibolites metamorphism in the kinzigite formation is interpreted as a result of a regional metamorphic event prior to the mafic intrusion (only partly obliterated by contact metamorphism close to the Mafic Complex) whiles the assemblages in the septa are interpreted as a result of thermal metamorphism during the gabbro emplacement. Therefore, the septa are the most promising rocks to provide constraints for the thermal budget of mafic magmas in the IVZ and, since they are quartz, zircon and rutile bearing, they offer the possibility to study the systematics of Ti-in-Zircon and Zr-in-Rutile thermometers.

Zircons and rutiles are investigated by LA-ICP-MS (magnetic sector-field spectrometer ELEMENT XR coupled with an ArF excimer ablation system NewWave UP-193). For Zr-in-rutile we apply the thermometer of Tomkins et al. (2007) assuming 8 kbar, for Ti-in-Zircon we apply the thermometer of Ferry and Watson (2007).

CL-images of zircon grains show complex patterns with inherited cores and metamorphic rims, the ages of homogeneous metamorphic rims obtained by LA-ICP-MS are close to ~280Ma, the ages of inherited cores vary between ~330Ma and >1Ga. Ti concentrations between the inherited core and the metamorphic rim of a single grain may vary, here we focus mostly on metamorphic rims.

Results indicate that the highest temperatures obtained by Ti-in-Zircon on metamorphic rims are close to 1000°C, while the lowest are around 850°C. Frequency diagrams display a bimodal temperature distribution, with a first peak around 880°C and a second around 980°C, this bimodal distribution is seen in some samples, others show only the lowest or the highest peak. The highest peak is observed mostly in rutile-poor samples, the lowest peak or bimodal distribution in rutile-rich samples.

Temperatures obtained by the Zr-in-Rutile thermometer are not correlated with grain size and only rarely decrease from core to rim. They show a bimodal distribution with a first peak around 750-800°C and a second peak around 950°C. This bimodal distribution is reproduced in some samples (in general, the same samples that showed the low temperatures by Ti-in-Zircon, see above); other samples show only the lowest peak (in general the same samples that showed the high temperatures by Ti-in-Zircon, see above).

Cr and Nb are used as discriminating proxy to distinguish between "metapelitic" and "metamafic" rutile (Zack et al., 2004b). The temperatures obtained from rutile with a "metapelitic" signature are clustered around the high and low temperature peak of frequency diagrams, in contrast rutile (even from the same sample) with a "metamafic" signature are clustered around the low temperature peak only. No rutile with Cr/Nb>1 gives temperatures above 900°C.

Rutile with zircon inclusions preserve the lowest temperatures, in general below 700°C and are interpreted as an effect of locally enhanced Zr diffusion during slow cooling after peak metamorphism.

Our preliminary data suggest a strong competition in controlling the distribution of Zr and Ti in rutile and zircon, respectively. A simple model of enhanced or inhibited post-peak diffusion should be replaced by a more complex model, where post-peak diffusion smoothes a previously established heterogeneous concentration of Zr (resp. Ti) in rutile (resp. in zircon), which in turn is a consequence of the changing activity and diffusion rates of Zr, Si and Ti during metamorphism and partial melting in the micro- and macroscale.

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P 3.2

The Permian evolution of the internal Austroalpine units (Sesia Zone, Dent Blanche tectonic system): Constraints from in-situ U-Pb geochronology

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Permian extension in the Adriatic lithosphere was responsible for asthenosphere upwelling. This caused high temperature metamorphism at medium pressure and widespread partial melting, which led to upper crustal magmatic activity (e.g. Marotta and Spalla 2007). A metamorphic record of this process is preserved in the Austroalpine and Southalpine portions of the Alpine chain, which were not significantly affected by Alpine metamorphism. In the Western Alps, Permian metamorphism has long been suggested, but so far not reliably dated, whereas the timing of magmatic activity is well constrained.

In this study, new geochronological data (U-Pb dating on metamorphic and igneous zircon) are presented to fill some of the gaps in the current knowledge on the pre-Alpine metamorphic evolution of the two most classic and relevant Austroalpine units in the Western Alps, i.e. the Sesia zone and the Dent Blanche tectonic system.

In the SW part of the Sesia Zone, within the II DK unit, upper amphibolite to granulite-facies metamorphism was dated at ~277 Ma and at ~270 Ma. HT metamorphism is also recorded in the most internal unit of the Sesia zone (eclogitic micaschist complex): Metamorphic zircon from a metagabbro and an orthogneiss yield ages of ~ 276 Ma and ~274 Ma, respectively. The metababbro was subsequently exhumed to shallow crustal levels and intruded by felsic and intermediate dikes (Rebay and Spalla, 2001). One of these dikes was dated at ~264 Ma.

Within the Valpelline Series of the Dent Blanche tectonic system, three stages of amphibolite- to granulite-facies metamorphism are now evidenced by our new data: at ~287 Ma, ~274 Ma, and ~263 Ma. These stages of metamorphic overprinting clearly postdate the Variscan metamorphic cycle, which occurred around 350 Ma and was also recorded in our study, normally by the oldest U-Pb ages found.

Together with petrological data (Manzotti and Zucali 2012, Pognante et al. 1988), the new age constraints suggest that the middle and lower crust of the Valpelline Series and of the II DK experienced an extended regime of high heat flow at Permian times, from 290 to 260 Ma. During that interval a protracted series of processes lead to partial melting, producing migmatites, numerous leucogranite layers and pegmatite dikes. HT metamorphism is also recorded in the most internal unit of the Sesia zone, the Eclogitic Micaschist Complex. Dating of an andesitic dike that intruded a metagabbro after exhumation to shallow crustal levels, indicates that at least parts of these Permian lower crustal rocks must have been exhumed by the late Permian, predating the initiation of Jurassic rifting by tens of millions of years.

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P 3.3

Thermal structure and metamorphic evolution of the Piemont-Ligurian metasediments in the northern Western Alps

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In the Western Alps, the Piemont-Ligurian oceanic domain recorded blueschist to eclogite metamorphic conditions during the Alpine orogeny. This domain has been classically divided in two zones (Combin and Zermatt-Saas), with contrasted metamorphic evolution, and separated by a major tectonic contact, known as the Combin fault. We present in this study new temperature data in the Piemont-Ligurian metasediments based on Raman spectroscopy of carbonaceous material (RSCM thermometry). We show that metamorphic record is very similar in the Piemont-Ligurian units with temperatures ranging from 420 to 530°C in the Combin zone and from 500 to 540°C in the Zermatt-Saas zone. These data demonstrate that there is no major temperature gap across the Combin fault. Moreover, we show that there is an increasing gradient of temperature towards the base of the Combin zone. Analysis of metamorphic assemblages and estimated temperatures points to a more pervasive retrogression in the Combin zone. Such thermal structure can be explained by a juxtaposition of Piemont-Ligurian units at depth that shared a common late metamorphic evolution. The heating observed in the Combin zone can be interpreted as the result of heat advection across the Combin fault or to an increase of the thermal gradient due to the incorporation of basement units in the orogenic prism during exhumation of high-pressure metamorphic units.

P 3.4

Serpentinization and fluid-rock interaction in mafic and ultramafic seafloor: Constraints from Ligurian ophiolite sequences

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The Bracco-Levanto ophiolitic complex (Eastern Liguria) represents one of the largest and better-exposed ophiolitic successions in the Northern Apennines. It is considered to be a fragment of heterogeneous Jurassic lithosphere that records a tectono-magmatic and alteration history similar to that documented in a number of oceanic core complexes along the Mid-Atlantic Ridge (MAR), such as the Atlantis Massif at 30°N. Structural and petrological studies on these rocks provides constraints on the metamorphic/deformation phases connected to the formation and hydrothermal alteration of Jurassic oceanic lithosphere (Menna, 2009) and allow comparisons to present-day oceanic systems.

We present a comparative study of deformation processes and fluid-rock interaction in modern oceanic hydrothermal system, such as the Lost City Hydrothermal Field (LCHF) hosted in ultramafic rocks on the Atlantis Massif, and the Bracco-Levanto ophiolitic complex. A focus is on determining water-rock ratios and fluid flow paths during hydrothermal activity, and on processes leading to hydrothermal carbonate precipitation and the formation of ophicalcites, which are characteristic of the Northern Apennine ophiolite sequences. Our studies particularly allow us to test the hypothesis that the LCHF is a modern analogue for hydrothermal processes that produced ancient ophicalcites.

The mineralogical assemblages and textures in the Bracco-Levanto ophicalcites indicate a multiphase history of alteration. Oxygen Isotope and radiogenic strontium analysis have been performed on different vein generations. These data allow us to estimate formation temperatures and evaluate fluid-rock interaction during precipitation of carbonates that form a variable but extensive vein-network accompanied by serpentinization. Serpentinization continued with decreasing temperature during intense water circulation. Further we present bulk rock and mineral chemistry data of variably deformed serpentinite basement rocks of the Atlantic Massif and the Bracco-Levanto unit and compare these with the oxidized ophicalcites overlying the serpentinite, which have experienced higher water rock ratios.

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Residual liquid segregation and rhythmic magmatic layering by syn-magmatic shear in the Punta Falcone intrusion (Sardinia, Italy)

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The Punta Falcone is a small (200-300m x 600m) vertically layered Variscan gabbroic pluton built by successive injection of magmatic pulses at mid-crustal level. The Central zone of the complex, which is supposed to be the youngest one, is formed by plg-cumulus gabbros. No facies corresponding to an expulsed liquid could be found in the outcropping part of the system. On the other hand, hybrid rocks with mafic microgranular enclaves form dykes and brecciate the early gabbros.

Different types of magmatic planar structures occur throughout the complex. From the Central part towards the West the following structures were identified (fig 1):

- 1. Systematic continuous rhythmic layering with a regular spacing of 3cm in a cumulative part near the centre of the intrusion. Layering is defined by modal variations of amphibole (4-5mm big poikilitic Mg-hornblende grains around homogeneous plagioclase in the dark parts), and plagioclase (with thin albitic borders occurring together with some interstitial poikilitic quartz in the white layers). Mean orientation: 104/65.
- 2. Black planar structures ca. 4-5cm thick occur in the same facies as structures 1. They mainly consist of amphiboles; they are discordant and cut layering 1. The spacing of these zones is much more variable (between 20cm and 1m). Mean orientation: 117/83.
- 3. Sheared hybrid dykes in apparently isotropic gabbros. Other dykes of the same type in the same place are undeformed. Mean shear orientation: 097/50.
- 4. Thin white planes in a homogeneous gabbro ascribed to percolation of a more evolved liquid. Mean orientation: 123/86.
- 5. Somewhat diffuse rhythmic layering with cm scale. Mean orientation: 103/77.
- 6. Three different orientation sets can be identified on stereoplots: group I (structure 3) with the flattest dipping; an intermediate group II (structures 1 & 5) and group III (structures 2 & 4) with the steepest dipping. The angular difference between group I and group III is about 40°.

As structures (3) evidence syn-magmatic shearing, we infer shearing to be at least partly responsible for all other described structures. Shearing has to occur during/shortly after the injection of the magma when it is still a crystal mush. The residual liquid is expected to be extracted during this process, as illustrated in the centre of the intrusion. Layering textures suggest that the residual liquid escapes the system following regular planes. The parameters which control the observed regularity of extraction and thus of layering have to be further investigated.

Variation in orientation of the structures could be related to different processes, such as change of the local/regional stress field, rotation of the rocks because of the injection of new pulses displacing them, or conjugate shear zones. These processes could explain the presence of the two discordant structures (1 & 2) observed in the same facies close to the centre of the intrusion.

If cooling is too fast no structures will develop at all, as in the Eastern part, which is considered to be one or the earliest magma batches to emplace. The most central part does not show any structure as well. Cooling could have occurred in a period of quiescence towards the end of magmatic activity.

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a) Magmatic layering & discord- b) Percolation planes (structure 4) c) Magmatic layering (structure 5) ant bands (structures 1 & 2)



d) Equal area projection. Big points were measured directely on planar structure. Small points are calculated from two lineations. e) Equal area projection. Mean orientations of: all points (triangle); big points counting double (circle); only big points (squares).

Figure 1: Magmatic structures and orientation of layering and shear zones.

P 3.6

Origin and emplacement of a clinopyroxenite body in the feeder-zone of an ocean island volcano (Fuerteventura, Canaries)

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The PX1 or Pajàra pluton is a 22 Ma-old vertically layered gabbro-clinopyroxenite body outcropping in the exhumed basal complex of the Canarian Fuerteventura ocean island. It is interpreted as the shallow-level feeder-zone of an alkaline volcano. PX1 consists in five 50 to 100m-wide gabbroic sequences with a NNE-SSW orientation, alternating with clinopyxroxenite sequences. This general structure has been interpreted by Allibon et al. (2011) as sequential emplacement of basaltic magma pulses in a tectonically-controlled transtensional environment in a similar way as a sheeted-dyke complex. Clinopyroxenite sequences would represent truncated differentiation units from which residual liquids were squeezed out by local overpressure resulting from emplacement of subsequent magma pulses during peak magmatic activity. Alternatively, gabbroic sequences would represent non differenciated melts crystallized during more quiescent periods.

New detailed field observations could not establish any direct evidence of vertical or horizontal fractionation or layering in the clinopyroxenites. The latter appear more like a heterogeneous host-rock to the gabbroic dyke sequences than as discrete crystallization units. They are mainly composed of olivine-clinopyroxenites and wherlites crosscut by clinopyroxenitic pegmatite veins. In some places more evolved melts percolated through the clinopyroxenitic body as intergranular porous flow and also through open fractures resulting in dykes of various compositions. Olivine-rich enclaves of various shapes and sizes are also commonly observed within the clinopyroxenites. It is not yet clear whether these enclaves are in-situ dismembered cumulitic layers or lumps formed at deeper levels and brought up by subsequent magma batches. These observations appear to contradict the pyroxenite emplacement model by crystal-mush squeezing and truncated differentiation of Allibon et al. (2011). On the other hand, clinopyroxenes frequently exhibit chemical zonations which point to polybaric crystallization at different levels. Preliminary geochemical results also indicate a clear differentiation trend among clinopyroxenites. The most primitive sample is related to a large enclave of cumulitic dunite wrapped into clinopyroxenite. Our current interpretation is to consider PX1 as a clinopyroxenitic body resulting from emplacement of clinopyroxenite-wherlite mixed mushes, through which more differentiated alkaline melts percolated and gabbro dykes were injected.

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Alkaline melts –peridotite reaction as the process responsible for the nephelinite-alkali basalt transition

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Alkaline lavas from continental volcanoes or oceanic islands are characterized by a compositional continuum from nephelinites to alkali olivine basalts and often to tholeiites. The trace-element patterns are generally similar for the various basic magmas from a single volcano, but with overall trace-element concentrations decreasing with decreasing alkalinity. The decrease of trace elements has been interpreted as an increase of the degree of partial melting of a common source [1]. We perform partial melting calculation to test this hypothesis for the cases of Cantal Massif (French Massif Central) and Iblean plateau (Sicily, Italy) alkaline series. These calculations show that even the nature of the source changes from peridotite to pyroxenite, the increase of the degree of partial melting of a common source is unable to explain the general decrease of trace-elements contents from nephelinite to alkali basalt. In addition, no lithologies potentially present in the mantle (peridotite \pm CO₂, pyroxenite, ...) seems able to produce the ~6 wt% SiO₂ variation observed in alkaline series by an increase of the degree of partial melting from ~2% to 10%, range predicted by the variation of Th or La in alkaline series.

An alternative to explain the nephelinite-alkali basalt transition is the partial melting of a heterogeneous source [2]. To test this hypothesis, we perform trace-elements simulation for the melting of a heterogeneous source including enriched mantle (EM) and pyroxenite (PX) embedded in depleted mantle (DM) [2]. Even the melt extraction depth and proportion of EM-DM-PX in the source could vary, no model has been able to produce the observed variations. A variation of depth at which the melt is extracted from the source could explain the variations observed for very incompatible elements but not for HREE. In addition such model predicts isotopic variations as function of the proportion of the melt coming from the different lithologies, variations that are in contradiction with the constant isotopic composition observed in Cantal and Iblean alkaline series.

A second alternative suggests that nepheline–alkali basalt transition could be linked to a reaction between alkaline melt and peridotite [3]. Reaction experiments at lithospheric pressure (0.8-2.5 GPa) [3, 4] have shown that key features of the major-element alkaline trend could be explained by interaction between nephelinitic melt and peridotite which generates a higher-Si melt plus ol via dissolution of opx from the peridotite. Here, we have calculated the effect of such reaction on the trace-element budget of alkaline lavas from Cantal massif and Iblean plateau. The opx dissolution induces a dilution of trace-elements which account for most of the variation observed between nephelinite to alkali basalt/tholeiite. Nevertheless, the best fit was obtained by combining melt-peridotite reaction with a slight increase of the degree of partial melting at which the initial nephelinitic melt is produced.

We conclude that the basanite–alkaline basalt transition more likely represents a reaction between low silica alkaline melt and peridotite rather than by an increase of the degree of partial melting of a common source.

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P 3.8

PT-t evolution of migmatites from the region of Todtnau (southern Schwarzwald, southwest Germany)

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The Schwarzwald is part of the Moldanubic Zone of the Hercynic fold belt of central Europe. The town Todtnau lies within the "central Schwarzwald gneiss complex" (CSGC) neighboring the "Badenweiler-Lenzkirch-zone". The gneisses of the central and southern Schwarzwald experienced a complex thermal history in Variscan time with an early ultrahigh-temperature metamorphism followed by a pressure-dominated granulite-facies event and a LP/HT event leading to explicit anatexis of the rocks (see Kalt et al. 2000 and references within). Zircon dating reveal Variscan ages of about 330 Ma for this metamorphic overprint (Kalt et al. 1994; 2000). The aim of this study was a petrographic and thermobarometric investigation of metabasic and metapelitic migmatites from the southernmost part of the CSGC.

Samples were taken from 3 different locations around Todtnau. North-west of the town outcrops of metabasitic dictyonitic migmatites occur, which are intruded by small granite veins. The pristine rocks display only a slight metamorphic foliation and are cut by leucosome veins containing numerous hornblende crystals. Similar metabasic rocks crop out near the Todtnau cascades, however, they often display a distinct metamorphic foliation and fold textures. The third location lies northeast of Todtnau and is dominated by a series of metapelitic migmatites. These rocks, which reveal a distinct metamorphic foliation and banding with mica-rich melanosomes and quartz-feldspar-rich leucosomes, are often strongly weathered.

Under the microscope, the metabasic migmatites display sections hardly affected by the melting (paleaosome), which bear the mineral assemblage garnet-clinopyroxene-biotite-plagioclase-quartz. In sections with dominant anatexis, garnet and clinopyroxene are resorbed and a growth of hornblende is observed; furthermore, quartz, plagioclase and K-feldspar are present. Using conventional thermobarometry, PT conditions of 750 (+++50)°C and 1.03 (+- 0.19) GPa are derived for the relic mineral assemblage in the palaeosome (Fig. 1). These data are supported by calculations with the TWQ-program of Berman (1991) and equilibrium assemblage calculations with the isopleth thermobarometry using the Theriak/Dominoprogram of De Capitani & Brown (1987). PT-conditions during the anatectic melting were estimated at 700-800°C at 0.55-0.75 GPa using the Al- and Ti-contents in hornblende that formed in the leucosome (Fig. 1).



Fig.1: Assumed PT-path for the migmatites around Todtnau.

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The metapelitic migmatites show a thorough anatectic overprint with leucosomes made up of K-feldspar, plagioclase and quartz while the melanosomes and palaeosomes contain additional sillimanite, Ti-rich biotite and rare garnet. Garnetbiotite thermometry combined with GASP barometry reveals PT-conditions of 700 (+-30)°C at 0.65-0.75 GPa, which is well in accord the results from the anatectic metabasic migmatites. Very similar results are achieved using the TWQ program. Equilibrium assemblage calculations with the Theriak/Domino program indicate a PT box ranging from 650-750°C at 0.3-0.8 GPa for the observed mineral assemblage in presence of anatectic melt (Fig.1).

Locally, the migmatites experienced a strong late hydrothermal overprint leading to an intense decomposition of the primary metamorphic minerals. In the metabasic rocks, mineral assemblage including prehnite and chlorite formed. Equilibrium assemblage calculations reveal PT-conditions of 200-350°C at <0.45 GPa for this overprint (Fig. 1). The timing of this last hydrothermal event is not constrained; it may have occurred during the late Palaeozoic magmatism or during the formation of the Rhine graben.

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P 3.9

Fe³⁺/Fe²⁺ ratios in minerals and bulk of metamorphic rocks: Mössbauer spectroscopy, wet chemistry and high resolution XANES on the blue-schists of Syros and Sifnos (Cyclades, Greece)

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Ferric/ferrous iron ratios influence pressure and temperature estimations in metamorphic petrology. Any thermobarometric recalculation requires bulk and mineral iron values; however they are often scarcely known and have to be either estimated or pure ferrous systems be assumed. We intend to create a data base for blueschist minerals that can be incorporated into solid solution models used for pressure/temperature recalculations.

To create standards and correlate wet chemistry and Mössbauer spectroscopy with micro-XANES, minerals with supposedly pure ferrous and ferric incorporation were analysed. In addition, focus was set on more complex sodic amphiboles incorporating both Fe²⁺ and Fe³⁺ because they define the stability field of blueschist facies metamorphism. Glaucophane iron ratios of different parageneses, protoliths and Fetot from the locus typicus Syros and from Sifnos blueschists were determined with Mössbauer spectroscopy to investigate the influence on iron oxidation state and coordination. The same glaucophane grains were analysed with micro-XANES looking at the iron k-alpha pre-edge structure to investigate Fe³⁺/Fe²⁺ ratios in situ.

Pressure/temperature estimations with the software PERPLE_X using measured bulk ferric/ferrous iron ratios and estimated ratios are compared. Significant discrepancy is discussed along with the consequences and misinterpretations that unknown or assumed ferric/ferrous iron ratios may introduce in the burial and exhumation history of the Syros and Sifnos blueschists.

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P 3.10

Geochemical investigation of fluid inclusions in fissure-quarzcrystals of the Meta-dolomites in the Binn-Valley, Wallis, Switzerland

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The aim of this investigation is a comparison of several sulfosalt bearing mineral localities in dolomitic rocks of the Binn-Valley (Wallis, CH), in terms of their occurring fluids. The Lengenbach quarry is one of the most famous mineral collecting sites in Switzerland. In the last decades, numerous investigations on geology, mineralogy and ore formation for this mineralization were done. The richness of sulfosalt minerals and the occurence of Tl-sulfosalts is of specific scientific interest. The mineral deposit is located in Triassic meta-dolomites, underlayed by Jurassic schists (Bündnerschiefer). Over the dolomitic rocks different Pretriassic ortho- and paragneises occure (Hügi 1988). Due to the tectonic settings the primary stratigraphic sequence of the rocks is reversed. Beside the Lengenbach quarry, other sulfosalt bearing deposits are known, situated within dolomitic rocks. The most famous are Reckibach and Turtschi. The localities Reckibach and Turtschi show considerable differences in their element dominances refered to the sulfosalt- and sulfide minerals. The outcrop Turtschi shows a Sb-Bi-dominance whereas Reckibach is clearly Ag-dominated. The Lengenbach quarry in addition is characterized by the occurence of Tl-sulfosalts and shows the largest mineral diversity of all outcrops (Graeser 1965).

Quartz crystals from alpine fissures are the hostmineral of the investigated fluid inclusions. Differentiated inclusion petrography and microthermometric investigations are the basis of this work. It enables to evaluate the succession, approximated composition and density of the fluid inclusions. With the help of a Raman-Microprobe it was possible to determine occurring daughter minerals (halite, calcite, sphalerit) and dissolved volatile species (H₂O, CO₂, H₂S). The qualitative composition of high-saline fluid inclusions were derived by SEM, analysing the perceipated solids after decrepitation.

The investigations show a clear fluid evolution, beginning with CO₂-rich fluid inclusions (Fig.1) too H₂O-rich inclusions (Fig.2). On two localities it was possible to determine high-saline fluid inclusions (Fig.3) which formed between the CO₂- an H₂O-rich fluid inclusions populations. It seems that the well developed sulfosalt-crystals in the fissures are the result of mobilization processes of preexisting sulfosalt precipitation within the dolomitic rocks more or less close to the fissure Systems. The occurrence and geochemistry of the ore penetration indicate a Sedex-formation (Knill 1993) for the different localities.

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Figure 1: CO₂-rich fluid inclusion. 1: CO₂ (vapour), 2: CO₂ (liquid), 3: H₂O (liquid).



Figure 2: Salt-rich fluid inclusion. 1: NaCl (solid), 2: Calcite (solid), 3: H₂O/CO₂(vapour), 4: H₂O (liquid).



Figure 3. H₂O-rich fluid inclusion. 1: H₂O (liquid), 2: H₂O (vapour).

P 3.11

Retrograde fluid evolution and its impact on mineral precipitation. An example from an Alpine fissure of the Gotthard rail base tunnel between Amsteg and Sedrun, external part of the Central Alps.

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Alpine fissures represent small hydrothermal systems in which the fluid evolution and mineral precipitation during retrograde conditions can well be investigated.

The present study is focused on a selected Alpine fissure, situated in the Central Aar granite of the Gotthard rail Tunnel. Its main topics are:

- 1. the evolution of the paleo- to the recent fluids (Bergwässer)
- 2. the evolution of the mineral assemblages due to changes in fluid composition and PT-conditions.

The Alpine fissure opened at 400 ±10° C and 3.5 to 3.8 kbar, due to compressional tectonics (Mullis, 2011).

Salinity of the mineralizing fluid evolved from 5.7 wt % NaCl equivalents in the earliest to < 3 wt % in the latest detected paleofluid. Recent fluids (Bergwasser) investigated by Bucher and Seelig (2010) show a bulk salinity of 0.27 wt %. This fluid evolution has been interrupted by a short input of a markedly higher saline fluid containing up to 8.7 wt % NaCl equivalents.

Several mineral assemblages formed during retrograde conditions: First the precipitation of biotite, epidote and quartz (early assemblage) succeeded by albite, adularia and chlorite (intermediate assemblage). Due to enhanced tectonic activity, a short but well developed assemblage followed with at least 3 generations of anhydrite (δ^{34} S = 25.6 ‰), baryte and hematite, containing higher saline fluid inclusions. Mineralization ends with the precipitation of the zeolite minerals laumontite, chabasite, stellerite and stilbite (late assemblage).

Interpretation:

- 1. The decrease in salinity from early metamorphic fluids in more or less closed systems towards late lower saline fluids is well known (Mullis et al. 1994). This possibly indicates dilution by meteoric water. This is the object of ongoing work including stable isotope and ICP-MS investigations.
- 2. Tectonic activity affected the fissure system episodically. A few strong events enabled infiltration of external fluids, containing Triassic sulfur. Sulfur bearing fluids are interpreted to originate from overlying evaporites (above the crystalline rocks of the Aar massif), from where they migrated into the actual position of the Central Aar granite.



Figure 1. Earliest aqueous saline fluid inclusions $(a_1 \text{ and } b_1)$ in anhydrite (a_2) and quartz (b_2) . Photos: a1 and b1 by Josef Mullis, a2 and b2 by Thomas Schüpbach.

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Experimental characterization of cement-bentonite interaction using core infiltration techniques coupled with 4D X-ray tomography

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Deep geological disposal of radioactive waste foresee cementitious materials as reinforcement of tunnels, backfill, or as waste matrix. Bentonite, or sand-bentonite mixtures, are proposed as backfill material enclosing spent fuel drums, or as drift seals. The emplacement of cementitious material next to clay material generates an enormous chemical gradient in pore water, which drives diffusive transport. Laboratory studies and reactive transport modeling predict significant mine-ral alteration on both sides of interfaces, mainly resulting in a decrease of porosity in bentonite [2].

The goal of the project is to characterize and quantify the cement/bentonite skin effects spatially and temporally. The expected analytical data set will be amenable to interpretation by reactive transport modeling. The project focuses on the advective-diffusive transport domain, resolved at intermediate spatial scales. The experiment is carried out in a newly developed X-ray transparent core infiltration apparatus, which allow performing X-ray computed tomography scans (CT) [2] without interrupting the running core infiltration experiment (Fig. 2).

The experiment is performed on cylindrical bentonite samples, previously compacted and saturated (Fig. 1). A sample is then subjected to a confining pressure in order to simulate underground repository conditions. The infiltration of high-pH cement pore-fluids into the bentonite plug is expected to alter the mineral assemblage over time as an advancing reaction front. The related change in phase densities, porosity and local bulk density is tracked over time periodically by non-destructive CT scans. The resulting micrographs describe the "density" distribution in three dimensions and as a function of time. "Densities" are actually radiodensities calibrated with reference samples mounted in an identical apparatus (Fig. 2). After 1-2 years we will stop the experiment and subject the rock samples to post-mortem mineralogical and petrophysical analysis.

In the current experiment a compacted and saturated MX-80 bentonite is used as starting material. A confining pressure of 40 bar is applied. The infiltration fluid pressure is 20 bar, and the rate of discharge is on average 0.077 ml/day. The hydraulic conductivity of the bentonite is 1.12E-13 m/s at the beginning. The infiltrating fluid represents an ordinary Portland cement pore-water after a hydration time of 623 days (chemical composition after B. Lothenbach [3]).

First CT data show that X-ray computed tomography is a feasible tool to monitor ongoing infiltration experiments (Fig. 2). Using the reference samples, a bentonite density could be determined. The maximal voxel size of the scans is 0.10 mm. A pore-scale resolution is not required to track changes in a relatively homogenous medium with a large porosity and significant changes in X-ray attenuation during formation of mineral precipitates.

Acknowledgement

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Figure 1. Two pictures of a bentonite sample. The upper image shows a CT scan and the lower one the original rock sample.

Figure 2. The two upper images are showing CT scans of the outer tube (left) and the bentonite specimen (right). The lower image is showing the mobile infiltration system in the CT scanner. The table and the gray-scale showing the relation between the radiodensity (HU) and the gray-scale values.

P 3.13

The enigmatic Songshugou complex (Qinling orogen, central China): mélange of high-pressure and (ultra) high-temperature metamorphic rocks?

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The ~25 × 5 km Songshugou complex abuts Devonian migmatites (P–T: 700-770 °C, 0.5-0.7 GPa) of the Qinling complex. It comprises a core of ultramafic rocks surrounded by amphibolite mylonites that host medium- to coarse-grained garnet-amphibolite and garnet-clinopyroxenite lenses. The latter underwent (ultra)high temperature metamorphism at 840-920 °C and 1.0-1.4 GPa (Zhang, 1999). Clinopyroxene-albite symplectites from these rocks were interpreted as relics of an earlier high-pressure stage, whose P–T conditions remain unknown (Zhang, 1999). Along a shear zone at the southern margin of the Songshugou complex, kyanite-bearing felsic granulite (peak P–T 800-900 °C, 1.3-1.6 GPa, Liu et al., 1996) and migmatitic, partly spinel- and corundum-bearing gneisses crop out. Herein, we focus on the garnet amphibolites, present new P–T data derived from garnet isopleth thermobarometry via DOMINO, and suggest a new model for the evolution of the Songshugou complex.

Samples 75282C and 75293E are composed of prograde zoned, ≤ 5 mm garnet porphyroclasts, mm-sized, light-greenish to greenish-brown, zoned amphiboles, and a mylonitic matrix of amphibole with subordinate plagioclase and quartz. Thermodynamic modeling in TNCKFMASH system points to quartz-eclogite facies conditions during garnet growth (Fig. 1), from 498 °C at 2.25 GPa to 530 °C at 2.54 GPa (sample 75293), and from 494 °C at 2.13 GPa to 510 °C at 2.44 GPa (sample 75282C). According to the calculation, garnet coexisted with omphacite, actinolite, lawsonite, phengite, quartz, and rutile at peak-pressure. During exhumation, omphacite and lawsonite were consumed and amphibole growth continued. Pronounced heating is reflected by steadily increasing Ti-contents in amphibole; Ti-in-amphibole thermometry (Colombi, 1988) applied to rims of large zoned amphibole prisms points to ~680 °C. Partial garnet-breakdown by formation of plagioclase-amphibole-quartz-coronas yielded similar conditions of 660-700 °C and 0.9-1.2 GPa by conventional thermobarometry (Bhadra & Bhattacharya, 2007; Colombi, 1988).



Figure 1. Published and new P–T estimates of mafic and felsic rocks from Songshugou complex.

It is debatable, which P-T path the two garnet amphibolites followed during exhumation, because nearby granulite-facies garnet clinopyroxenites also show relics of an earlier eclogite-facies metamorphism (Zhang, 1999), outlining P-T path I in Fig. 1. As our samples show no indications of granulite-facies metamorphism, this scenario does not apply to them and PT-path II in Fig. 1 is suggested. To account for these distinctly different P–T paths, we interpret the Songshugou metabasites as part of a tectonic mélange. The investigated samples stem from the downgoing slab, while the (U)HT garnet clinopyroxenite either represent a part of the overriding plate that was dragged to upper mantle depths or a different part of the downgoing slab that was exposed to distinctly higher temperatures during exhumation. The ultramafics stem from the upper mantle underneath the overriding plate. During their exhumation, all rocks were juxtaposed at P–T conditions of ~650-700 °C and ~1.0 GPa, as they have the amphibolite facies overprint in common.

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P 3.14

New data about regional metamorphism and magmatism of Khrami crystalline massif (the Caucasus, Georgia)

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The Khrami crystalline massif (KhM) represents a deeply eroded part of pre-Alpine basement of the Black sea – Central Transcaucasian terrane.

Among the pre-Alpine formations, that build up the KhM according to their age succession following major rock complexes are present: 1 – Precambrian gneiss-migmatite complex (GMC), 2 – pre-Variscian (Cambrian) basitic, 3 – Sudetian granitic and 4 – Late Variscian, volkcanigenic-sedimentary and quartz-porphyry – granite-porphyry complex (Khutsishvili, 1977; Gamkrelidze, Shengelia, 2005).

Two stages of regional metamorphism are identified within the KhM: prograde HT/LP (700-720°C, p<1.5 kbar) and retrograde (420-500°C, p 1.3-1.6 kbar).

The formation age of granites and basitic magmatism of the pre-Alpine basement of KhM was considered as Variscian for a long time. Based on special geological and isotope- geochronological investigation has been determined neo- Proterozoic age of initial rocks of GMC, Grenvilian prograde and Sudetian retrograde RM and Sudetian age of granites. La-ICP-MS U-Pb dating of two zircon crystals from paraplagiogneisses of GMC shows the age of RM 931±16 Ma.The average age of 28 crystals of zircon from granites and outer rims of the zircon from paraplagiogneisses corresponds to 325.6±2.6 Ma and covers interval 319-332±Ma.

Sudetian age of granites is firmly determined by geological data as well. In particular the age of developed on the periphery of KhM volcanigenic-sedimentary complex based on faunal and flora dating covers the interval from Visean till the late Bashkirian stage. To this time interval is related volcanic activity of quartz-porphyry and granite-porphyry composition. Their dikes inject postmetamorphic granites of KhM, accordingly the age limit of the latter couldn't be younger than Visean.

Geological, petrological and geochemical data as well as isotope-geochronological data enables to trace the stages of RM and granite formation and accordingly formation of pre-Alpine continental crust of KhM.

Basic mineral parageneses of Grenvile Regional Metamorphism – Crd+Bt+Qtz+Ort, Hbl+Bt+Pl+Qtz, Bt+Pl±Cum+Qtz while exposure of Sudetian phase of tectogenesis are emplaced by paragenesis Ms(Ser)+Chl+Ab±Mikr±Bt±Qtz, Ab+Chl+Mikr+Ep±Qtz+Car, Ab+Act+Chl+Ep±Qtz.

In GMC vein bodies of Cambrian (?) metagabbro are present which underwent only Sudetian RM and are injected by granites of the same age. The age of metabasites is apparently Cambrian (Shengelia, 2000; Gamkrelidze, Shengelia, 2001).

Isotope-geochronological data as well as existed geological, petrological and geochemical data enable to trace major stages of regional metamorphism and granite formation and accordingly formation of pre-Alpine continental crust of KhM.

On the first stage (1000 Ma and more) of formation of pre-Alpine continental crust of KhM takes place accumulation of terrigenous sediments (graywackes and pssamites) with minor amount of basic volcanites, that correspond to interplate and transitional between interplate and oceanic basalts. The source area for non-Proterozoic marine basin that provided it with clastic material, was located to the north from the basin and was built up by the rocks of subcontinental crust with low content of K₂O. The total thickness of non-Proterozoic sheet is not less than 10 kbar.

On the second stage (1000-900 Ma) of crust-forming processes under suprasubduction conditions was formed of subcontinental or immature continental crust. As a result of Grenvilian RM (T=700-720°C, P,1.5 kbar), non-Proterozoic formations were transformed into plagiogneiss-plagiomigmatite complex. Plagiogneisses correspond to S-type granites and according to chemical and geochemical parameters belong to upper crust.

Cambrian metagabbroids occupied 25% of total volume of gneissimigmatite complex of KhM and caused basification of Grenvilian subcontinental crust.

According to geochemical data the most of Late Variscian granitoids belong to upper crustal type and are more comparable with S – type granitoids.

Simultaneously with formation of Late Variscian granitoids retrograde metamorphism (T≈420-500°C, P=1.3-1.6 kbar) and intensive rhiolitic volcanism takes place.

So, true continental crust in pre-Alpine basement of KhM is being formed during exposure of Late Variscian phase of tectogenesis. KhM was rich in leucocratic bodies of crustal-anatectical eutectoidal granites of different size. It's significant, that great masses of all pre-Alpine rocks of different ages underwent intensive and almost total microclinization and are saturated by granitic material.

In the very end of Variscian orogenesis takes place unusually abrupt exhgumation of deeply burried parts of the earth crust, caused by izostatic and intensive erosion.

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P 3.15

Elemental composition of a bangle shard from Harrappa, an Indus valley settlement

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A terracotta bangle shard, collected from Harrappa, was tested for mineralogical and thermal characteristics and the results were reported by Kayani & Siddiqui in 2011. Although Harrappa is the most important site of Indus valley civilization yet little research has been carried out on terracotta jewellery unearthed at this site.

In order to complement the results of mineralogical and thermal testing, a brief research study has been carried out to determine the elemental composition of the components of the same bangle shard specimen using WD-XRF spectrometry analysis. (The testing was carried out at Geoscience Advance Research Laboratories, Islamabad, a facility maintained by Geological Survey of Pakistan.) Concentration of all major elements is included in the following table.

Element	Wt%				
Si	46.845				
Ti	0.712				
AI	20.714				
Fe	6.247				
Mn	0.055				
Mg	17.467				
Са	1.364				
К	2.816				
S	1.08				

Loss on ignition (LOI) for above reported values is 2.7 wt%. As a consequence of the limitation imposed by the type of equipment used, no data on trace elements is available. However, the values of major elements for the tested specimen are comparable with the results of similar tests reported by Kumar et al. in 2006 (for Harrappan era pottery specimens only). Their pottery specimens were collected at Sanghol, another Indus valley site located near the city of Chandigarh in present day India. Minor variations may exist depending upon nature of the local soil.

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P 3.16

Geochemistry of Silurian Niur Sandstones in Tabas Block, Central Iran

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An integrated petrographic and geochemical study of sandstone portions of Silurian Niur Formation, Central Iran was carried out to infer their provenance and tectonic setting. This study is based on the petrography (40 rock samples) and geochemistry (12 rock samples) analysis from one stratigraphic section in Derenjal Mountains in Northwestern Tabas block.

Modal analysis data of 40 medium sand size and wellsorted samples reveal most of quartz composed of monocrystalin grains with straight to slightly undulos extinction but there are about 3% polycrystalin quartz. These monocrystalin and polycrystalin quartz grains with rutile needle inclusions can be derived from felsic igneous rocks of a craton interior setting.

On the basis of the framework composition and geochemistry (major and trace elements) data, the sandstones are classified as quartzarenite, sublitharenite, and subarkose types. Petrographic studies reveal that these sandstones contain quartz, feldspars and fragments of sedimentary rocks.

The detrital modes of these sandstones indicate that they were derived from recycled orogen and stable cratonic source. Major and trace element contents of them are generally depleted (except SiO_2) relative to UCC (Upper Continental Crust) which is mainly due to the presence of quartz and absence of other Al-bearing minerals.

Modal composition and discrimination diagrams based on major as Roser & Korsh(1988, Fig.1a) and Bhatia (1983, Fig.1b) also trace element concentrations, such as Ti, La, Th, Sc and Zr, and Bhatia & crook (1986, Fig.2) diagram, suggest a felsic igneous source rock and quartzose polycyclic sedimentary provenance in a passive continental margin setting. Furthermore high Zr/Sc values in these sandstones, considered as a sign of recycling, which can be related to effects of the Kaledonian orogeny in Central Iran.

The results of this study suggest that the main source for these sandstones was likely located in Tabas block in Central Iran as an upplifted basin. Paleoweathering conditions indicated by modal compositions and $Al_2O_3+K_2O+Na_2O\%$ versus SiO_2 bivariate of these sandstones. Our studies suggests humid conditions for source area.



Figure 1. Plots of the major element composition of the Silurian Niur Sandstone member on the (a) different provenances discrimination diagram of Roser and Korsch (1988) and (b) tectonic setting discrimination diagram of Bhatia (1983). A=oceanic island arc; B=continental island arc; C=active continentalmargin; D=passive continental margin.



Figure 2. Trace element composition of the sandstones from IlanqarehFormation on the triangleand bivariate tectonic setting discrimination diagrams of Bhatia and Crook (1986). A=oceanic island arc; B=continental island arc; C=active continental margin; D=passive continental margin.

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P 3.17

Early Palaeozoic tectonic process in north-western Gondwana as revealed by zircon hafnium isotope analysis: tectonic switching along an active margin

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An increasing number of global plate reconstructions for the lower Palaeozoic, place the southern Rheic Ocean passive margin in the Northern Andes, across present day Venezuela, Colombia and Ecuador. These reconstructions are based upon the hypotheses that: a) the lower Palaeozoic position of these terranes was outboard of the Colombian Andes basement and b) Ordovician tholeiites exposed in Mexico record a rift to drift transition during the opening of the Rheic Ocean (e.g., Keppie et al., 2008 and references therein). However: a) these units are separated from South America by the intervening Caribbean Plate, and their lower Palaeozoic position is speculative; b) the same basement complexes have also been interpreted as a tectonic assemblage of Early and Late Palaeozoic high pressure belts formed in convergent margin settings (e.g., Vega-Granillo et al., 2009 and references therein); and c) these models seem to ignore all existing data and working hypotheses from Northern Andean geology, which predict Ordovician accretionary orogenesis, rather than rifting (e.g., Restrepo-Pace and Cediel, 2010).

The study of basement rocks exposed in the Northern Andes of Venezuela and Colombia should be a less controversial basis for understanding the tectonic history of northern South America. We present new, in-situ zircon Lu-Hf isotopic and U-Pb geochronological which place new constraints on the tectonic settings of the Northern Andes in the Early Palaeozoic.

The Northern Andes host Precambrian basement overlain by Middle to Late Cambrian metasedimentary units whose detrital zircon signature suggests a Gondwanan provenance. Metamorphism of these units to upper amphibolite facies and deformation together with early Ordovician orthogneisses suggests metamorphism may have culminated at ~470 Ma. Middle Ordovician to latest Silurian granitoids are mostly undeformed, have continental arc geochemistry, and Hf isotopic data shows a much more juvenile input in the magmatic source after ~470 Ma.

Zircons from a Felsic tuff associated to a VMS deposit and marine sedimentary rocks from the western Mérida Andes in Venezuela, yield a late Ordovician age. The development of a marine basin suggests crustal thinning, and the common association of post-Archaean VMS deposits to back-arc or intra-arc settings suggests that the middle Ordovician shift to less crustal magmatism was accompanied by extension driven by slab roll-back. Subsequent Late Ordovician to Silurian magmatism rapidly became more crustal, which may suggest a period of crustal thickening driven by compression.

Due to their very similar geological histories, isotopic trends, and detrital zircon signatures, we propose that the basement rocks exposed in the Santander Massif of Colombia and the Mérida Andes of Venezuela do not define separate allochthonous terranes as previous authors have suggested. Instead, these basement blocks followed similar histories on the north western Gondwanan margin since at least the Cambrian.

Intense Lower Palaeozoic deformation and magmatism, followed by an absence of Devonian – middle Carboniferous magmatism in Colombia and Venezuela, are features shared with the central and southern Andes of Peru, Chile and Argentina (Bahlburg et al., 2009), where tectonic switching may also have been the modus operandi in the lower Palaeozoic (Miller and Söllner, 2005). This suggests a similar tectonic setting along the same active margin.

Collectively, these findings strongly suggest that the north-western corner of Gondwana was host to an active margin. Therefore, the southern passive margin of the Rheic Ocean was situated eastwards from the basement rocks exposed in the Northern Andes.

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Symposium 3: Mineralogy, Petrology, Geochemistry

P 3.18

Accessory ilmenorutile of diamondiferous terrigenous rocks of South Timan in the north-east borderland of the East-European platform.

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The diamond-bearing terrigenous rocks is located in the Timan ridge in the north-east borderland of the East-European platform. The geological history of the Timan there was a huge break in sedimentation which was in the early Paleozoic. It promoted of wide manifestation of rock weathering processes so that there was a concentration of a number of useful minerals. There are unique on reserves of a deposit of bauxites and the titanium, and perspective show of rare, nonferrous and noble metals, diamonds and many other mineral resources.

The problem of a diamond content of Timan is the center problem of explorer more than 50 years. But the question of conditions of their formation, placement and a structure remains a subject of discussions. In spite of the long mineralogical study of this stratigraphical subdivision, there is still no answer to two important questions: 1 - whether the productive formations are sedimentary rocks; 2 - if the productive deposits of the Pizhma series are a secondary collector, as it was traditionally thought, where are provenances of Timanian diamonds?

Individual indicator minerals is important in determining the conditions of formation of diamond-bearing terrigenous deposits in the Timan problematic genesis. As featured typomorphic ilmenorutile we can select the specific conditions of formation and history of the further development of minerals.

Microprobe analysis ilmenorutile of diamondiferous terrigenous mid-devonian deposits, composed of sandstones with gritstone and clay bands, showed that the basic components of the mineral are niobium, tantalum, titanium and iron, there are the following admixture element: tungsten, vanadium, tin, manganese and scandium. According to available data [1] we can conclude that we are dealing with the decay products ilmenorutile. From the ratio of $(Nb_2O_5 + Ta_2O_5) / TiO_2$ they are similar to ilmenorutiles typical of granitic pegmatites, in Ta_2O_5/Nb_2O_5 ratio they similar to be ilmenorutiles beryl-columbite albitization granitic pegmatites. According to the content to V they refer to ilmenorutile of carbonatites, Sn contain ilmenorutiles of pegmatites.

According to the results of the study the author comes to the conclusion, that the rocks of Asyvvoj relate to secondary deposits. Ilmenorutile formation passed in different conditions, basically it is connected with granitice pegmatites, but there are some admixture elements connected with carbonatites.

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Exocontact Metamorphism in Klich Gabbro-diorite Intrusive

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The Klich gabbro-dioritic intrusive participates in the make-up of the crystalline core of the Greater Caucasus and is exposed in the limits of the Pass subzone of the Main Range zone. The exposure of the intrusive is fixed in the eastern part of mountainous Apkhazeti, in headwaters of the river Kodori, covering about 10km². According to different authors the intrusive is represented by "eye-shaped" biotite-hornblende bearing and biotitic orthogneisses (Somin, 1971), or by gabbros and gabbrodioritic orthogneisses (Javakhishvili, 1979). According to our data, the most widespread among the rocks composing the Klich intrusive are hornblende bearing and weakly biotitized gneissose diorites, and relatively less spread are their last marginal members – gabbros and especially quartz-diorites. The rocks including the intrusive are represented by the rocks of Gwandra suite of Buulgen series, which underwent regional metamorphism corresponding to the staurolite facies connected with the Late Baikalian orogenic cycle. In the Late Paleozoic time, the Gwandra suite rocks together with the rocks composing the Klich intrusive, underwent prograde regional metamorphism connected with the Bretonian phase of the Variscan orogeny, which corresponds to the andalusite-sillimanite pressure type and temperature conditions of biotite-muscovite bearing gneissic facies (Shengelia, Ketskhoveli, 1982; Shengelia, 2000).

According to K_2O/Na_2O-SiO_2 diagram figurative points of the Klich gabbro-dioritic intrusive are disposed in Na-, K-Na- and Na-MORB series. In FeO*/MgO-SiO₂ and AFM diagrams they occupy the calc-alkaline and tholeiitic fields, but in Na₂O+ K₂O-SiO₂ diagram they correspond to the calc-alkaline only.

According to ACM and AFM binary diagram figurative points of the studied rocks arranged predominantly near the fields of MAR and basic cumulates and in Ti/Cr-Ni diagrams they occupy an IAT field.

In Ce/Pb-Ce, Sm/Yb-Ce/Sm diagrams the figurative points indicating the rocks composing the Klich intrusive occupied the MORB, IOB and MORB+IOB fields. According to Th/Y-Nb/Y, Th/Yb-Ta/Yb and La/Nb-Ti diagrams their content corresponds to the MORB. In the Th/Yb-Nb/Yb diagram the points are distributed in the area of the depleted mantle, but in Rb/Y-Nb/Y diagram they correspond to the middle and lower crust formations.

Spider diagrams of the Klich gabbro-dioritic intrusive rocks are characterized by low angle of inclination and positive Eu minima that is indicative of typical mid-acidic rocks.

Thus, from petrochemical and geochemical study of the Klich gabbro-diorite gneisses it has been established that composition of the intrusive:

- 1. varies between gabbro-diorites and quartz diorites;
- 2. corresponds to weakly differentiated low potassium series;
- 3. is characterized by low ratio of K_2O/Na_2O .

In the contact zone of the Klich intrusive and the enclosing metapelitic crystalline schist the products of contact metamorphism, massive metamorphic rocks-felses are spread. 10-30m wide stripe of felses is spread around the intrusive, into the gorges of the river Klich and its right tributary the Achapara river. As a result of thermic metamorphism, in the exocontact of the intrusive are developed following parageneses: $Cor+Grt\pmSill(Andl)\pmSpi$, $Sill+Bt\pmSpi\pmQtz$, $Cor+Spi\pmQtz$, there are established reactions: $St+Qtz\rightarrowCor+Grt\pmAndl(Sill)\pmSpi+H2O$, $Ms+St+Qtz\rightarrowSill+Bt+H_2O$, $St\rightarrowCor+Spi$, $St\rightarrowAndl(Sill)+Spi$ and is fixed Andl \rightarrow Sill inversion in them. Felses are represented in the contact zone 1-5m of the Klich intrusive by cordierite-sillimanite-spinel parageneses; in 5-20m from contact area there have developed stable mineral association of garnetbiotite-sillimanite-andalusite; in 20-90m^{-s} they are substituted more low–temperature mineral parageneses – stavrolitebiotite-andalusite-garnet.

Felse has an exotic mineral composition, as there are fixed both relicts (stavrolite, muscovite, quartz, andalusite) and newly originated minerals (cordierite, garnet, sillimanite, spinel, biotite). These rocks are very nice: black-yellowish-pinky inclusion make harmonious pattern against the grey background. Physical-chemical characteristic of these rocks; completely meet the requirement of facing stone raw material, they correspond to the (A d) I class of quality of ornamentality. Felse belongs to the most stable group of rocks and can be used for interior and exterior lining.

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¹¹⁸ P 3.20

Metamorphism of the polarural precambrian rocks

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There are blocks of the Early Proterozoic crust in the north of the Urals represented by deeply metamorphosed amphibolites, schists, and gneisses of the harbeysky complex. Petrographic and micromineralogical studies of amphibolites and amphibole schists allowed to distinguish several generations of mineral formations using a scanning electron microscope JSM – 6400.

In massive and weakly foliated amphibolites major rock – forming minerals are green amphibole of the pargasite – hastingsite series, oligoclase, and andesine. Quartz grains, clinozoisite and chlorite are rare, the last one often replaces amphibole at the edges. Garnet (high – calcium pyrope – almandine), clinozoisite, biotite, chlorite, and muscovite are distributed along with blue – green and light green amphiboles of the series pargasite – hastingsite in foliated amphibolites. Albite forms porphyroblasts and also is presented in the form of tabular grains in the intergranular space. Chlorite and muscovite are developed perpendeculary to the schistosity and often replace garnet, indicating their later forming. Schists were found in local areas and were divided into mainly amphibole, quartz – amphibole, garnet – muscovite – chlorite – clinozoisite – amphibole, and garnet – glaucophane – albite species with the presence of bluish – green, light green amphiboles of the pargasite – hastingsite series, and pale green actinolite.

As a result the minerals parageneses formed under different thermobaric conditions were distinguished. They are pargasite – hastingsite + oligoclase (andesine), pargasite – hastingsite + albite + garnet, pargasite – hastingsite + albite + garnet + clinozoisite, garnet + glaucophane, actinolite + chlorite + clinozoisite, muscovite + chlorite + clinozoisite + quartz. Calculations of thermodynamic parameters of the amphibolites metamorphism were performed using the TPF program developed by A. N. Konilov, A. A. Grafchikov (Institute of Experimental Mineralogy, Chernogolovka), and based on a system of agreed goetermometers and geobarometers, in which the minerals compositions are used in a variety of mineral associations. We applied plagioclase – amphibole (Holland & Blundy 1994; Jaques et al. 1982), garnet – amphibole (Lavrentyeva & Perchuk 1989; Powell 1985; Wells 1979) geotermometers, and also amphibole (Hammarstrom & Zen 1986; Hollister et al. 1987; Schmidt 1991) and plagioclase – amphibole (Fershtater 1990) geobarometers. As a result it was found that temperatures generally range from 600 to 7900 in accordance with the pargasite – hastigsite + oligoclase mineral assemblage, in rare cases they are lower. The pressure is 5,5 - 10,0 kbar in the massive and weakly foliated amphibolites. Conditions of the amphibole and plagioclase metamorphism from these rocks correspond to high stages of moderate pressure amphibolite facies.

The garnet – containing parageneses of foliated amphibolites correspond to low stages of metamorphism amphibolite and epidote – amphibolite facies (T 480 – 6400) of increased pressures (P 8 – 12 kbar). The rocks were exposed to low temperature changes in the epidote – amphibolite and green schist facies conditions in local areas. Thus the harbeysky complex rocks experienced a polimetamorphism in conditions of the moderate pressure high temperature amphibolites, epidote – amphibolite facies, and low – temperature changes.

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P 3.21

The Madneuli polymetallic deposit, Bolnisi district, Georgia: Evidence for a magmatic input in a submarine, transitional hydrothermal system.

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The Late Cretaceous Madneuli polymetallic deposit is located in the Bolnisi district, southern Georgia and hosted by a volcanogenic sedimentary subaqueous sequence. The Bolnisi district is located in the Somkheto-Karabakh island arc of the Lesser Caucasus, which extends towards the West in the Eastern Pontides, Turkey. The origin of the Madneuli deposit is controversial. In order to constrain its genesis, we have undertaken a detailed study of ore paragenesis and alteration combined with a stable isotope investigation.

Two different ore types are recognized at the Madneuli deposit (Fig. 1):

- a) A subvertical stockwork part, constituted mainly of pyrite, chalcopyrite and sphalerite with enargite in the core of the system. Quartz and abundant barite are the main gangue minerals. A stratiform, massive sulfide orebody and sandstone lenses cemented by barite are located on the top of the stringer zone; the massive sulfide body is characterized by a sphalerite, galena, chalcopyrite, pyrite and tennantite-tetrahedrite assemblage. The alteration halo surrounding this ore zone is composed of a strongly silicified core, grading out into a quartz-sericite-pyrite zone and an outer quartz-chlorite-sericite zone. Drilling has intersected a Late Cretaceous granodiorite to quartz-diorite porphyry intrusion 800-900 m below this ore zone.
- b) Subvertical pyrite-chlorite-hematite-gold±chalcopyrite veins occur on the eastern flank of the open pit and are mainly mined for gold. Native gold is associated with telluriumbismuthite contained in pyrite, or as intergrowths with hypogene hematite. Silicified platy calcite occurs locally and documents boiling conditions. The alteration assemblage is formed by quartz-chlorite-pyrite and confined to the immediate proximity of the veins.



Fig. 1 – Correlation between ore zones, hydrothermal alteration distribution and sulfur isotopic composition of pyrite and barite in the Madneuli open pit.

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Pyrite from the stockwork and massive sulfide orebodies has δ^{34} S values from -2 to 0‰, and pyrite from the gold-bearing subvertical veins has δ^{34} S values between +3 and +5‰. Barite from the stockwork area has δ^{34} S values between +16 and +19‰. Our results, except the negative pyrite values from the stockwork orebody, are consistent with those obtained in other studies for Late Cretaceous VHMS deposits in the Eastern Pontides.

The combined field, petrographic and isotope data, show that the Madneuli ore deposit consists of the tight spatial association of two ore forming events: one which forms the subvertical stockwork (Fig. 1 zone a), and an event interpreted as epithermal responsible for the subvertical veins in the eastern flank (Fig. 1 zone b).

The negative sulfur isotope values in pyrite and the presence of enargite in the stringer zone (Fig. 1 zone a) could be attributed to a magmatic input, akin to interpretations proposed for submarine mineralizing systems in the Western Pacific. The Madneuli ore deposit reflects transitional ore formation processes under shallow submarine to emerging conditions in a rifting volcanic arc.

P 3.22

The Gedabek epithermal Cu-Au deposit, Lesser Caucasus, Western Azerbaijan: geology, alterations, petrography and evolution of the sulfidation fluid states.

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The Gedabek-Karadagh ore district is one of the main producing mining districts of Western Azerbaijan, and is the largest porphyry-epithermal ore field of the country. It belongs to the Lesser Caucasus, located in the central part of the Tethyan metallogenic belt. It is emplaced within the Jurassic-Cretaceous Somkheto-Karabakh magmatic arc, resulting from the subduction of the Tethys Ocean along the Eurasian margin (Sosson et al., 2010).

The Gedabek ore deposit has been exploited since the 19th century, first for copper and silver, and nowadays for gold by open pit mining. This deposit is still controversial, and previously, it was classified as a porphyry deposit, and more recently as a high-sulphidation epithermal deposit. The ore body consists of a flat lens-shaped silicified-body emplaced between Middle Jurassic andesitic volcanoclastic rocks and a Late Jurassic granodiorite. Several generations of mafic to intermediate dikes, as well as dikes with a breccia texture, crosscut the volcanoclastic rocks and the granodiorite. Their relationship with the mineralizing process is still unclear.

This study aims at constraining the tectonic setting of the deposit using lithogeochemistry of the various magmatic country rocks, characterizing the hydrothermal alteration and the ore paragenesis, as well as the nature of the fluids involved in the ore formation processes.

Lithogeochemistry based on immobile elements suggests a sub-alkaline magmatic setting with basaltic to andesitic compositions. Our study questions the primary magmatic nature of the so-called "quartz-porphyry" intrusion, which hosts the main orebody, and rather suggests that this rock is the product of extensive silicification. Field observations reveal a strong lithological control (more permeable horizons) for silicification processes, as well as the propylitic alteration, within bedded pyroclastic rocks. X-Ray diffraction analyses revealed a late argilic alteration crosscutting the silicified body with the presence of dickite and kaolinite.

A preliminary petrologic study allowed us to distinguish two main mineralization events. An early pervasive silicification composed of microcrystalline quartz and adularia, associated with disseminated pyrite and low ore grades. A later semimassive to veins or veinlets minerazation composed mainly of sphalerite and chalcopyrite, and subsidiary fahlore, galena and arsenopyrite. Chalcocite and covellite are spatially associated with chalcopyrite and sphalerite, and are attributed to secondary enrichment of hypogene origin, as indicated by the presence of some enargite. Rare native gold has been observed associated to the second event. But ICP-AES analyses yield a strong correlation between Au, Bi and Te, distinctly higher than between Au and Ag. It suggests an association of Au and Ag mainly with Te-Bi enriched minerals rather than in electrum or native gold. Variable but high contents of volatile elements (Te, Se, Hg, Sb, As) are consistent with a shallow epithermal environment.

Petrological observations and microprobe measurements of the FeS content of sphalerites indicate an intermediate state of the fluids, within a quartz-adularia-sericite-calcite deposit, with an evolution from lower toward higher sulfidation state (Einaudi et al., 2003; Simmons et al., 2005; Sillitoe & Hedenquist, 2003).

	Stage 1 Disseminated mineralization	Stage 2 Semi-massive mineralization or vein/veinlet 2 Dissemineralization	ated Copper Enrichment	Stage 4 Veins	Stage 5 Oxydation Zone
Pyrite		-			
Rutile					
Quartz		7			
Adularia					
Sericite		?			
Barite					
Sphalerite					
Chalcopyrite					
Arsenopyrite					
Tennantite					
Pyrrhotite		i			
Galena		?			
Hessite					
Electrum					
Pyrite spheroidal					
Pyrite euhedral					
Magnetite		?			
Chalcocite					
Covellite		2			
Enargite/Luzonite		1		-	
Calcite					
Azurite		7			
Malachite					
Mottramite		?			

Figure 1. Paragenetic sequence from the Gedabek ore deposit; Thick bars: dominant minerals; Thin bars: Minor mineralization; Doted bars: Rare to uncertain.

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P 3.23

Present copper-rich "gel" formation in the giant porphyry copper deposit of Chuquicamata (northern Chile)

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In the frame of a project focused on supergene processes in the Chuquicamata deposit (Pinget et al., 2011 and 2012), copper-rich "gel" crusts that are presently precipitated in the exotic deposit of Mina Sur, south of the Chuquicamata porphyry deposit (Fig. 1A, 1B), are studied.

The "gels" are precipitated from moderately saline waters containing up to several 100 mg Cu/l. Three groups of copperrich "gels" (up to 61% Cu in weight, Table 1) have been distinguished according to the pH of the waters from which they precipitate. In "gels" formed from waters with pH between 5.8 and 6.0, posnjakite $(Cu_4 (SO_4)(OH)_6)$, brochantite $(Cu_4 (SO_4))$ (OH)_a), malachite (Cu₂(CO₂)(OH)₂) and possibly dioptase CuSiO₂(OH)₂ were identified using XRF, XRD, SEM and ESEM analyses. In "gels" precipitating from waters with pH between 7.2 and 7.7, devilline $(CaCu_4(SO_4)_2(OH)_{\epsilon}^{+3}(H_2O))$ is mainly present. A third group of "gels" consists mainly of atacamite (Cu₂Cl(OH)₂) and were precipitated of water with a pH of 5.7. In addition to the above copper minerals, the "gels" contain also gypsum, a not yet identified sodium sulphate, and halite (Fig. 2A). The sodium sulphate occurs as lenticular crystals (Fig. 2A) and as efflorescent aggregates (Fig. 2B).

Table 1 : Semi quantitative analyses of "gel" sampled at Mina Sur (XRF, using UniQuant, in wt-%). Part of the aluminium content may be due to clay particles transported in suspension and incorporated in the gel crusts.

Gels sample	рН	Na2O	MgO	AI2O3	SiO2	MnO	Fe2O3	P2O5	K20	CaO	SO3	CI	Cu	Zn
2Nord	7.2 to 7.7	b.d.	0.3	5.3	1.7	0.1	0.5	b.d.	0.3	2.4	15.7	1.3	57.5	0.1
2Sud	7.2 to 7.7	b.d.	0.8	1.4	6.2	0.1	1.1	b.d.	0.8	5.4	19.8	1.6	49.4	0.5
7C1	5.8 to 6.0	5.2	2.3	3.1	3.5	0.1	0.8	b.d.	0.9	7.4	23.4	3.3	39.1	0.4
7C2	5.8 to 6.0	b.d.	1.0	3.0	2.3	0.1	0.7	b.d.	0.8	6.9	21.7	3.4	47.1	0.4
EX2	5.7	b.d.	b.d.	2.7	2.8	0.1	0.4	0.3	0.1	0.5	2.5	13.4	<mark>61.6</mark>	0.1

(b.d. = below detection limit)

The possibility of using the precipitation mechanisms of the present copper gels as analogue for the formation of copper minerals in the exotic Mina Sur is examined.

Acknowledgements

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Figure 2: Phases formed by drying gels formed from water with pH between 7.2 and 7.7. Microscope observation shows that the phases precipitate in the following order: gypsum, sodium sulphate and halite.

P 3.24

New mineralogical and fluid inclusion genetic constraints for Archean batholith-hosted gold veins at the Lac Herbin deposit, Val-d'Or, Canada

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The Val-d'Or district is a major quartz-tourmaline-carbonate gold-bearing vein field, which occurs in the Archean Abitibi greenstone belt, Superior province, Canada. The district underwent regional greenschist to amphibolite metamorphism and the mineralized veins post-date metamorphism. The Lac Herbin mine consists of a network of parallel steep reverse faults, hosted by the synvolcanic Bourlamaque granodiorite batholith. There are two related vein sets: subvertical veins in ductile shears with banded textures formed by one or more episodes of filling, and subhorizontal veins in extensional fractures between shear zones with typical open-space filling textures. Veins are surrounded by zoned alteration envelopes consisting of an outer zone of cryptic alteration characterized by a chlorite-carbonate-white mica assemblage, and an inner zone of visible alteration characterized by a carbonate-white mica-albite. This study presents detailed mineral paragenetic and fluid inclusion study of a gold deposit hosted by the Bourlamaque batholith in the Val-d'Or district.

The paragenetic sequence is typical for the Val-d'Or district, characterized by a vein filling deposition of carbonate, tourmaline, pyrite, pyrrhotite +/- chalcopyrite, sphalerite and cobaltite, chlorite, sericite and quartz. Pyrite contains inclusions of gold, chalcopyrite, tellurobismuth, pyrrhotite and cubanite. However, most of the gold, chalcopyrite and tellurobismuth associated with Ca-Fe-Mg-Mn-bearing carbonates were deposited into fractures in deformed pyrite, but the two types of gold have similar Au/Ag ratios (90/10). The gold-tellurobismuth filling fractures in pyrite at Lac Herbin are reminiscent and could illustrate the process described by Frost et al. (2002), who interpret them as a result of melt coexisting with hydrothermal fluids.

Fluid inclusion petrography outlines five fluid inclusion types in quartz: (1) three-phase L-L-V (H_2O-CO_2); (2) two-phase CO_2 -rich; (3) high temperature two-phase H_2O -rich; (4) low temperature three-phase saline and (5) low temperature two-phase H_2O -rich. Inclusion types 1 and 2, which occur together, were described in other studies from the Val-d'Or district, whereas the timing of type 3 remains uncertain. Inclusion types 1 and 2 are arranged in three dimensional clusters unrelated to fractures in quartz crystal whereas type 3 are observed both alone in quartz crystal and in healed fractures. They post-date inclusion types 4 and 5 which are only related to fractures.

In terms of an exploration guide, the presence of chalcopyrite is a good indicator for auriferous mineralization, in addition to the well-constrained regional structural setting.

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Figure 1. Paragenesis sequence recognized in the Lac Herbin deposit.

P 3.25

Reactivation of fault zones in Precambrian crystalline basement and the location of stratabound, sandstone-hosted Pb-Zn deposits along the front of the Scandinavian Caledonides.

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Non-stratiform yet stratabound, sandstone-hosted Pb-Zn deposits and minor occurrences are known along the front of the Scandinavian Caledonides over a distance of more than 1000 km and include the Laisvall and Vassbo deposits. Mineralisation is emplaced in the Ediacaran-Cambrian autochthonous sedimentary rocks beneath the Caledonian thrust nappes resting unconformably on top of Precambrian crystalline basement, as well as in the lowermost allochthonous units.

The present study is part of a broader project aiming to assess the role of the basement, the migration flow path, the driving force, the precipitation mechanism, and the age of mineralisation in a structurally-constrained geological frame. It is based on abundant drilling and mine data as well as on existing and new geochemical data.

In this work we present data aiming to understand the structural and tectonic controls of the ore distribution at the Laisvall stratabound Pb-Zn deposit, hosted in autochthonous sandstone. Magnetic lineaments, which correspond to geological features in the Precambrian crystalline basement, were identified in airborne magnetic data. Magnetic maxima match the main regional geological trends (N-S to NNE-SSW and NW-SE trends) in the Precambrian basement (rock units, ductile deformation zones and foliation). There is a correlation between some magnetic minima and faults in the Precambrian basement (e.g. the Hornavan fault). A similar correlation between certain magnetic minima and faults in the Ediacaran-Cambrian sedimentary cover rocks was revealed by geological modelling of the Laisvall deposit in 3D space. The magnetic maxima show inflection areas that correspond to locations where their trend changes from NNE-SSW to NW-SE. Mineralisation at Laisvall is closely associated with such inflection areas as shown by ore grade modelling.

In addition, and in order to examine the possibility of an analogue feeder for Laisvall-type deposits, a detailed structural analysis was conducted on the Åkerlandet Pb-Zn-Ba-F vein deposit hosted in the Precambrian crystalline basement.

Airborne magnetic data and 3D modelling of ore grades and geology suggest that mineralisation is related to faults in the Precambrian crystalline basement. These data are consistent with the hypothesis that faults provided channelways during mineralisation after deposition of an aquitard on top of the host rock. The faults were active during Ediacaran-Cambrian sedimentation. Current work is examining the possibility that ore is related to extensional domains along the faults.

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P 3.26

Isotope composition of lacustrine vapour of Lake Geneva

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The measurement of isotope compositions of water ($\delta^{18}O$ and $\delta^{2}H$) has become a routine in many fields of Earth science such as hydrology, hydrogeology, and (palaeo)climatology. Yet, the evolution of the isotope composition of water vapour in continental settings is still poorly known. It has clearly been established that the original isotope composition of continental water vapour is controlled by the meteorological conditions during evaporation above the oceans and that the subsequent evolution is mostly controlled by condensation and rainout as the air mass travels across the continent. However, for air masses that have a low amount of moisture, the evapotranspiration above the continents has a strong influence on its isotope composition. This is particularly valid above big lakes where a significant proportion of moisture comes from the evaporation of surface water. As most of these air masses do not produce rain in the location of evaporation, the evolution of the isotope composition of this contribution has rarely been studied. Isotopic analysis of atmospheric vapour may, however, help scientists to better understand the influence of big lakes on the regional climate. It may also provide a better estimate of lake water loss through evaporation.

A preliminary study on the isotope composition of water vapour in the region of Lake Geneva was conducted in 2011 and 2012. A method was developed to sample water vapour and to analyse its isotope composition. The final aim of the project is to estimate the influence of evaporation of lake water on the atmospheric water vapour, to describe the isotopic fractionation during evaporation, and to estimate the influence of evaporation on the isotope composition of water in Lake Geneva.

Atmospheric water vapour was sampled with 2 l vacuum-sealed bottles. Samples were collected from a sailing boat at approximately 4 km south of Lausanne. For each sampling, 3 to 5 samples were collected along an elevation profile (0.3 to 10 m above water surface) to sample the 'lacustrine atmosphere'. In addition, 1 to 3 samples were collected on land at different sites (Echichens 470 m alt., Sauvabelin Tower 700 m alt., and Cugy 700 m alt.) to sample the 'free atmosphere'. For each sample, relative air humidity and temperature were measured. Surface lake water was also sampled and its temperature recorded. Water was then extracted from each bottle in the laboratory using a vacuum line. One bottle provided between 5 to 30 µl depending on the humidity. For the measurement of the isotope composition of water vapour, subsamples of 1.5 µl were injected manually into a Picarro L2102-i WS-CRDS system. For each sample, 8 injections were done and the last 5 used to calculate the values. Analytical errors are estimated to be 0.2 ‰ and 1.0 ‰ for $\delta^{18}O_{vapour}$ and $\delta^{2}H_{vapour}$, respectively. The isotope composition of water vapour originating from evaporation of surface lake water ('lake vapour') was calculated using the isotope composition and temperature of surface lake water, relative humidity measured just above the lake surface, and fractionation factors given in Majoube (1971) and Merlivat (1978).

Most samples show that the lacustrine atmosphere contains more water vapour and has lower water vapour isotope composition than the free atmosphere (Figure 1). Besides, calculated values for lake vapour are substantially depleted in the heavy isotopes compared to the atmospheric values. While air moisture increases near the water surface, the isotope composition of water vapour above the lake surface is homogenous from 0.3 to 10 m. Higher values were measured during summer while lowest values were measured during winter.

Lower values for lacustrine atmosphere are interpreted as being due to the addition of lake vapour to the free atmosphere. Based on oxygen isotope results, the contribution of water evaporated from the lake to the lacustrine atmosphere is estimated to range between 34 and 57 %. Because of the very dynamic behaviour of atmospheric processes, further studies including continuous measurements of water vapour are needed to better understand the influence of evaporation on the regional atmosphere and the evolution of surface lake water.

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Figure 1. Concentration and isotope composition of atmospheric water vapour measured along elevation profiles above the lake surface and at different sites on land. Values calculated for water vapour originating from the evaporation of surface lake water (lake vapour) is also illustrated for comparison.

P 3.27

Thermal ionisation mass spectrometric determination of the ⁴⁰K/³⁹K ratio

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The isotope ⁴⁰K is radioactive and undergoes β - decay to ⁴⁰Ca (ca. 89.3%) and electron capture to ⁴⁰Ar (ca. 10.7%). Both decays can potentially be used as dating systems. The most commonly used branch is the decay of ⁴⁰K to ⁴⁰Ar because it can yield highly precise ages. Both decay schemes rely on the knowledge of the ⁴⁰K branching ratio and the natural ⁴⁰K abundance.

A ⁴⁰K abundance of 0.011672±41 % was measured on terrestrial material [1]. The relative uncertainty of 0.35 % has not been improved since. Recent improvements in the precision of mass spectrometric measurements have led to the situation that the uncertainties on the K decay constant and the abundance of ⁴⁰K are a major source of uncertainty on the measured ages. A more precise definition of the ⁴⁰K decay constant was attempted by different research groups within the last decade [2-9] but the goal of obtaining 0.1 % relative uncertainty on K-Ar ages for geological materials, as requested by the EARTHtime initiative, has not been achieved yet. In order to improve on this situation we studied the abundances of the K isotopes in terrestrial standards.

A ThermoFischer Triton+ thermal ionisation mass spectrometer was used for K isotope ratio measurements of the NIST SRM 918b K standard loaded on Ta filaments with 0.1M phosphoric acid. Three techniques were applied: (A) dynamic measurement with in-run normalisation to the IUPAC value ${}^{41}K/{}^{39}K$ =0.072168; (B) a simple total evaporation procedure; (C) the "NBL-modified" total evaporation [10]. The ${}^{40}K$ ion beam was measured in a Faraday cup with a 1E12 Ω resistor; ${}^{39}K$ and ${}^{41}K$ were collected in Faraday cups with 1E11 Ω resistors. Amplifier gains were intercalibrated by supplying fixed voltages off-line. Different measurement techniques were combined with different loading procedures. We also tested ionisation yields for the evaporation procedures (B) and (C).

Our measured ⁴⁰K/³⁹K ratios are statistically indistinguishable from those reported by [1] but have lower uncertainties. Techniques A, B and C gave 1 standard error of 0.07%, 0.2%, and 0.14%, respectively.

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6. Geophysics and Rockphysics

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Swiss Geophysical Commission

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6.1

Fault zone porosity determination by joint interpretation of 3D seismic and gravity data for geothermal exploration - application in the St. Gallen geothermal project

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In recent years, most of the geothermal projects developed in Switzerland and neighboring regions or underway are targeting the exploitation of deep aquifers. Indeed, in a setting of sedimentary basin, these reservoirs are frequently present beneath highly populated areas. In this geological context, fault zones are frequently the target of the project because faulting zone increases the rock fracture density. This local increase of fracture density can result in an increasing of permeability within the aquifer, and thus the flow rate that it is possible to extract from it. This can be inferred through the transmissivity of the rock, which is related to its effective porosity. An increase of this porosity should result in a lowering of the rock bulk density which can be measured by gravimetry.

However and in this case, the resulting gravity anomaly is of relatively small intensity. In order to characterize the associated gravity anomaly due to the change of rock density, it is necessary to remove any other gravity signal present in the measured gravity values. Thus after the stripping step, the final residual (or misfit) is only influenced by the targeted structures. To do so, we modeled the geological structures and calculated the gravitational effect of the model using a forward modeling. Even if gravity can be used to determine the geometry of the geological model, it is not widely used because it presents a nonlinear problem. That's the reason why other method such as 3D seismic must be used, when data are available, such as in St Gallen geothermal project.

The geothermal project of the city of St. Gallen, which targets a fault zone in the potentially aquifer formations of Mesozoic lying at more than 3 km deep, was good and rare opportunity. A large 3D seismic survey was conducted early 2010 and the results give a 3D model of the regional geological structures.

In order to characterize the local increase of rock permeability, a high precision gravity measurements campaign was done in the St Gallen region. Our gravity results have been combined with the data from the Swiss Atlas of Gravimetry (Olivier et al., 2010) to allow a better determination of the connected porosity in the targeted area.

Based on the 3D geological model from the 3D seismic, a forward gravity map of the region has been computed and then compared to our residual gravity map. The comparison indicates that the regional 3D structural model is not sufficient to explain the entire residual anomaly (Fig. 1a) and that some structures that were not modeled, such as Permo-Carboniferous Graben and quaternary deposits have a significant gravity effect. Consequently these two structures have been added to the 3D model, their gravity effect calculated and subtracted to the residual gravity (Fig. 1, b & c). As there was no other known geological structures from which the gravity effect could be resulted in the residual anomaly, we consider that this final residual anomaly was due to a lowering of the bulk rock density in the fault zone. This end was modeled, its gravity effect calculated and subtracted from the previous stripping result (Fig. 1, d). We found that this residual anomaly corresponds to a bulk rock density change comprised between 4 and 6% (Fig. 1, d). However this value is equal to the porosity only if rock is not saturated. So if the rocks are saturated, it corresponds to a porosity comprised between 6.5 and 9.5%.

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Fig 1. Top: model and localization, bottom, different steps of stripping: a. Effect of the geological model established using 3D seismic data. b. The effect of the Permo-Carboniferous graben is added to (a.). c. Quaternary deposits effect is added to (b.). d. The effect of the fault zone assuming a diminution of 5% of the density due to fracturing is added to (c.). The light blue area represents the assumed residual anomaly, the thin blue line being the measured value.

6.2

Seismic and magnetic anisotropy of the Finero Peridotite (Ivrea Zone)

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The Ivrea-Verbano zone (north-western Italy and southern Switzerland, Alps), provides one of the most spectacular outcropping sections through rocks of lower crustal provenance .This crustal cross-section has not been affected by the Alpine deformation, except for very localized retrograde metamorphism structures. Therefore, the Ivrea-Verbano zone provides the unique opportunity to improve our understanding of the lower and upper continental crust and the primary metamorphic and magmatic processes that generated the current assembly of rocks.

The Ivrea-Verbano zone consists of an original sequence comprised of metasedimentary gneisses and schists, metabasites and minor marbles and quartzites; a large volume of mafic rocks has intruded at the base of the crustal section. At the base of the section, there are also mantle-derived peridotites (i.e. Boudier et al., 1984, Quick et al., 1995), the emplacement of which is still on debate.

From south to north, three major peridotites crop out: the Balmuccia Peridotite in Val Sesia, the Premosello Peridotite in Valle d'Ossola and the Finero Peridotite in Val Cannobina. The last one is distinctive due to the presence of hydrous minerals, such as phlogopite (up to 15 vol.%) and hornblende (up to 20 vol.%), which were produced by dramatic metasomatism (Zanetti et al., 1999; Grieco et al., 2001). The concentrations of Sr, Rb and Ba and ⁸⁷Sr/⁸⁶Sr ratios indicate a significant amount of crustal contamination (Grieco et al., 2001), but there is still controversy as to its origin.

To date, there is a lack of data on seismic and magnetic properties of such peridotites that underwent metasomatic undercrustal processes. The difficulty to obtain reliable measurements on this kind of rocks is related to the difficulty in finding rock samples that do not contain serpentine minerals (weathering); even a minimum amount of serpentine has a large influence on the magnetic and seismic properties of the whole aggregate.

In this study we present a combination of experimental results on both seismic and magnetic properties in the peridotites from Finero, with the intent to investigate the influence of those hydrous minerals on the overall seismic behaviour of the Finero peridotite body. We also correlate seismic and magnetic anisotropies and their relation to the deformation.

The studied samples are virtually free from serpentine; their modal composition has been determined using electron microscopy techniques. Samples, selected on the basis of phlogopite and hornblende content, have been used to measure ultrasonic wave velocities, using the pulse transmission technique (Birch, 1961) at confining pressure and temperature, simulating in situ conditions. Vp absolute values confirm literature data (i.e. Ullemeyer et al, 2010); seismic anisotropy is dominated by the phlogopite and hornblende content.

Anisotropy of magnetic susceptibility (AMS) has been measured both in low and high magnetic fields. High-field measurements allow for the separation of paramagnetic and ferromagnetic contributions to the magnetic anisotropy, which can be related to silicates and iron oxide inclusions, respectively. Magnetic anisotropy is often used as a proxy for mineral fabric. The low-field AMS is dominated by the ferromagnetic component and does not show any preferred orientation of the principal susceptibility axes. The paramagnetic sub-fabric, however, is clearly related to the rock texture. All samples except one have their minimum susceptibility parallel to the pole of the foliation plane. The degree of anisotropy is similar to that expected for olivine in most samples. Samples contains a large amount of hornblende, have more pronounced anisotropies.

These results will be used to understand the role of metasomatic fluids on the seismic and magnetic physical properties of lower crustal peridotites and how magnetic and seismic anisotropies can help us understand deformation in these rocks.

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6.3

Talc lubrication of faults at seismic velocities: comparison between the rate and state approach and a fluid constrain.

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Exposures of fossil or active mature faults at the Earth's surface show that in the shallow crust most of co-seismic slips occur within a clay-rich gouge material. Field observations, theories and laboratory experiments show that the thermoporo-mechanical properties of this gouge slip zone significantly influence the dynamic fault strength by controlling the efficiency of the slip-weakening.

Talc can represent a fault gauge material which explain weak zones among the all seismogenic zone (e.g., San Andreas fault in USA; Zuccale fault in Italy). However, the mechanical behavior of talc at seismic velocities remains purely speculative.

We compare here two comportmental law, one relates the strain and semi empirical rate and state equation while the second is based on a visco-elastic approach. The latter is compared to rotary-shear friction experiments conducted on dry and water saturated natural talc gouge, at 0.01, 0.13 and 1.31 m s⁻¹ slip-velocities and 0.3 - 1.8 MPa normal stress.

At 0.13 and 0.01 m s⁻¹ the experimental results always display i) a strengthening behaviour with time, ii) the development of a mm-thick Principal Slip Zone (PSZ), and iii) a re-orientation of grains parallel to the sense of shear. From litterature, such strengthening mechanisms remain still unclear.

At 1.31 m s⁻¹ the results evidence i) a weakening behavior, ii) the development of a mm-thick PSZ, and iii) progressive reorientation of the grains parallel to the sense of shear for the central part of the gouge. In dry conditions, the slip-weakening is attributed to solid lubrication of the gouge in the central part of the PSZ (i.e., frictional sliding between favourably C-oriented (001) planes of forming talc lamellae). Under wet conditions, the slip-weakening is also attributed to fluid lubrication of the gouge in the central part of a thin film of fluid between talc grains).

A previous work has already explained these effects as a structural self-organization of the PSZ grains to provide minimum dynamic friction during strain rate localization. The observations for dry conditions suggest that grains are subjected to sliding and rolling regimes during the same experiment. The association of sliding and rolling friction suggests strain partitioning during the slip-weakening, and so powder lubrication as a possible additional weakening mechanism for dry conditions.

With this work we propose a granular flow approach from visco-elastic comportmental laws. A linear visco-elastic type equation is thus applied to fit our results with parameters obtained from the experiment and physical properties measurements. The strengthening gets consequently explained as a simple relaxation process of the material. The weakening arises from the formation of slifind-rolling structures affecting the physical parameters of the material.

Analysis of seismic attenuation mechanisms in unconsolidated surficial sediments

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The attenuation of seismic waves is an important material parameter, which contains potentially valuable information on key hydraulic and geomechanical properties of the probed medium. An inherent and important complication arising in the interpretation of such measurements is, however, that there are multiple physical mechanisms contributing to the dissipation of seismic energy, such as wave-induced fluid flow at the micro-, meso-, and macroscopic scales as well as scattering and inelastic effects, and that their relative contributions and importance is generally unknown and difficult to unravel. To address this problem for the practically particularly relevant case of unconsolidated surficial alluvial sediments, we analyze multi-frequency sonic logs with dominant source frequencies ranging roughly between 1 kHz and 30 kHz. To obtain reliable estimations of attenuation, appropriate corrections for near-field and geometrical spreading effects are fundamental requirements. In order to estimate these effects, we model our experimental setup using a 3D poroelastic simulation code in cylindrical coordinates. After having applied corrections, this broadband dataset, in conjunction with a comprehensive suite of complementary logging data, allows for building a realistic rock physics model, which in turn provides the basis for simulating the various seismic attenuation mechanisms and for assessing their relative importance.

6.5

Geophysical monitoring of the Excavation Damaged Zone during a gallery excavation in the Opalinus Clay (Mont Terri underground rock laboratory, Canton of Jura)

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At the Mont Terri underground rock laboratory we excavated the rock mass of the "EZG-08 segment" located at the junction between the advancing face of Gallery 08 (Ga08) and the existing end-face of Gallery 04 (Ga04). This offered a unique opportunity to monitor the Excavation Damaged Zone (EDZ), simulating the short-term "excavation phase" of a repository. Different geophysical methods (i.e. electrical tomography, active and passive seismic monitoring, spontaneous potential monitoring) were applied from the Ga04 end-face, to observe the evolution of the rock mass of the "EZ-G08 segment" during the progress of the excavation (Fig. 1A). The geophysical dataset was complemented by noble gas measurements, structural data of the fracture network (mainly composed of pre-existing tectonic fault and of scarce EDZ micro-fractures) and its reconstruction means statistical approaches.

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During and after the gallery excavation process we detected and located in time and place a large number of microseismic events (MSEs) (Le Gonidec et al. 2012). Most of the MSEs were induced in the excavated face Ga08. Only a few MSEs were located inside the rock mass itself, and these were arranged close to a SE-dipping fault, which seems to have been reactivated by the excavation process. According to laboratory experiments performed by Amann et al. (2011) on Opalinus Clay samples, the first MSEs can be related to microcrack initiation in the tensile failure mode. This stage was also clearly reflected by the increase of the measured resistivity. When the tunnel face of Ga08 was getting closer to the tunnel face of Ga04, the growth and coalescence of EDZ microcracks lead to macroscopic shear failure, associated with a decrease of the MSEs, which mainly occurred along bedding plane structures and pre-existing tectonic faults.



The short-term pore pressure response monitored during the excavation of the "EZG-08 segment" revealed rapid negative pore pressure changes in the gallery walls, followed by pore pressure increase deeper within the rock mass. Pore pressure measured directly at the tunnel wall was substantially below the in-situ pore pressure. These low pore pressures could be due to a desaturation process. The presence of many tectonic faults in the Ga04 end-face, reactivated by the excavation of Gallery 04 in 2004, together with the EDZ microcracks, had enhanced the penetration depth of the desaturation zone up to 2m. This was demonstrated by resin-impregnation experiments performed for the microstructural characterisation of the EDZ fracture network (Fig. 1B). Fig 1C illustrates the influence of a reactivated tectonic fault on the electrical resistivity on the Ga04 end-face (Nicollin et al. 2010). Möri et al. (2010) showed that degree of saturation and depth penetration may be due to seasonal variations in relative humidity in the tunnel. During the excavation of the "EZG-08 segment," performed in Summer 2008, the humidity content in the ambient air was close to 100%. We suggest that the presence of air at atmospheric pressure within the fracture network created a suction effect. The slow decrease of resistivity measured after the excavation phase may be interpreted as consequence of slow re-saturation of the fracture network triggered by suction within the unsaturated zone.

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6.6 3D-Seismic for Geothermal Energy in St. Gallen

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Geothermal energy has gained rising interest in Switzerland during the last few years. Geothermal energy is reliable, sustainable, and environmentally friendly. In the last 20 years near-surface geothermal energy (d < 400 m) has become a standard energy source for heating houses. Contrarily, deep geothermal energy (d > 400 m) is not a standard energy form yet. Deep geothermal energy has the potential to continuously and nearly inexhaustibly provide energy. Initiative has been taken to promote and provide electrical power and heat from deep geothermal energy in some urban regions. Riehen (Basel-Stadt) is already connected to deep geothermal energy. Basel-Stadt, Zürich Triemli and St. Gallen are some of the pioneers in exploring the potential of deep geothermal energy in Switzerland (géothermie.ch, 2010; energeia, 2012).

Deep geothermal energy can be extracted either by producing hot water from an existing aquifer (hydrothermal) or by extracting heat from a basement rock (petrothermal). Particularly for hydrothermal projects careful exploration is important due to reduce the risk of drilling in the wrong location. Current knowledge about the deep subsurface satisfies rough estimation of possible aquifers or hot rock volumes only. An efficient and adequate future energy supply demands a close localization of a promising target zone. To plan a borehole one should know in advance, at which spot of a specific layer it should be placed to maximize the extraction of energy. An important tool to illuminate the subsurface at the desired depth of 3 to 6 kilometers is reflection seismic. The Swiss midland is covered with a loose grid of 2D-seismic lines. Depth maps produced from 2D-seismic data are not very accurate due to lack in signal directivity and surface coverage (Figure 1). Developments in seismic field equipment, seismic data processing and interpretation makes 3D-seismic applicable to large-size industrial projects at a reasonable cost. It allows a very accurate and detailed mapping of geological structures in the deep subsurface (Figure 1). This advantage is essential to narrow down a potential target zone.

The city of St. Gallen is aiming for a geothermal power plant that produces heat and electricity. A 3D-seismic survey was carried out at the beginning of 2010 (Figure 2, surface area ca. 270 km2). This was a crucial step that helped in mapping the fault systems at target level and to define an optimal location for drilling. The first step was planning and designing the 3D-seismic survey. The acquisition parameters had to be chosen so that enough energy could be recorded from the deepest target level. The ideal grid-layout had to be adapted to the road network and to deal with obstacles like railway lines. Permission from authorities and land-owners had to be requested early enough. Good planning is an essential first step for the success of a 3D-seismic campaign. At this point, St. Gallen is now preparing to drill to the most promising targets at the level of the Malm, the Muschelkalk and possibly a fractured basement.

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Figure 1. The image from 3D-seismic (below) renders a clearly more continuous structure of the reflector than the image from 2D-seismic (top). Geothermieprojekt St. Gallen, St. Galler Stadtwerke, 2010.



Figure 2. The 3D-seismic layout covers the northern part of canton St. Gallen and some of the neighboring cantons. Red points indicate source locations (vibration, explosions). Blue lines indicate recording lines (geophones). Geothermieprojekt St. Gallen, St. Galler Stadtwerke, 2010.

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6.7

How stress affects Berea sandstone seismic-wave-attenuation

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Seismic wave attenuation (Q¹) in the bandwidth 1-100 Hz can help to understand the saturation of crustal and reservoir rocks (e.g. Chapman et al., 2006). Attenuation for frequencies <100 Hz in partially saturated porous media have been studied by several authors. White (1975), Mavko and Jizba (1991), and Pride et al. (2004) described i) patchy saturation, ii) squirt flow and iii) wave-induced fluid flow, respectively. The latter theory has been modelled for instance by Gurevich and Lopatnikov (1995) and by Quintal et al. (2011). In addition, experimental studies focused on attenuation in the bandwidth 1-100 Hz have been conducted by several authors (e.g. Peselnick and Liu, 1987, and Batzle et al. 2006). All these efforts improved the knowledge about the attenuation mechanisms in partially saturated rocks. However, the mechanisms responsible for attenuation and its dependence with the stress applied on partially saturated rocks are still not fully understood, and there are still many lithologies and physical conditions for which experimental data do not exist. In addition numerical models, like Quintal et al. (2011), need to be calibrated.

In this contribution we describe a series of seismic wave attenuation measurements as function of frequency (1-100 Hz) and confining pressure (0-20 MPa) for two partially saturated Berea sandstone specimens (samples). For the same lithology the longitudinal and transverse wave speeds at ultrasonic frequency (~1 MHz), as function of confining pressure, have been also measured and will be presented here.

The quality factor of dry samples confined with a pressure lower than 20 MPa is constant and around 100 over the entire bandwidth. On the other hand the same samples, but partially saturated (e.g. 60% with water), show a dependence of attenuation on saturation and stress (Fig. 1). Thanks to the i) calibration performed with aluminum, ii) the data related to dry samples and iii) the calculation made to evaluate the open-boundary condition effect (Dunn, 1986) we ruled out the possibility that the frequency dependent attenuation observed is the result is an artefact related to the apparatus (Peselnick and Liu, 1987) or the sample (Dunn, 1986).

To conclude we can state that the results show a frequency and stress dependence attenuation which could be explained with i) squirt flow (Mavko and Jizba, 1991), and ii) in part with patchy saturation (White, 1975) related attenuation. The variation of attenuation, as function of confining pressure, could be explained by cracks aspect ratio reduction and bulk module increasing. Longitudinal and transverse wave speeds measured on a similar sample also indicate that crack like voids close for confining pressure <20 MPa.



Figure 1. Q of 60% water saturated Berea sandstone sample for confining pressures between 0 and 14 MPa.

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6.8

Seismic-induced stick-slip friction in simulated granular layers

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Stick-slip friction has been long recognized as a mechanism of earthquakes (Brace & Byerlee, 1966). Several laboratory experiments have been performed to explore quasi-static fault slips at a range of slip rates, with and without fault gouges, and under the effects of temperature, normal and pore pressures. The slip durations in most of these studies are longer than 0.01s, which agrees with a variety of fault-slip observations (Peng & Gomberg, 2010). In nature, dynamic triggering has been found as the origin of most of seismic events (Ujiie et al., 2009), such as seismic-induced landslides and blast-induced collapses. The instantaneously triggered stick-slip friction also significantly contributes to fault instabilities, however, has been subjected to less attention.

The experimental study investigates the seismic-induced stick-slip friction on a simulated granular fault zone using a novel dynamic direct shear apparatus. The rock fault model consists of two thin norite plates with a thickness of 30 mm and 120 mm in width, namely the incident plate (1000 mm in length) and the transmitted plate (500 mm in length). The short side of the transmitted plate contacts the center part of the incident plate long side as a frictional interface. The normal load is fixed on the other short side of the transmitted plate. A layer of crushed norite is used as the granular gouge and sandwiched in the simulated fault.

The experimental results show a generated plane P wave propagates in the incident plate and drives stick-slip friction in the simulated granular layer. The frictional slip is rate-dependent at high shear rates. The amplitude of the induced shear wave recorded in the transmitted plate depends on gouge thickness, loading rates and normal loads. The experimental study extends our understanding of fault instability from quasi-static to dynamic triggering with the observation of seismic wave radiation.

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Delineation of the Permo-Carboniferous graben in the crystalline basement of Switzerland using gravity

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Although many are suspected from seismic observations, few and far between Permo-Carboniferous (PC) graben at the top of the Variscian basement in Switzerland are confirmed by wells. Challenges in localization of PC troughs using seismic data include (Marchant et al., 2005): i) Uncertainty in the origin of the characteristically weak reflections below the Mesozoic in the absence of boreholes. ii) Where PC deposits are present, the little expressed base Mesozoic reflection can be mistaken for an internal PC reflection, and iii) the structural interpretation is often uncertain, as faults below the Mesozoic cannot be traced along marker horizons on the seismic sections. These difficulties are also comprehensible in the new Atlas of the Swiss Molasse Basin (Sammaruga et al., 2012).

Gravity studies have been proven to be a good exploration tool for the investigation of the troughs. It was this method which permitted the first regional interpretation on the extension of the Northern Swiss trough (Klingelé and Schwendener, 1984). Unfortunately, since the 80-ties, the gravimetric exploration method was not used further to better understand the PC graben in Switzerland subsurface. In this study, we have investigated the application of 2D and 3D geology for gravity forward modeling as well as the application of Butterworth filters of different wavelength. Real application was conducted in the northern part of Switzerland under the Molasse basin.

In order to systematically assess the potential of the gravity data to detect and characterize PC troughs in the Molasse basins, 2D and 3D conceptual models were set up. Synthetic gravity data sets were generated for these models using a homogeneous basement density of 2670 kg m³. According to different types of measurements, a range of density for the PC graben is obtained (Klingelé and Schwendener, 1984), resulting mainly in the 3 scenarios: (1) an extreme density contrast of -220 kg m³ (PC density ρ_{PC} = 2450 kg m³), which is slightly smaller than the value obtained from gamma-gamma ray density logs in the wells of Böttstein and Weiach, (2) an intermediate density contrast of -100 kg m⁻³ (ρ_{PC} = 2570 kg m⁻³) obtained from gravity measurement (BHGM) in the same wells, and (3) a small density contrast of -50 kg m³ (ρ_{pc} =2620 kg m⁻³) is assumed as worst case scenario.

Gravity forward modeling is carried out using developed and unpublished Finite Element (FE) code. The FE modeling allows approaching the geological geometry using tetrahedrons shape. To simulate the real conditions, the gravity stations are located on the real topography. After computing a gravity effect of the 3D geological model, we get a complete Bouguer anomaly. Since, and as expected from the geology, the Bouguer anomaly is strongly dominated by the gravity effect of the Molasse sediments, where the slightly bended Mesozoic sediments are inclined by about 2-5 ° towards the Alps and the Tertiary filling of the molasses basin is deepening following this geometry.

A code using Butterworth filter was developed and applied on the computed Bouguer values to eliminate this trend (Abdelfettah and Schill, 2012). This filter is characterized and controlled mainly by two parameters: (1) cut-off frequency or wavelength and (2) the filter order. The advantage of this filter is that we can easily use different wavelength to i) delineate and characterize different negative anomalies at depth, and ii) to choose an adequate residual anomaly which provides the comparable gravity response with the conceptual model. Depth and size of the origin of the anomalies are indicated among others by the wavelength of the filter. With increasing wavelength, we are able to visualize increasing larger or deeper structures until approaching the Bouguer or residual anomalies. Moreover, the filter order parameter can be also changed to delineate a very small variation, for instance, in the case of low density contrast between the PC graben and the basement. With increasing filter order the horizontal density contrast is emphasized.

Gravity modeling was conducted on the basis of 2 and 3D geological models in order to understand the gravity variation with increasing depth of the top of the grabens. It reveals high potential in the delimitation of the Permo-Carboniferous troughs by the combination of both. Assuming a similar geometry for these graben structures, gravity data processing traces these structures at different depth using a Butterworth filter with different wavelength to calculate a residual gravity anomaly. Filtered Bouguer anomaly with different wavelengths is an essential tool to detect and trace the horizontal and vertical extension of the PC troughs. The sensitivity studies on the conceptual geological models reveal that the negative anomaly related to PC grabens persists through the different steps of Butterworth filter with varying wavelength. The different wavelengths provide insight into different vertical levels of the trough and thus, allow describing 3D geometry of the graben structures. Finally, the application of the filters to real measurements reveals the distribution of the PC grabens in the northern part of Switzerland where it was confirmed by wells. It, however, shows that the tracing of the
geometry is more complex, since long wavelengths risk to take up also other more regional structures, such as in this case the deepening of the Molasse basin, which introduces a broader negative anomaly overlying the expected narrowing of the PC graben at depth.

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Localization of temperature anomalies in Soultz area (Upper Rhine Graben): insights from gravity, magnetics and slip and dilation tendency analysis

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The recently developed new 3D geological model of Soultz area (Baillieux et al., 2011; Dezayes et al., 2011) is used as a basis for understanding the localization of temperature anomalies at a regional scale. Gravimetric, magnetic and slip and dilation tendency analyses are used to investigate the implication of structural patterns of the 3D geological model, density and magnetic variations, and stress patterns associated to hydrothermal circulation along the faults. A mean temperature anomaly of 30°C at top basement is found to be linked to a light and magnetic granodioritic pluton offering a rather high radiogenic heat production. Three temperature anomalies above 60°C at top basement show similar patterns: they are located along N-S directed fault with a west dipping signature in the western side of horst structures (Fig. 1).



Fig. 1: Residuals anomaly after 80 km Butterworth filter (Abdelfettah & Schill, 2012), surface features from the 3D model (fault system, horizons) and contours of temperature anomaly at top basement (°C)

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Attempt to identify the fault associated with the great Mw=6.2 Earthquake of Visp 1855

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The Valais area in the Swiss Alps shows the largest seismic hazard in Switzerland. During the past 500 years, the Valais region experienced six earthquakes around magnitude 6 or larger. Those earthquakes occurred with a periodicity of about 100 years, the most recent one in 1946. The Valais presents rough topography, unstable and steep slopes, deep sedimentfilled valleys and wide glacier- and snow-covered areas that potentially increase the seismic risk level due to earthquakeinduced phenomena such as strong site- and topographical effects, liquefaction, landslides and snow avalanches. In addition, important critical facilities of Switzerland, such as hydroelectric power plants and chemical plants have been built in the Valais, making the region even more exposed to damaging earthquakes. On July 25, 1855 the strongest earthquake in Switzerland in the last 300 years struck the region of Visp, with an estimated moment magnitude of 6.2 (ECOS09). It caused an epicentral intensity of VIII and therefore heavy damage (Fäh et al. 2003a, Kozak & Vanek, 2006). There was a large aftershock activity within the following months and years, with intensities up to VII. The reconstruction of the damage field showed largest damages between Visp and Stalden, which may suggest the location of the epicenter (Fritsche, 2008). The general nature of the damage field and the geological structure suggests that the responsible fault is close to the surface and also supports the thesis of a normal fault striking along the Valley of Visp (north-south) and dipping to the west (Créalp, 1999). Several further geological observations support the thesis of a fault between Stalden and Visp. Joris (personal communication) observed a neo-tectonic fault approximately 2Km southeast of Visp near Unterstalden. Further indications come from the examination of a fault, which was discovered during the construction of the tunnel Eyholz and a historical geological map in which a transversal fracture between Unter- and Oberstalden is mapped. We applied a passive seismic investigation method, which is based on the assumption that the fault of interest is surrounded by fractured rock. When seismic waves penetrate the damage zone consisting of fractured rock, energy is absorbed, which leads to a decrease in amplitude of the seismic waves. The loss of energy finally leads to a decrease of seismic velocity. The damage zone, the zone in which the seismic velocity is reduced, is called low velocity zone (LVZ). The attempt is to detect reduced amplitudes in the power spectra of the seismic traces at seismic stations, which could be an indicator of a LVZ. We performed several seismic surveys during day and night, usually measuring about 3 hours. The number of sensors was in average 10 and the maximum spacing between them around 15m. Data acquisition was carried out with LE-3D/5s seismometer sensors and digitized with Quanterra Q330. Our measurements confirmed the existence of signature in the power spectra of the seismic noise that may correspond to a LVZ as defined above. This signature is observed along the trace of the expected fault that reinforces the existence of it. These observations together with geomorphological indications support the thesis of a fault in the corresponding investigation area.

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Magnetic fabrics and anisotropy in rock-forming minerals

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Magnetic susceptibility is a material property that is often anisotropic in rocks. The anisotropy of magnetic susceptibility (AMS) can be used as a proxy for the mineral fabric qualitatively and possibly quantitatively. To obtain a quantitative estimate of mineral fabric it is necessary to know the intrinsic anisotropy of the constituent minerals. Compared to other fabric techniques, determining the magnetic fabric is fast and has the advantage that not only the material surface is sampled, but the whole volume. AMS has also been used to determine e.g. the flow direction in magma or river deposits, or reflect the strain ellipsoid during tectonic events. However, this method can be applied more effectively if we understand what minerals have the strongest contribution to the susceptibility of the bulk rock.

All minerals in a rock contribute to the magnetic susceptibility and hence its anisotropy. We determined single crystal AMS in the common rock-forming minerals olivine, amphiboles and pyroxenes. Both low- and high-field AMS were measured. Analyzing high-field data allows for separation of paramagnetic and ferromagnetic contributions to the AMS, i.e. contributions arising from the silicate lattice or iron oxide inclusions, respectively. The paramagnetic component is related to the arrangement of cations, particularly Fe, in the crystal structure and therefore reflects the crystal orientation. Ferromagnetic inclusions, e.g. magnetite or hematite, are generally randomly distributed.

Samples in this study are natural crystals and were chosen so as to cover a wide range of chemical compositions within each mineral group. Crystal chemistry was measured using laser ablation inductively coupled plasma mass spectroscopy (LA-ICP-MS) and data were used to establish a relationship between iron content and AMS parameters. We were mainly interested in the paramagnetic contribution to the AMS. For example, in olivine the maximum principal susceptibility of the paramagnetic component is parallel to the crystallographic c-axis, whereas the intermediate and minimum principal susceptibilities are parallel to a or b at room temperature (Figure 1). At 77 K, all minimum axes are parallel to the crystallographic b-axis. Chemical analysis shows that the samples can be divided into two groups: those with 3-5 wt.% FeO and those with 7-9 wt.% FeO. The first group shows a switching of the minimum and intermediate axes at room temperature compared to low temperature, whereas directions do not change with temperature in the second group. Further, the shape of the AMS ellipsoid is more prolate in the first group. The degree of anisotropy appears not to be affected by iron content as long as this is less than 8 wt.% FeO (Figure 2). Similar relationships are established for amphiboles or pyroxenes. Thus, the paramagnetic fabric in e.g. peridotites, amphibolites or pyroxenites is an indicator for preferred crystal orientation. On the other hand, if the orientation distribution function in a rock is known, our results can be used to model the bulk rock AMS.



Figure 1: Lower hemisphere, equal area stereoplots of principal AMS directions in olivine single crystals. Squares show the maximum principal axes, triangles and circles intermediate and minimum axes of the paramagnetic component, respectively. Low temperature AMS measured at 77 K.



Figure 2: Relationship of anisotropy degree Δk and iron content both for room temperature and 77 K.

P 6.5 Brittle onset of monodispersed magmatic suspensions: impact of the particle shape.

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The brittle-ductile transition remains a central question of modern geology as rock failure is the main parameter in mitigating geological risks, such as, for volcanic eruptions, the transitions from effusive to explosive eruptive style. Although numerical simulations are the only way to fully understanding the physical processes involved, we are in a strong need of an experimental validation of the proposed models.

We first recall some experimental results obtained under torsion and uni-axial compression on both pure melts and crystalbearing magmas. Torsion experiments were performed at high temperature (600 to 900 degC) and high pressure (200 to 300 MPa) using a Paterson-type rock deformation apparatus (ETH Zurich). We characterized the brittle onset of two phases magmas from 0 to 65 vol% crystals. The strain-rates span 5 orders of magnitude, with a change in the behavior of the material from viscous to brittle (10^{-5} - 10^{0} s⁻¹). The materials tested are a standard borosilicate glass (NIST717), a natural crystal bearing rhyolitic melt (Mt Unzen volcano) and a suspension of haplogranitic synthetic sample with corundum particles.

To characterize the physical processes leading to failure in the experiments, we performed 2D and 3D numerical simulations on monodispersed rigid spheroids with eccentricities ranging from 10⁻² to 10². The model is numerically solved with Finite Elements Methods. The pre-processing, processing and post-processing are all performed under MATLAB. For the largest meshes, the computation has been performed with the help of the BRUTUS cluster at ETH Zurich. For solving the system of equation we used the MILAMIN solver and extended it from 2-D to 3-D by the use of Crouzeix-Raviart type elements. MILAMIN is a native MATLAB implementation, which takes advantage of Tim Davi's SuiteSparse package. Here we solve the incompressible Stokes equations. We tested random to structured configurations (Simple Cubic, Body Centered Cubic and Face Centered Cubic) for different particle orientations from random to aligned. These numerical simulations allow us to estimate the stress concentration in magmas due to the presence of the crystals.

Our results first confirm the hydrodynamics effects on the flow of elongated particles. The calculated apparent viscosity of the material versus the crystal fraction confirms an early increase for the suspensions viscosity with elongated particles. More importantly, the stress localization due to the particles suggests that the melt will start cracking for a relatively lower bulk stress. Finally, the experimental trend is supported by the numerical simulations, which highlight the importance of the critical packing fraction in addition to the maximum packing fraction.

The combination of experimental results and numerical modeling allow us to characterize the physical processes responsible for the failure of particle bearing suspensions and characterize the effect of fraction and shape on the brittle-ductile transition.

VLF Measurement in the cristallin area, new survey in the EGS research project in Black Forest

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The exploitation of the shallow geothermic sites for systems of heating and cooling was accentuated and showed its advantages during the last years. Nevertheless, the questions concerning the electric exploitation of major geothermics continue to be the object of many work of research and development. Contrary to other generating stations of the clean energy, the major projects in the geothermics are characterized by the high and an important risk factor for technical and financial investment costs. This is why accurate geological knowledge, until several hundred meters of depth, is necessary. The research project EGS (Geothermal Enhanced System) in the south of the Black Forest had the aim to develop a methodology integrating several geophysical exploration methods, in order to better identify and to characterize geothermic sites, with lower costs and hence reduce the financial risk.

An alternative and/or complementary method to the already existing geophysical methods, is the VLF measurements (Very Low Frequency). It can be used in order to better characterize the geothermal sites, and thus helping the planning of the project. This method was tested for the localization and the characterization of the vertical and sub-vertical contacts of structure and also for the identification of fault zones in the crystalline rocks. To achieve this, a test measurements on a gas pipeline were carried out and the results were discussed. After this test, the method is employed in wide zone of the investigation in Black Forest. The VLF Method, or EM-VLF, use the terrestrial radio transmissions in the radio frequency band between 10 and 30 kHz to measure the value of the magnetic field, whose amplitude and phase are influenced by the geology of the subsurface. The interpretation of these data which gives access to the anomalies of electric conductivity of the vertical and sub-vertical contacts under ground, makes it possible to better characterize the faults and the faulted zones. Two device of VLF data acquisition VLF were used; VLF-Car and a portable devices. The first was used to cover a long distance to carry out the recognition studies. The second device used to realize more detailed measurements and for a small distance.

Both instruments are suitable for the characterization of the horizontal and sub-horizontal electrical conductivity contrast, but the VLF-Car method proved to be effective in Hotzenwald area with an optimized time.

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Seismic response of the active instability above Preonzo (TI)

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Recent passive seismic recordings in unstable rock slopes have revealed that the seismic response within instabilities is distinctly different than on adjacent stable ground. Ground motion is strongly amplified at distinct frequencies and polarized primarily in the direction of rock mass movement. At the slowly-moving slope instability above Randa (VS), site-to-reference amplification factors of up to seven at a frequency of 3 Hz were derived from ambient noise measurements and recordings of regional earthquakes. Similarly, localized amplification reached a factor of about seven at 1.6 Hz at Walkerschmatt (VS), an inactive instability characterized by widely open tension fractures. These observations are interpreted as eigenmode vibration of individual blocks delineated by highly-compliant tension fractures.

We recently performed new ambient noise measurements at the active slope instability above Preonzo (TI), a few weeks after the catastrophic failure of 15 May 2012. That failure involved roughly 200'000 m³ of rock, which is about half the estimated total unstable volume. The remaining unstable rock mass is dissected by a network of tension fractures, with apertures of several decimetres, that break the rock mass into blocks a few meters to decameters in length. Fracture opening rates since failure have decelerated to values of much less than 1 mm/day, except for one strongly tilting block at the May 2012 scarp that moves at around 1 mm/day (information late August 2012).

Twelve seismic stations were installed on the accessible bench behind the scarp, with four stations positioned on stable ground and two of these close to the tension fracture forming the back boundary of the instability. The remaining instruments were installed on different unstable blocks with the aim of observing spatial heterogeneity in the seismic response. The stations continuously recorded ambient noise over a period of about one hour. By chance two distant earthquakes were also recorded, with epicentres in northern Italy. Polarization analysis showed strong directionality of ground motion at ~3 Hz for all stations except the two farthest from the instability boundary.

Maximum polarization is oriented in the main direction of slope movement. Relative amplification with respect to the stable ground was also estimated and reached factors of 30 at 3 Hz within the instability. Local amplification characteristics vary considerably among the different stations. In comparison to the two less-active slope instabilities investigated previously, measured amplification at Preonzo is extraordinarily high.

We argue that the seismic response of rock slopes may be a diagnostic measure of instability and perhaps also of the degree of destabilization. We stress that amplification of the wavefield within unstable rock masses is a site effect making slope instabilities more vulnerable to triggering by nearby earthquakes.

Geophysically based estimations of rock/air/ice/water contents and validation with ground truth data at three alpine permafrost sites

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During recent years geophysical monitoring approaches in permafrost regions have evolved quickly regarding the observation of changes in the ice and unfrozen water content of the subsurface over short and long time periods. Relative changes in electrical resistivities or seismic velocities provide rough estimates of spatio-temporal changes in the subsurface. Additional information on the distribution of high and low ice contents within 2-D subsurface sections are provided by electrical resistivity tomography (ERT) monitoring and refraction seismic tomography monitoring, in contrast to 1-D temperature monitoring in boreholes. Furthermore, the spatial variability of the temporal changes can be adressed. However, as straightforward relations between observed resistivity or velocity and ice content do not exist, absolute quantification of ground ice degradation is still impossible from the consideration of relative resistivity/velocity changes alone.

An approach to estimate volumetric fractions of ice, water, and air within the pore volume of a rock matrix by jointly using complementary data sets from geophysical surveys was introduced by Hauck et al. (2011). The so-called four-phase model (4PM) uses coincident ERT and seismic data sets to relate the physical properties of the subsurface to the measured electrical resistivities and seismic velocities. Due to inherent ambiguities in the model the approach is still limited to specific cases and often allows only a rough estimation of the quantities of the solid (ice), liquid (water), and gaseous (air) constituents of the available pore volume.

One of the major drawbacks of the current 4PM approach is that it is underdetermined and one of the four phases (usually the porosity) has to be prescribed based on rough estimations. However, as the porosity of a subsurface section will not change over the period of several years, the calculation of temporal changes in ice, water and air contents may give a more reliable indication on the subsurface characteristics than the estimation of total fractions. Applying the 4PM to timelapse ERT and seismic data sets and regarding only the temporal change in the fractional composition will thus reduce the uncertainties and gain higher confidence in the calculated values.

In this contribution, a further step towards the reduction of the uncertainties of the 4PM is presented. Based on a unique data set of observed porosity and ice content data determined from borehole geophysical measurements at three permafrost sites in the Swiss Alps, measured porosity values could be used to constrain the 4PM. The calculated ice contents could then be validated with the observed ice contents in the boreholes. Based on this study the performance of the 4PM is evaluated and an estimate of the reliability of the 4PM results can be given.

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P 6.9

Laboratory experiments of seismic wave attenuation from 0.01 Hz up to 100 Hz.

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Seismic velocities are sensitive to pore fluids and pore shapes. Thus, seismic attributes can provide qualitative and quantitative information on underground structures and processes.

Among these attributes, seismic attenuation can be valuable to identify the pore

fluid type and to monitor sub-surface reservoir processes. There is currently an enormous lack of attenuation data for many lithologies under various physical conditions and dramatic ambiguity on theories explaining attenuation mechanisms and velocity dispersion. Laboratory experiments are required to close the data gap and validate theories.

One goal of this research was to create a laboratory apparatus to understand attenuation with respect to rock type, anisotropy, fluid type and fluid saturation. The Seismic Wave Attenuation Module (SWAM) was developed to experimentally measure the attenuation in extensional-mode (Q_{E}^{-1}) and the Young's modulus inside a pressure rig (Paterson). The sub-resonance method was employed to measure attenuation in the seismic frequency range. It allows performing measurements at low strain magnitudes ($\epsilon < 10-6$) for which the rock behaves as a Linear Time Invariant (LTI) system. A series of measurements on different materials in a dry condition and saturated with different fluids is presented (Fig. 1). Berea sandstone, Fontainebleau sandstone, Crab Orchard sandstone and shale rocks were tested at 10 MPa confining pressure.



Figure 1. Phase shift and quality factor (Q_E) for dry and glycerin-water solution saturated Berea sandstone.

Application the similarity attributes and the fault enhancement for 3D seismic data from the Kerkennah islands (Tunisia).

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The 3D seismic, a relatively recent technique that provides a powerful tool for detailed investigation of the often complex geometry of sediment basin (Nalpas, 1996) is now widely used in areas of intensive oil exploration. Modern visualization and image processing techniques are revolutionizing the art of seismic interpretation. The seismic attributes have been used for many years to improve the structural and stratigraphic interpretation of seismic data and the advent of 3D seismic technology and powerful workstation computers has made it possible to extract as much information as possible from the character of seismic waveform for the generation of several attributes. Hydrocarbon exploration in geologically complex and technologically challenging environment is feasibly the driving force for the use of these attributes for seismic data interpretation in order to minimize the exploration risks of drilling very expensive wells.

The hydrocarbon migration is often associated with fault intersection or splinter faults related to shear along the fault; we use here multiple seismic attributes for highlighting faults. This report describes two concepts; firstly we give an introduction in seismic attributes for faults detection to set the context to understand imaging of faults. Secondly, we discuss the application of post attribute filters to demonstrate how the attribute image can be enhanced by improving the completeness, resolution, and contrast of the similarity attribute.

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P 6.11

Mountains – Up and Down: the Role of Groundwater Pressure

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In fractured and granular porous aquifers a change in groundwater pressure results in a modification of the effective stress state. Decreasing groundwater pressures can result in a consolidation of the porous media, increasing groundwater pressures in an expansion. This coupled hydromechanical process named fluid-to-solid, i.e., a change in fluid pressure results in a change of the porous volume, has been observed also in the crystalline fractured rock of the Gotthard Massif (Hansmann et al, 2012). Increasing/decreasing water pressures during groundwater recharge/discharge periods lead to cyclical expansions/compressions of the fractured rock mass resulting in a subtle mountain "up and down" (Figure 1). Hansmann et al. (2012) detected these reversible deformations by means of high precision leveling surveys in the framework of the Gotthard Alp transit Base Tunnel Project.

A recent modelling approach specific for fluid-to-solid coupled hydromechanical processes in fractured aquifers has been proposed by Preisig et al. (2012). This method allows the simulation of groundwater flow in the deformable fractures of the aquifer. The deformation of fractures and the associated change of hydrogeological parameters, i.e., porosity, hydraulic conductivity and specific storage, are based on Hooke's law of elasticity. The integration of all fractures deformations under increasing/decreasing water pressures result in the fractured aquifer expansion/compression.

This work presents the modelling of the process detected by Hansmann et al. (2012) using the approach proposed by Preisig et al. (2012). The model is calibrated using the measured deformations data of Hansmann et al. (2012), by varying hydrogeological parameters. Calibrated parameters are compared with measured values.



Figure 1. (a) Relative horizontal extension between two reflectors located on slopes of the Santa Maria Valley (solid black line), precipitation and snow height (in gray) as a function of time (Hansmann et al., 2012). (b) Conceptual model illustrating the fractured rock mass expansion (blue line) / compression (red line) under seasonal variations in water table levels, leading to a shortening/extension of the distance L orthogonal to the valley (modified from Hansmann et al., 2012).

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Measuring local seismic anisotropy using ambient noise: a three-component array study

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We study seismic noise in the frequency range 0.1 to 1.1 Hz using data from a temporary three-component seismic array in Central France that was deployed in April 2010 during four days. Fourier domain beam-forming is applied simultaneously on all components to jointly estimate back azimuth, apparent phase velocity as well as polarization features as a function of frequency (Esmersoy et al., 1985). This allows us to investigate azimuthal velocity anisotropy of Love and Rayleigh waves, separately. We observe a fast direction at the measurement site that is consistent with the preferred direction of a local fault system. Furthermore, the magnitude of azimuthal anisotropy is larger for Love waves compared to Rayleigh waves. We discuss the potential of such three-component seismic array studies for other applications (Moschetti et al., 2010).



Figure 1. Measured slowness spectrum at 0.72 Hz, based on 65 hours of data (back azimuths are used). Colours identify wave polarization. Strong azimuthal anisotropy in Love wave phase velocity is observed.

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Numerical support of laboratory experiments: Attenuation and velocity estimations

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We show that numerical support of laboratory experiments can significantly increase the understanding and interpretation of the obtained results. First we perform simulations of the Seismic Wave Attenuation Module (Figure 1) to measure seismic attenuation of reservoir rocks. Our findings confirm the accuracy of this system. However, precision can be improved by optimizing the sensor positions (Figure 2). Second we model wave propagation for an ultrasonic pulse transmission experiment that is used to determine pressure- and temperature-dependent seismic velocities in the rock. Multiple waves are identified in our computer experiment, including bar waves. The metal jacket that houses the sample assembly needs to be taken into account for a proper estimation of the ultrasonic velocities (Figure 3). This influence is frequencydependent.



Figure 1. Schematic cross-section of the ETH-developed SWAM (Madonna et al. 2011). a) CAD drawing, b) Sketched construction, c) Physical model.

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Figure 2. Results of the SWAM computer experiments for a Rock sample with an attenuation of Q=12.33 (green line) for a range of applied excitation frequencies. Q_{real} (red solid line) can be compared with the real experimental setup. An optimized sensor positioning allow for more accurate measurements of $Q(Q_{out}; dashed blue line)$.



Figure 3. Simulated vertical displacement at bottom transducer of the sample assembly for ultrasonic velocity measurements in the Paterson gas-medium apparatus (Burlini et al., 2005). The reference signal (blue line) using a Sapphire sample arrives first. The time delay of the signal for the rock sample (green line) is normally used to estimate the velocity of the rock. However, the signal with no sample (red line; wave propagation through the iron jacket only) may disturb the signal for the rock.

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Simulating the in situ physical properties of the upper Muschelkalk aquifer, northern Switzerland

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Anthropogenic emission of carbon dioxide (CO_2) is widely believed to contribute to climate change and global warming. Hence, it has been recognized that there is a need for the reduction of carbon dioxide emissions. Recent technologies for carbon capture and storage (CCS), have therefore been developed. Geological CO_2 sequestration is one of the most thoroughly investigated CCS technologies, and its potential for use in Switzerland is currently under investigation (Chevallier et al., 2010).

In this study, the aim is the characterization of one potential storage aquifer and seal pair, in order to gain a better idea of where to geologically store CO_2 in Switzerland. The potential seal and aquifer Formations investigated are the Gipskeuper and upper Muschelkalk, respectively. The stratigraphically underlying aquifer is divided into the Trigodonusdolomit and Hauptmuschelkalk units.

A series of laboratory measurement techniques were employed to characterize the physical properties of core samples of dolomite, recovered from drill core. These measurements consist of density, porosity, permeability and ultrasonic wave velocities. Specifically, the permeability and ultrasonic velocity measurements were performed at conditions similar to reservoir conditions, with elevated pressure, spanning near surface conditions to >3 km depth.

The laboratory measurements were compared with well logging data (courtesy of the National Cooperative for the Disposal of Radioactive Waste, Nagra), from the Benken and Weiach drill sites (northern Switzerland) where the core was recovered. Of particular interest is to understand and quantify the distribution of the physical properties, with the aim to better understand the geophysical signature of the Muschelkalk aquifer (in terms of borehole properties, and seismic surveys). In addition, the laboratory permeability is one of the key parameters in this project since the well logging data can only extract a very rough permeability and hydraulic conductivity data by injection pump tests.

The study found that, in general, the measured velocities show a positive correlation with density and an inverse correlation with porosity. It was also found that higher porosity tends to reduce the ultrasonic velocity, but positively correlates with permeability.

A simple but effective model is created to predict the seismic reflection coefficient (R) in the Trigodonusdolomit, with porosity varying from 0 to 50 %. At low porosity, the reflection expected at lithological boundaries is weak, but with increasing porosity in Trigodonusdolomit, the amount of reflected energy increases. At the Gipskeuper to Trigodonusdolomit horizon the reflection coefficient is negative. In contrast R is positive at the Trigodonusdolomit to Hauptmuschelkalk horizon.

The empirical model agree qualitatively well with the reflection coefficient observed in seismic surveys at the Benken and Weiach drill sites (Nagra, 1989; 2001). Differences in the absolute values of the reflection coefficient are expected, likely related to the scale differences in laboratory and borehole logging results, compared to seismic surveys. In addition, although the volume of pores is the main contributing factor to reduction in seismic velocity, other factors need to be taken into consideration, especially the pore structure resulting from diagenetic alteration.

This model indeed provides a preliminary tool to understand how porosity influences the seismic reflection at the seal/ aquifer boundary. The empirical model can be complimented by further laboratory measurements at temperatures suitable for the upper crust, and by employing a fluid substitution model (e.g., Gassmann relations) to account for brine saturation in the carbonates.

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Phase velocity dispersion and attenuation of seismic waves due to trapped fluids in residual-saturated porous media

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Propagation of seismic waves in partially saturated porous media depends on various material properties, e.g. saturation, porosity, elastic properties of the skeleton, viscous properties of the pore fluids and, additionally, capillary pressure and effective permeability. If the wetting fluid is in a discontinuous state, i.e. residual saturated configuration, phase velocities and frequency-dependent attenuation additionally depend on microscopical (pore-scale) properties such as droplet and/or ganglia size. To model wave propagation in residual saturated porous media, we (Steeb et al., 2012) developed a three-phase model based on an enriched continuum mixture theory capturing the strong coupling between the micro- and the macroscale.

The three-phase model considers a continuous and a discontinuous part (Figure 1). The continuous part, consisting of the porous solid skeleton and the continuous non-wetting fluid, exhibits similar behavior as the poroelastic model introduced by Biot (Biot, 1956). The discontinuous part describes the movement of blobs/clusters of the wetting fluid and is based on an oscillator rheology (Figure 1; Frehner et al., 2009, 2010; Steeb et al., 2012). In comparison with other three-phase models, the presented one (Steeb et al., 2012) accounts for the heterogeneity of the discontinuous fluid clusters by use of their statistically distributed inertia, eigenfrequency and damping effects. The heterogeneous and discontinuous distribution of the wetting fluid in form of individual blobs or fluid clusters is represented by a model-embedded distribution function of the cluster sizes. We define a dimensionless parameter, D, that determines if the overall motion of the residual fluid is dominated by oscillations (underdamped, resonance) or not (overdamped).



Figure 1. Upscaling from the heterogeneous pore-scale to an oscillatoric behavior of the wetting blobs with different eigenfrequencies and damping mechanisms at the macroscale (REV). The extended poroelastic model with the continuous solid skeleton φ^s , the continuous non-wetting phase φ^n and the discontinuous oscillators representing the wetting phase φ^w is depicted.

In the case of only a single fluid blob size (Figure 2), our results show that the residual fluid has a significant impact on the velocity dispersion and attenuation, no matter if it oscillates or not. For small damping parameters (underdamped oscillations), a dispersion anomaly and a strong attenuation peak occurs around the resonance frequency. For large damping parameters (overdamped oscillations), the dispersion and attenuation curves are equal to the ones of the Biot's theory, but shifted to higher frequencies. In the case of distributed fluid blob sizes (Figure 3), the same observation can be made comparing very narrow with wide size distributions. In Steeb et al. (2012), we show under which conditions and how the classical biphasic models can be used to approximate the dynamic behavior of residual saturated porous media.



Figure 2. Frequency dependent phase velocity C_{P1} (a) and inverse quality factor $1/Q_{P1}$ (b) of the fast P-wave for different characteristic damping parameters *D* of the wetting fluid. The porous skeleton is a typical reservoir rock saturated with a continuous gas phase. The eigenfrequency of the blob is f_0 =100 Hz.



Figure 3. Frequency dependent phase velocity C_{p_1} (b) and inverse quality factor $1/Q_p$ (c) of the fast P-wave for different distributions of fluid blob sizes $c(\omega)$ and damping coefficients $\alpha(\omega)$ shown in a).

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Measuring and simulating transient pore pressure as a consequence of seismic waves

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It has been demonstrated that seismic wave attenuation (Q¹) in the bandwidth 1-100 Hz can arise from stress induced fluid flow (White, 1975; Mavko and Jizba, 1991; Pride et al., 2004). Flow of fluid within the pores of a saturated rock is driven by pressure gradients. Therefore the measure of pressure transients while the rock is stressed can be crucial to better understand the attenuation mechanism. Understanding attenuation in fluid-saturated rocks is of enormous importance because attenuation can provide information about saturation of crustal and reservoir rocks (e.g. Chapman et al., 2006).

Among other authors, Quintal et al. (2011) have numerically modeled wave-induced fluid flow in the mesoscopic scale. Experimental studies, such as the studies performed by Spencer (1981), Batzle et al. (2006), Tisato and Madonna (2012), show that rock samples dissipate more seismic energy when saturated with fluids and that in those cases attenuation is strongly frequency dependent. However, the scientific community still needs to better understand the mechanisms for fluid-related seismic attenuation in partially saturated rocks.

In this contribution we describe in detail a new experimental technique to measure the stress-induced transient fluid pressure at different positions in a partially fluid-saturated rock sample (Tisato et al., 2011). The laboratory data are compared with results from a numerically modelled creep test on a poroelastic analog rock sample (see Figure 1). The numerical results can explain the laboratory data, providing the first step towards understanding the ongoing physical processes of energy loss in a fluid-saturated porous medium.



Figure 1. Measured (left) and numerically calculated (right) pore pressure evolutions as a functions of a step stress applied on the top of the sample. The pressure is measured/calculated on five points along a 250 mm long Berea sandstone sample 85% water saturated (15% consists of air).

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Inferring earthquake source properties from dynamic rupture models by means of non-linear kinematic source inversion

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An essential element of understanding earthquake source processes is obtaining a reliable source model via geophysical data inversion. Spontaneous dynamic rupture modeling, that incorporates conservation laws of continuum mechanics and constitutive behavior of rocks under frictional sliding, is capable of producing physically self-consistent kinematic descriptions of earthquake faulting and its associated seismic wave propagation, resulting in ground motions on the surface. Therefore, testing kinematic source inversion techniques by inverting synthetic ground motions obtained from dynamic rupture simulations is a solid step to explore the reliability of source inversion techniques to explore the physics of real earthquake source.

We use 24 models of Mw 6.5~7.0 from a large spontaneous dynamic source models database. This set of models is characterized with stochastic initial stress distribution for three classes of faulting (thrust, normal and strike slip) with buried and surface rupturing faults. The state of initial stress and frictional strength are parameterized using two different cases of normal stress: depth-dependent, and depth-independent (Dalguer and Mai, 2011). Compsyn code (Spudich and Xu, 2002) was deployed to generate forward synthetic waveforms, and an Evolutionary Algorithm was used to search for the source parameters: peak slip velocity, rupture time, rise time, and rake angle at low frequency (up to 1Hz). As a first attempt, the regularized Yoffe function is applied as a single window slip velocity function, which is a flexible slip velocity function defined by three independent parameters: the final slip, the slip duration and the duration of the positive slip acceleration, Tacc (Tinti, et al. 2005).

Our preliminary results show that we can obtain better solutions with the regularized Yoffe function, consistent with the overall properties of dynamic rupture models, and the inversion models could capture large slip patches of the dynamic models with better velocity waveform fitting than the wildly used boxcar and triangular functions. However, details of slip velocity complexities resulted from the dynamic rupture models are not well captured by the inversion procedure. Besides, the model spaces could be significantly perturbed, depending on data and modeling schemes used in the inversion. In the next step, we will try to examine how the station geometries effects the source inversion result, and more geodetic data such as high-rate GNSS data will be included to source inversion research.

7. Stratigraphy in Switzerland - from field to application

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7.1

Die Ifenthal-Formation im nördlichen Jura

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Die Schichten des "oberen Doggers" (später Mitteljura) im Gebiet des Schweizer Juras bilden zwei regressive Schelfzyklen (Shallowing-Upward-Zyklen). Sie bestehen aus Gesteinsabfolgen mit zunehmender Korngrösse im Verlauf eines Zyklus. Tonige oder mergelige Gesteine an der Basis der Zyklen gehen in Mergel mit Knauerlagen und schliesslich in schräg geschichtete Kalkarenite über. Im Dach der Kalkarenite sind regionale Hartgründe ausgebildet, auf denen geringmächtige Eisenoolithe lagern.

Der zyklische Charakter der Ablagerungen eignet sich zur lithostratigraphischen Unterteilung der Abfolge. Die harten Kalkarenite prägen sich im Gelände als Felsrippen aus, die weicheren Mergel bilden ausgeprägte Senken (Comben). Typische Lithologien geringmächtiger Gesteinsbänke können auch in Lesesteinen erkannt werden. Die Mächtigkeit des Schichtstosses erreicht im Gebiet Hauenstein, Allerheiligenberg rund 45 m und nimmt gegen Nordosten auf wenige Dezimeter ab (z.B. Auenstein, AG).

Auf den Karten des Geologischen Atlas der Schweiz 1:25'000 wird die gesamte Abfolge mit einer Formation dargestellt: Die **Ifenthal-Formation** umfasst den Schichtstoss zwischen dem Hartgrund im Dach der Hauptrogenstein-Formation und dem Birmenstorf-Member an der Basis der Wildegg-Formation, welches sich lithologisch und farblich vom Herznach-Member der Ifenthal-Formation unterscheidet.

Das Typusgebiet liegt in der Hauenstein-Synklinale S Ifenthal. Die starken lithologischen Kontraste erlauben eine Unterteilung der Formation in mehrere Member. Chronostratigraphisch umfasst die Ifenthal-Formation ein Intervall vom frühen Bathonien (Progracilis-Zone?) bis ins frühe Oxfordien (Cordatus-Zone).

Das Schweizerische Stratigraphische Komitee hat die Ifenthal-Formation und ihre Member anlässlich der Sitzung vom 12. Januar 2012 akzeptiert.

Erläuterungen Blatt 1089 Aarau	Geologische Karte der
des Geologischen Atlas der Schweiz	Umgebung von Aarau, 1:25000
(Jordan, et al. 2012)	(Geologische Spezialkarte 45, 1908)
Ifenthal-Formation	Oxfordien, Callovien und Varians-
(Bitterli, 2012)	Schichten
Schellenbrücke-Bank	Lamberti-Cordatus-Schichten
Herznach-Member	und
Unter-Erli-Bank	Athleta- und Anceps-Schichten
Angistein-Member Bözen-Member Saulcy-Member	Macrocephalus-Schichten (gegen Westen Callovien-Tone) Varians-Schichten
Anwil-Bank Schelmenloch-Member	

Figur 1: Vergleich der Ifenthal-Formation mit älteren Einheiten.

Schelmenloch-Member (Mächtigkeit: Einige Dezimeter bis 13 m).

Entspricht den Varians-Schichten und Teilen der Macrocephalus-Schichten. Dunkle Mergel mit Mergelkalkbänken (Beckenfazies) sowie eine kondensierte Fazies aus Mergeln und Mergelkalken, die Lagen mit limonitisierten Grapestones und Eisenooide enthalten. Typusprofile: Schelmenloch S Reigoldswil (Beckenfazies), BL und Oberwald SE Ifenthal (kondensierte Fazies).

Anwil-Bank (Mächtigkeit: 20 bis 60 cm).

Violettroter eisenoolithischer Mergel oder Mergelkalk im Dach des Schelmenloch-Members. Typusprofil (Grabung): Aechtelmatt, NE Anwil, BL.

Saulcy-Member (Mächtigkeit: 0 bis 20 m).

Entspricht dem Callovien-Ton. Im nördlichen Jura dunkle, pyritreiche, tonige Mergel, die hellgrau anwittern. Typusprofil: Bachanriss W Saulcy, JU (siehe Abstract B. Hostettler).

Bözen-Member (Mächtigkeit: 0 bis 10 m).

Entspricht einem Teil der Macrocephalus-Schichten. Mergel oder sandige Mergel (Biodetritus) mit Lagen von Kalkknauern, die lagenweise zu knauerigen Mergelkalk-Bänken zusammenwachsen. Typusprofil: Strassenanschnitt NE Hof Wolftel (NE Hornussen, AG).

Ängistein-Member (Mächtigkeit 0 bis 15 m).

Entspricht einem Teil der Macrocephalus-Schichten und der Anceps-Schicht. Bitterli (1977) bezeichnete die Kalke als Äquivalente der Dalle nacrée. Feinspätige Kalkarenite ("Sandkalke"), die unten knauerig, oben schräg geschichtet auftreten. Typusprofil: Gebiet Ängistein S Ifenthal.

Unter-Erli-Bank (Mächtigkeit einige Dezimeter).

Entspricht der Spatkalk-Bank älterer Autoren. Harte, teilweise verkieselte, spätige Kalkbank, die sich durch intensiv rotbraun anwitternde Ankerit-Füllungen diagenetisch gelöster Schalentrümmer auszeichnet. Die charakteristische Bank im Dach des Ängistein-Members ist in Lesesteinen gut erkennbar und im ganzen Gebiet des nördlichen Juras vorhanden. Typusprofil: Bachanriss im Gebiet Unter Erli, S Ifenthal.

Herznach-Member (Mächtigkeit: 0 bis ca. 7 m, meist aber weniger als 1m).

In Gygi (2000) als Herznach-Formation ausgeschieden. Eisenoolithische Mergel und Mergelkalke. Typusprofil: Zugangsstollen Bergwerk Herznach.

Schellenbrücke-Bank (Mächtigkeit 20 bis 30 cm).

Eisenoolithischer Mergelkalk mit zahlreichen limonitisch umkrusteten Knollen. Die Bank bildet im gesamten nördlichen Jura das Dach des Herznach-Members. Typuslokalität: Asperchlus (NNE Küttigen, AG).

Im Rahmen dieser Arbeit wurde das Gebiet des nördlichen Juras bearbeitet. Eine Zusammenfassung der Resultate wird im Swiss Bull. angew. Geol. Vol. 17/2, 2012 publiziert. B. Hostettler (Universität Bern) bearbeitet zurzeit die gleiche Schichtfolge im westlich anschliessenden zentralen Jura. Es ist vorgesehen die neue Formation in einer zusammenfassenden Publikation für das ganze Gebiet darzustellen und die Grenzen der Einheiten festzulegen. Dabei werden auch die chronostratigraphischen Daten der Member dargestellt.

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7.2

The Urgonian Formation in the Helvetic Alps (late Barremian to early Aptian): a multidisciplinary approach for the correlation of a transect through the Säntis realm.

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Urgonian platform carbonates are a common feature of subtropical and tropical shallow-water environments of late Early Cretaceous age. They include the remains of rudists, corals, chaetetids and stromatoporoids, which are interpreted as indicators of a predominantly photozoan, oligotrophic carbonate-producing ecosystem. The late Early Cretaceous is also marked by the occurrence of several oceanic anoxic episodes, such as the latest Hauterivian Faraoni and the early Aptian Selli Events, which are both interpreted as the consequence of generalized eutrophic conditions. These observations imply that the late Early Cretaceous underwent larger fluctuations in nutrient supply, which may have interfered with the evolution of the widespread Urgonian platforms.

Our goal is to study the interactions between paleoceanographic and paleoclimatic change, and Urgonian carbonate buildup in the northern, Helvetic Alps. This unit remains understudied relative to its counterparts in eastern and central France. We specifically intend to compare the Urgonian units of late Barremian age and early Aptian age, which are separated by the so-called "Lower Orbitolina Beds". The late Barremian was less affected by anoxia, whereas the early Aptian witnessed progressive change in paleoceanographic conditions, which led up to the Selli Event.

The preliminary results of a proximal-distal transect is presented; it consists of three sections, on which an analysis of geochemical proxies, such as phosphorus and stable-isotope (C, O) contents, have been performed. Two sections (Tierwis, Valsloch) belong to the Säntis nappe whereas the most proximal section (Kistenpass) has been prospected in the Infrahelvetic area. Based on sedimentological and geochemical data, a correlation with the Alvier section (after Briegel, 1972, and Wissler et al., 2003), which corresponds to the distalmost part of the platform, aims to pinpoint depositional geometries, which are necessary to develop a sequence-stratigraphic model.

7.3

Die Ablagerungen des Eiszeitalters: stratigrafisches Konzept und Nomenklatur am Beispiel der Nordschweiz

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Im Auftrag der Schweizerische Geologische Landesaufnahme wurde ein strati-grafisches Konzept für Gliederung und Nomenklatur der Ablagerungen des Eis-zeitalters für den Geologischen Atlas der Schweiz 1:25,000 erarbeitet, welches den gültigen "Richtlinien zur stratigraphischen Nomenklatur" (Remane et al. 2005) genügt.

Zuerst wurde untersucht, ob die bisher als Basis für Gliederung und Darstellung der eiszeitlichen Ablagerungen auf den Blättern des Geologischen Atlas der Schweiz 1:25>000 verwendete so genannte "klassische" Gliederung, welche im süddeutschen Alpenvorland erarbeitet wurde (Penck & Brückner 1901-09), weiterhin verwendet werden kann. Anhand eines Überblicks über den aktuellen Kenntnisstand der Quartärgliederung in diesem Gebiet sowie der Nordschweiz wird aufgezeigt, dass (insbesondere im Rheingletschergebiet) für Mittel- und Spätpleistozän durchaus vergleichbare, für das Frühpleistozän aber stark diver-gierende Befunde vorliegen. Dass dies nicht ein Frage des Kenntnisstandes, sondern mit grundsätzlichen Unterschieden der beiden Gebiete zu begründen ist, wird anhand einer Betrachtung über die jeweiligen Steuerungsmechanismen der regionalen Morphogenese aufgezeigt. Ein wesentliches Element bei der Entwicklung des

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Gewässernetzes ist die Hebung der Alpen, welche für beide Gebiete als vergleichbar angenommen werden kann. Für die zum Rheinsystem entwässernde Nordschweiz spielt aber das seit dem Eozän aktive Senkungsge-biet des Oberrheingrabens eine mindestens ebenso grosse Rolle. Im zur Donau entwässernden Deutschen Alpenvorland fehlt ein entsprechendes Senkungsge-biet. Somit ist von einer grundsätzlich unterschiedlichen tektonisch-geomorpho-logischen Entwicklung der beiden Regionen auszugehen, die eine Korrelierung anhand von geomorpholgischen Kriterien grundsätzlich in Frage stellt.

Vor diesem Hintergrund wurde ein Gliederungs- und Nomenklaturkonzept ausgearbeitet, welches neu für den Geologischen Atlas der Schweiz 1:25'000 zur Anwendung kommt. Es baut auf den allgemein gültigen Richtlinien für die Ausscheidung und Nomenklatur von lithostratigrafischen Einheiten auf, die vom Schweizerischen Komitee für Stratigrafie erarbeitet wurden. Es wird gezeigt, wie die spezifischen Eigenschaften der Ablagerungen des Eiszeitalters im Rahmen dieser Vorgaben berücksichtigt werden können. Schliesslich wird ein Vorschlag für ein entsprechendes Legenden- und Kürzelsystem für geologische Kartenblätter vorgestellt (Fig. 1).

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Figur 1. Legendenaufbau für die Ablagerungen des Eiszeitalters im Geologi-schen Atlas der Schweiz 1:25'000 (Beispiel aus der Nordschweiz, z.T. hypothetisch). 7.4

Middle Triassic of the Weiach borehole – results from palynology and isotope chemostratigraphy

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The Middle Triassic (Anisian) of the Weiach borehole comprising the Plattensandstein, Wellendolomit, Wellenmergel, Orbicularis-Mergel and the Sulfatschichten has been studied for palynology, palynofacies and C isotope chemostratigraphy.

The detailed study of well-preserved sporomorphs allowed the discrimination of four distinct spore-pollen assemblages (A-D). The presence of acritarchs and foraminiferal linings in the interval from the Plattensandstein to the top of the Orbicularis Mergel documents marine depositional environments; above there is no indication of a marine influence.

The lowest assemblage A, observed in the Plattensandstein, Wellendolomit and the Wellenmergel, is dominated by a highly diverse pollen assemblage associated with a number of spores (e.g., *Densoisporites nejburgii*), which are typical for Early Triassic, but are known to range up into the basal part of the Middle Triassic. This assemblage is closely comparable with spore-pollen associations of the upper Röt Fm. (topmost Buntsandstein) from the central part of the Germanic Basin (e.g., Germany, Poland and Netherlands; for references see compilation of Kürschner & Herngreen, 2010). Similar assemblages are also known from the lower part of the Grès à Voltzia of eastern France (Adloff & Doubinger, 1969). The above mentioned assemblages, including assemblage A, are interpreted to correspond to an early Anisian (Aegean) age (Kürschner & Herngreen, 2010).

A different type of assemblage (Assemblage B) has been recovered from the Orbicularis Mergel. It is characterised by the dominance of the xerophytic conifer group *Triadispora*, whereas the abundance and diversity of spores are reduced. This assemblage compares well with those ranging from the uppermost Röt Fm. to the lowermost Middle Muschelkalk (Jena Fm.) of the central part of the Germanic Basin. A latest Aegean to Illyrian age is suggested for this interval (Heunisch, 1999; Kürschner & Herngreen, 2010).

The quantitative composition of the following Assemblage C is similar to assemblage B, but contains a few specific marker species (e.g., *Dyupetalum vicentinensis*). Spores occur only sporadically. In the Weiach borehole assemblage C has been observed in the lower part of the Sulfatschichten. In the central Germanic Basin comparable spore-pollen associations have been reported from the Jena Fm. and the lower part of the Heilbronn Fm. Based on the appearance of the marker species a Pelsonian age has been suggested (for reference see Kürschner & Herngreen, 2010).

Assemblage D is defined by the appearance of a few marker species (e.g., *Podosporites amicus*). In comparison to assemblage C there are only slight differences in the quantitative composition of the pollen assemblage. Assemblage D covers the upper part of the Sulfatschichten. Comparable assemblages have been published from the Heilbronn Fm., the Trochitenkalk Fm. and the Meissner Fm. They are interpreted to correspond to the Illyrian (Heunisch, 1999; Kürschner & Herngreen, 2010).

The main turnover in the sporomorph association – between Assemblage A and B - is interpreted to reflect a distinct increase in aridity. This change coincides with a marked negative shift in the δ^{13} C isotope values. This negative shift confirms the environmental turnover suggested by the spore-pollen assemblage. Negative shifts are usually related to volcanic activity ejecting CO_2 . Increased CO_2 affects the global carbon cycle and hence the climate.

The present age interpretation of palynological results contradicts the generally accepted correlations based on lithologic similarities. The new age model implies a pronounced heterochronity of Middle Triassic lithofacies and has important consequences for the palaeogeography of the epicontinental Germanic Basin.

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7.5

New lithostratigraphic units for the Callovian stage in the central NW Swiss Jura Mountain

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Numerous lithostratigraphic units, e.g., Dalle nacrée, Lumachellenbank or Callovien Ton, are in use in the Callovian stage of the central NW part of the Swiss Jura Mountains which are mainly based on biostratigrapy. Here we present a new lithostratigraphy in accordance with the rules of the international stratigraphical comission. The proposed members are part of the Ifental Fm. (Bitterli-Dreher, 2012) and an additional formation (e.g., Bollement Mb.) to be defined in the future.

Châtillon Member (previously Macrocephalen-Kalke). The typlocality is at Sur le Mont, SW Châtillon JU (591 650/239 800). Lithologically, it is a grey, biomicritic marl at the base and a very fossiliferous (bivalves, ammonites) limestone which contains sometimes iron-ooids. The limestone bed is normally condensed. In the region of Liesberg the limestone is split into several beds interlayered with marls. The thickness varies between 30cm (typlocality) and 2.8m (Liesberg) (Dietl and Gygi, 1998).

Saulcy Member (previously Callovien Ton). The typlocality is in the riverbed 250m west of STEP (station d'épuration), Saulcy JU (577 650/238 800).

Lithologically, it is a grey marl to marly clay with a poor macrofauna (e.g., Bositra buchi) but locally a rich microfauna (e.g., echinoderm ossicles, foraminifera). The thickness varies between 1.2m (Col de la Croix, JU) and 16m.

Les Fuchies Member (previously Dalle nacrée Äquivalent). The typlocality is

at the roadcut E les Fouchies, S Courtételle, JU (591 275/240 200).

Lithologically, it is a fine-grained light grey to beige biomicritic marly limestone to limestone. In the lower part marly intercalations and in the upper part with a tendence to cross-bedding. Thickness: 2 m (Saulcy) to 15 m (S. of Soulce JU)

Bollement Member (previously Dalle nacrée). The typlocality is at the roadcut E. railway station Bollement JU (576 300/238 600). This unit is ca. 20 m, thin-bedded, middle to coarse grained and mostly cross-bedded biosparitic grey to brown limestone with some oolites. The fossil content consists of echinoderm ossicles, bryozoan branches, bivalve- and brachiopod shells. The unit contains often chert nodules or layers.

Unter Erli-Bank (part of the Herznach Member) (previously Lumachellenbank.

Lithologically it is a beige to dark grey hard biomicrite with abundant bivalves, ammonites and shell fragments. The thickness in the study area is 30 cm.

Herznach Member (previously Herznach Formation, Anceps-Athleta beds, fer sous oxfordien or eisenoolithische Lumachellenbank). The typlocality is at the Bergwerk Herznach. Lithologically it is a grey, red (weathered yellow to beige) iron-oolithic marl to marly limestone often with a rich fauna (e.g., ammonites, bivalves, gastropods, echinids.)

Graitery Member (previously Kellaway, Renggeri Tone). The typlocality is near

Combe d'Eschert, BE (597 250/233 650). Lithologically it is a gray marl with some marly limestone beds. Except of the middle part this member is very fossiliferous (e.g., ammonites, echinids, sponges, brachiopods). In the upper part glauconite and phosphatized ammonites. The thickness at the typlocality is 9-12m

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Figure 2: Lithostratigraphic N-S transsect through the central NW Swiss Jura Mountains

7.6

Neugliederung der Trias in der Nordschweiz – ein Diskussionsvorschlag

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Zur Zeit der Trias war die Nordschweiz ein Randbereich des Germanischen Faziesraums. Entsprechend einfach konnten die Definitionen des Buntsandsteins (A. G. Werner ca. 1780), Muschelkalks (G.C. Füchsel 1761) und Keupers (L. von Buch, ca. 1820) auf die hiesigen Verhältnisse übertragen werden, und fanden bald, wie auch der 1834 von F.A. von Alberti geschaffene Sammelbegriff «Trias», Eingang in die lokale Fachliteratur (z.B. Gressly in Desor 1856, Heer 1865).

Später wurden in der Schweiz zur weiteren Unterteilung sukzessive Formationsnamen und -definitionen aus näheren und ferneren Regionen mehr oder weniger glücklich übernommen oder neu kreiert. Dabei gelang es nicht, zu vermeiden, dass vorhandene lithostratigraphische Definitionen frei interpretiert, bestimmte Abfolgen mehrfach, aber unterschiedlich benannt und ähnliche Namen für unterschiedliche Formationen verwendet wurden.

Monographien zur gesamten Trias der Nordschweiz oder zu den heute als Gruppen verstandenen Teilgliedern Buntsandstein, Muschelkalk und Keuper gibt es bislang nicht und zu deren Formationen und Member nur wenige: So nimmt sich Merki (1961) dem Oberen Muschelkalk und Erni (1926) dem Rhät der Nordschweiz an. Dronkert et al. (1990) und Widmer (1991) beschreiben die Evaporit-Abfolgen des Keupers und Muschelkalks. Weitere Arbeiten untersuchen vor allem die Verhältnisse im angrenzenden Baden-Württemberg: Etwa Ortlam 1974 den Buntsandstein, Frank 1929 und Becker et al. 1997 das Wellengebirge, Wurster 1968 den Lettenkeuper und Wurster 1964 den Schilfsandstein und die Bunte Mergel.

Die Arbeitsgruppe Jura-Ost des Schweizerischen Komitees für Stratigraphie SKS (Burkhalter & Heckendorn 2009) hat die Überarbeitung der jurazeitlichen Formationen abgeschlossen und wird sich nun denen der Trias widmen. Zu diesem Zweckwurde eine Gesamtschau der vorhandenen Informationen durchgeführt und darauf basierend ein Diskussionsvorschlag zur Neugliederung der Trias in der Nordschweiz ausgearbeitet. Mit dieser integralen Betrachtungsweise soll schon zu Beginn eine generelle Gliederung geschaffen werden, welche sich streng an die Vorgaben der SKS (Remane et al. 2005) hält: Im Vordergrund steht die Kartierbarkeit und Darstellbarkeit auf Karten 1:25'000, das einfache Erkennen und Abgrenzen der Formationen nicht nur in Bohrungen und Aufschlüssen, sondern auch im aufschlussarmen Gelände. Daher wird wahrscheinlich mit verschiedenen etablierten, teilweise willkürlich, teilweise aufgrund von chrono-, bio- oder allostratigraphischen Überlegungen eingeführten Unterteilungen gebrochen werden müssen. Der Vorschlag einer neuen generellen Gliederung soll daher bereits früh dem interessierten Publikum zur Diskussion unterbreitet werden.

Innerhalb dieser generellen Gliederung sollen anschliessend die Formationen und Schichtglieder genau oder, wenn nötig, neu definiert werden. Dabei stellt sich die Frage, in wie weit man sich der kürzlich in Deutschland neu etablierten Trias-Stratigraphie anschliessen will (vgl. Geyer & Gwinner 2011 für eine Zusammenstellung der Verhältnisse im angrenzenden Baden-Württemberg). Dies wäre sicher eine noch zu diskutierende Novität, die sich aber durch die paläogeographische Rand-Situation des betrachten Gebietes wie auch aus aktueller geologischer Sicht rechtfertigen liesse.

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7.7

Stratigraphy of the Upper Marine Molasse in central Switzerland

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This presentation aims at a new classification of Upper Marine Molasse (OMM) sediments of the central Swiss Molasse Basin (Zofingen region).

In Switzerland OMM-sediments (Burdigalian, early-middle Miocene) are classically subdivided into the Lucerne and St Gallen formations based on detailed field studies of the last decades. This subdivison can so far best be applied in beautifully exposed OMM-sediments along the southern basin margin (Keller 1989), where several hundred meter thick successions are available. In that region, the base of the St Gallen formation is defined by a transgressive surface that developed on top of partly terrestrial sediments of the Lucerne formation underneath. There, small mammal teeth allow a correlation of both formations to the Neogene mammal stratigraphy: faunas of the Lucerne formation revealed MN3a and MN3b ages, while the St Gallen formation is of MN4 (probably MN4b; Keller 1989) age.

Classification of OMM-sediments in central parts of the Molasse Basin has been carried out by Büchi (1957, 1958) based purely on lithostratigraphy. He used well-recognizable beds of frequent occurrence and established a system of sandstone "zones" separated by these marker beds. For instance, the separation of the Lucerne and St. Gallen formation ("Burdigalien" and "Helvétien", respectively) was tentatively drawn at the base of the well-visible and widespread "basal conglomerate". However, while studying the fossil teeth of OMM-faunas (particularly sharks and rays) it became obvious that these beds were not at all good biostratigraphic markers (a fact Büchi already assumed).

At the southern basin margin, a transgressive surface at the base of the St Gallen formation indicates a basin-wide transgression and thus an overall increase in water depth with the onset of the formation. Based on this premise, we investigated the faunal evolution through time in detail. It turned out that based on the composition of shark and ray teeth open marine conditions of greatest diversity and deepest water occurred long before the occurrence of the first conglomerate beds. Moreover, the faunal compositions indicate rather unstable marine conditions above those conglomerates. We found these highly diverse open marine faunas in particularly coarse-grained, pebbly sandstones that are abundantly distributed across the investigated region. This bed, the "Staffelbach-Grobsandstein", is located above the "Muschelsandstein". Therefore, the onset of the St Gallen formation in the investigated area occurred earlier in the succession than assumed. Ages based on mammal teeth, which show a wide range of MN3b-MN4, are somewhat irritating but can be explained by intense reworking in this particular sandstone. We therefore propose that the "Staffelbach-Grobsandstein" represents the base of the St Gallen formation. Onset and termination of marine conditions most probably established gradually, a clear, sharp marine/terrestrial facies change can nowhere be observed.

- Age of the terminal Lower Freshwater Molasse (USM): younger MN2a to early MN2b
- Age of the Lucerne formation (Upper Marine Molasse, OMM-I): younger MN3a; younger deposits of the formation especially the "Muschelsandstein" revealed until now no biostratigraphic data
- Age of the St Gallen formation (Upper Marine Molasse, OMM-II): younger MN3b/older MN4 within the "Staffelbach-Grobsandstein", and MN4b from ca. 20 m above it until the top
- Age of the earliest Upper Freshwater Molasse (OSM): early MN5

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7.8

Lithostratigraphy of Switzerland: options and challenges for a harmonisation.

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Geological maps aim at representing the distribution of rocks at the (sub-) surface on a given territory for a wide range of applications. The subdivision and classification of the cartographic objects mainly depend on the scale of representation and the thematic purpose of the map. At the Swiss Geological Survey (SGS), the basic philosophy for the Geological Atlas of Switzerland 1:25'000 (GA25) is to map lithostratigraphic formations. Indeed, these are the most objective (descriptive) and stable entities on the long-term, as their definition relies on petrographic and geometric criteria observable in the field. Contrary to other stratigraphic units they do not directly imply chronologic and/or genetic interpretations likely to change with the evolution of ideas and techniques (although these interpretive data can – and should – be included and discussed in the documentation of the units). The data encompassed in the GA25 can then be used and complemented to derive a variety of thematic maps.

In close collaboration with 40 experts from the Swiss geoscientific community, the SGS is currently elaborating a nationwide harmonised lithostratigraphic legend for the GA25, under the scientific supervision of the Swiss Committee of Stratigraphy (SKS). Although encompassing a large diversity of rocks (unconsolidated deposits, sedimentary and crystalline rocks) and complex geological settings (e.g. mélanges, polymetamorphic basements), the final legend should be kept as homogeneous as possible and will be fully integrated into the structure of the Swiss Geologic Data Model. The procedure used to catalogue, document, correlate and validate existing or newly defined cartographic units also complies with the guidelines for stratigraphic nomenclature of the SKS (Remane et al. 2005).

Several questions arose in the initial working sessions with the participating experts, in particular as concerns the applicability of the lithostratigraphic concept to crystalline rocks and other complex settings such as "mélanges". No international agreement has yet been reached on this topic. However, the formal naming of units does not fundamentally differ from one classification to the other. The SGS favors a procedure as similar as possible for all units and therefore understands lithostratigraphy in a broad sense. In particular, the principle of cross-cutting relationships, the principle of inclusion and radiometric dating techniques usefully complement and/or replace the law of superposition to order the sequence of events chronologically.

Much time and expertise will still be needed to fully document and formalize the existing units (sometimes implying adaptation of names or the definition of new formations). The practical consequence is that "informal nomenclature" will remain in usage until the required information (e.g. type locality) has been collected, published and approved.

Finally, the conversion of the description of the lithostratigraphic units into attributes for the GIS-version of the GA25 (GeoCover Project) also raised a number of technical questions. The Swiss Geologic Data Model standardizes this procedure and first tests are underway to establish a consistent practical routine.

The results of this ambitious project will be progressively made available through the website of the Lithostratigraphic Lexicon of Switzerland (www.stratigraphie.ch). Contributions, rectifications and comments from the geoscience community are welcome any time and will be taken into account to enlarge and improve our reference database.

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A new stratigraphic scheme for the Early Jurassic of northern Switzerland: The Staffelegg Formation

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The Early Jurassic sedimentary rocks of NW Switzerland have been completely revised lithostratigraphically. Based on new as well as on existing, but re-evaluated, litho- and biostatigraphic data, the litho- and chronostratigraphy of the Early Jurassic strata in the study area has been refined. In accordance with the rules of stratigraphic nomenclature in use at present, a new lithostratigraphic scheme has been developed. Methodologically, lithofacies units and correlation horizons are combined to provide a dual lithostratigraphic classification frame.

The Swiss Committee of Stratigraphy has approved the new scheme introduced by Reisdorf et al. (2011). As such, the Early Jurassic deposits of N Switzerland are now taken as one formal mapping unit, called the Staffelegg Formation. This name, therefore, officially replaces the previously used informal mapping unit "Lias."

The Staffelegg Formation is almost completely composed of Early Jurassic rocks. The onset of the Staffelegg Formation is dated within the Planorbis Zone of the Early Hettangian. The upper boundary to the overlying Opalinus-Ton is regionally heterochronous. Corresponding to SW Germany, this boundary occurs mostly within the aalensis Subzone of the Late Toarcian, but may extend into the opalinum Subzone of the Aalenian.

In the entire N Switzerland, the Early Jurassic comprises exclusively marine sediments, which are dominated by finegrained terrigenous deposits and intercalated calcarenites and phosphorite-rich strata. The thickness of the Staffelegg Formation varies from 25 to 50 meters. In the Klettgau area, in the Tabular Jura, in the eastern Folded Jura, and in the regions to the south, up to 90% of the thickness are formed by deposits Sinemurian in age. In the western Folded Jura (the Mont Terri area), however, Pliensbachian and Toarcian sediments compose up to 70% of the Early Jurassic deposits. In some regions of N Switzerland, no sediments at all are preserved for particular time intervals of the Early Jurassic. These hiatuses cover time spans ranging from a substage up to an entire stage (e.g., Hettangian, Late Pliensbachian, Early Toarcian).

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Facies heterogeneity versus lithostratigraphic nomenclature – examples from shallow-water limestones in the Swiss Jura

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With the HARMOS project, the Swiss Geological Survey aims at harmonizing the lithostratigraphic legend used in the Geological Atlas of Switzerland, i.e. in the geological maps at the 1:25'000 scale. This effort is carried out by specialists under the aegis of the Swiss Stratigraphical Committee. In addition, the definitions of the lithological units considered will be used to update the lithostratigraphical lexicon of Switzerland (which will be in constant evolution). While the goal of this endeavor is clear in that it should lead to a common (and hopefully simplified) nomenclature for lithostratigraphic units, the way to reach this goal is far from straightforward.

A major obstacle is facies heterogeneity. Especially in shallow-water sedimentary systems, different facies can be juxtaposed within the same time unit and form facies mosaics. For example, reefs and ooid shoals build up a platform barrier, while behind the barrier low-energy lagoonal sediments are deposited. On the ocean side, reef breccias and ebb-tidal deltas may develop. This will produce lithologies of reef-limestone, oolite, bioclastic limestone, and limestone breccia that pass from one to the other over distances of a few tens to a few hundreds of meters. In the definition of formations and members that must be mappable at the 1:25'000 scale, different lithologies thus have to be grouped together. Under which criteria shall these lithostratigraphic units be defined, and how to define their limits? Similar difficulties arise if the evolution of a sedimentary system through time is gradual and not marked by a rapid facies change, or if lithology was modified by palaeotectonic constraints.

We present and discuss two case studies from the western Swiss Jura. (1) The Late Oxfordian Vellerat Formation contains three members: the Röschenz Member composes its lower part, while in its upper part the Hauptmumienbank and Steinebach members are laterally juxtaposed. Facies changes are such that unequivocal member boundaries are impossible to place. (2) The lower part of the Early Valanginian "Calcaire roux" defined in the Neuchâtel, Vaud, and Geneva regions passes laterally, in the French Jura, into the upper member of the Chambotte Formation, while its upper part is the lateral equivalent of the Bourget Formation. However, sedimentary gaps and biostratigraphical controversies have so far precluded a common lithostratigraphic definition and nomenclature.

While lithostratigraphic subtleties and scientific controversies can be discussed in the lexicon, decisions must be made when a line has to be drawn on the geological map and a color has to be attributed. This remains a major challenge for cartographers.

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Lower Carboniferous corals from Gerd-kuh section, Eastern Alborz, North Iran

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The Mobarak Formation is developed in the northwest through the northeast of Iran. It comprises thick Lower Carboniferous succession (Tournaisian through the Namurian) in different parts of Central Alborz. Some descriptive papers have been published on Lower Carboniferous corals from The corals of this formation were not known of until 1963 and no monographic study had been carried out on them until that date. Some investigations have been reported the presence of some genera. Iranian Lower Carboniferous coral studies have been effectuated by Douglas (1951), Flugel (1963, 1993), Khaksar (1994, 2004). Nevertheless of effectuated studies heretofore, Iranian Lower Carboniferous corals are not identified completely yet. Corals of Mobarak Formation in Gerd-kuh Section is located in Eastern Alborz Mountains, North part of Iran, has been studied. Mobarak Formation in this section located on Jeirud formation conformity and located under Doroud Formation by a disconformity (Boundavy of Mobarak formation and Doroud formation). 21 species belongs to 11 genera of rugosa corals, and 5 species belongs to 3 genera have been recorded and assigned to 3 local assemblage zones.

First assemblage corresponding to the lithozone A that located in the deeper areas of open shelf with low rate of sedimentation. Corals fauna of this lithozone include solitary rugosa and some tabulata corals that they are as follows: *Caninia cornucopiae* sp., *Bothrophyllum* sp., *Bothrophyllum dobrolyubovae multiseptata* KHAKSAR,1994, *Kueichophyllum alborsense minor* KHAKSAR, 1994, *Tehranophylum* sp., *Haplolasma keyvani* KHAKSAR,1994, *Faberolasma* sp., *Arachnolasma* sp., aff. *Heintzella* sp., *Quinghaiphyllum Pygmaeum* KHAKSAR, *Lophophllidium* sp., *Syringopora* sp., *Syringopora honanesis* LIN, 1958, *Syringopora quadriserialis* SOKOLOV, *Michelinia megastoma* PHILIPS, 1836, *Protomichelina* sp.

Second assemblage corresponding to lithozone B in Gerd-Kuh section, that has been formed in the shallow areas of platform to barrier. This lithozone contain solitary, large and dissepimented rugosa corals, part of them with thick dissepiments that indicate they have been adapted for resistance to high pressure of turbulent environment (barrier area). The corals of this lithozone are as follows: *Caninia cf. irinae, Caninia ? lonsdaleiforme, Caninia sp., Pseudozaphrentoides ? sp., Siphonophyllia cyllindrica cylindrica, Siphonophyllia* aff. hettonensis, Kueichophyllum sp., Kueichophyllum alborsense minor, Kueichophyllum lalunense, Clisiophyllum sp.

Third assemblage is present in the back reef zone (taidal flat) and indicates Early Visean in age. There are dominantly belong to cyathaxonia fauna and some tabulata: *Zaphrentites parallela, Caninia* sp., *Syringopora* sp.,

According to collected species of corals the Age of Mobarak Formation in Gerd-kuh section is Lower Carboniferous (Tournaisian-Visean).

The Gerd-kuh assemblages are typical of the Mediterranean province, having abundant specimen of *Kueichouphyllum*, the genus that define the eastern part of the province, but the whole assemblage show higher similarity with the western Europe assemblages.



Figure 1. Location of the study area.



Figure 2. Gerd-kuh section.





Figure 4. Extension of corals in the Carboniferous shallow carbonate platform.

Figure 3. Stratigraphical column of Gerdkuh section

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Lithostratigraphy of Penninic nappes in Valais: Legend harmonisation of the Geological Atlas of Switzerland

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Recent works in geological survey and geological studies allow to harmonize and formalize the stratigraphy of some Penninic units in Valais.As part of the project of nationwide harmonized lithostratigraphic legend for the Geological Atlas of Switzerland 1:25'000 (GA25) – of the Swiss Geological Survey under the scientific supervision of the Swiss Committee of Stratigraphy (cf. Morard et al. this symposium) – correlations are made for every sheet of the GA25 already published and affected by these units.

The block of the Siviez-Mischabel and the Mont Fort nappes, although very deformed and cut by post-nappe shear zones, constitutes a coherent lithostratigraphic series. His Mesozoic–Cenozoic cover can be attributed to different formations defined in the Préalpes médianes rigides nappe. Under this cover, a succession of seven formations makes this portion of the Briançon upper crust: the Ergischhorn unit and the Adlerflüe Formation (maybe of Proterozoic age), the Lirec Formation and the Distulberg Formation, (probably Cambrian), the Métailler Formation (Cambrian-Ordovician), the Col de Chassoure Formation (Permian) and the Bruneggjoch Formation (Late Permian – Early Trias).

The Mesozoic–Cenozoic sedimentary cover of the Cimes Blanches nappe may be correlated with similar formations of the Breccia nappe within the Préalpes.

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P 7.2

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Frasnian reef biostromes of the Hojedk section, North Kerman, Central Iran

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The corals of Bahram Formation in the Hojedk section were studied. The section is located in the Noth of Kerman city, Central Iran (Figs. 1, 2), 4 km west of Haruz village and 64 km north of Kerman mountain (Kuh-e-Kanseh section of Wendt et al. 2005), is noteworthy for abundantce of macrofauna. It is located on the western part of Kerman. Its base is at N 30° 43' 30'', E 57° 00' 37'', Its top at N 30° 43' 33'', E 57° 00' 24''.

Two level of biostromes, consisting mainly of tabulate and rugose corals (Rohart 1999; Brice et al. 1999) are diachronously exposed at the base of the Bahram Formation in several sections in central and eastern Iran: the late Givetian-early Frasnian in Ozbak-Kuh (Khaksar et al. 2006), the early Frasnian in Hojedk Gholamalian et. al. (2008), and the mid Frasnian in Chahriseh, near Esfahan and at Howz-e-Dorah, in southern Tabas.

A systematic study on the corals of Bahram Formation in the Hojedk Section, resulted in recognition of 19 species belong to 7 genera of rugosa and tabulate corals; that as follows: *Hexagonaria, Thamnophyllum, Charactophyllum, Disphyllum, Thamnopora, Squameoalveolites* and *Alveolites*.

Two level of biostromes, consisting mainly of tabulate and rugose corals are distinguished: first biostrome consist mainly of tabulate corals such as: *Thamnopora, Squameoalveolites* and *Alveolites* and second biostrome compost mainly of rugosa corals *Hexagonaria* and some solitary corals such as: *Thamnophyllum, Charactophyllum* and *Disphyllum*.

Studied corals, lithology and accompanying fossils (gastropoda, brachiopoda and bryozoans) show that Bahram Formation has been formed in the shallow, turbulent, oxygen- rich and rich on nutritional materials in the shallow areas of barrier reef environment. The biostrome developed in shallow platform, but without marks of restriction, because waters were well oxygenated and salinity was marine normal. The hydrodynamic energy was mostly low to moderate, but the influence of waves was strong, at least periodically, because fragmentation is considerable in the biostrome. The environment was optimal for the development of very diverse skeletal organisms because the diversity is very high and the competition for space indicates a high organic productivity. Nevertheless, the organisms living there had some problems in their growth, probably due to the strong competition, because skeletal anomalies are common.In base of coral studied and stratigraphical position the Bahram Formation is determined Frasnian in age.



Figure 1. The location of section.



Figure 2. Geological map of studied area.



Figure 3. Stratigraphical column

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Lower Carboniferous corals from the Namake section in the North Damghan, East Alborz-Iran

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The study is based on the corals of the Mobarak Formation in the Namakeh section (North Damghan, Central Alborz). The Namakeh section is situated in the East of Iran, in the latitude 36° 20' 18" N and Longitude 54° 12' 36" E situation. Namakeh Section is situated in the 65 km north of Damghan. In this Section, Mobarak Formation is faulted over Khoshyylagh Formation and it is covered by Doroud Formation. The thickness of the Mobarak Formation is 670 meter (Figure 1). Some descriptive papers have been published on Lower Carboniferous corals from several localities in the Alborz (Flugel, 1963; Khaksar, 1996, 2007). The paper by Flugel (1963) is the most important for understanding of the Lower Carboniferous coral fauna of Iran. The Mobarak Formation developed in this area contains rich and diverse coral fauna (Assereto, 1963). Biostratigraphy of the Mobarak Formation is based on conodonts and brachiopods (Ahmadzadeh-Heravi, 1971), and also on corals (Khaksar, 1994).

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Up to 22 species of corals belong to 13 genera have been distinguished. The following species are: *Hapsiphyllum* sp., *Sychnoelasma* sp., *Lophophyllum* sp., *Zaphrentites parallela*, *Allotropiophyllum* cf. *cuspidium*, Hapsiphyllidae indet., *Pleramplexus* cf. *leptoconicus*. *Meniscophyllum* sp., *Amplexizaphrentis iraniense*, *Amplexizaphrentis* sp., *Ufimia infracarbonica*, *Ufimia* cf. *elogata*, *Rotiphyllum* sp., *Rotiphyllum* ? *densum*, *Plerophyllum* sp., *Rotiphyllum* omaliusi omoliusi, *Caninia* cf. *cornucopiae*. *Allotropiophyllum* sp., *Zaphrentoides* sp., *Plerophyllum* sp., *Pleramplexus* cf. *leptoconicus*, *Cyathopsidae* indet. and *Hecatomcyathus* tylosense new gen. & sp. (Figure 2).

The succession show regressive sequence from Upper Tournaisian to Lower Visean. According to corals morphology, two ecological assemblages were distinguished.

The assemblage I is composed of solitary undissepimented rugosa corals of smal sizes and dissepimented corals of median size. This assemblage is typical from open and deep platform and attribute to Tournasian in age.

The assemblage II is composed of solitary undissepimented rugosa corals of smal sizes and occurs at shallow areas of the open shelf. This assemblage is Lower Visean in age. These evidences of microfacies and the existent biota confirm totally that they have occurred in the shallow areas of the open shelf to back reef zone. The cyathaxonia and tabulata corals available in this area can tolerate this condition. The cyathaxonia adaptive morphology enables them to exist in lagoon condition to 4000 m depth. A relative abundance of these corals is in two habitats of the subnatural terms of marine for purposes of salinity, temperature, amount of Oxygen and nutrient currents.



Figure 1. Stratigraphical section of Namakeh section

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P 7.5

Sulfur isotope stratigraphy of Middle to Upper Triassic marine evaporites in the Jura Mountains, Northern Switzerland

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Sulfur isotope stratigraphy is potentially a powerful tool for the correlation of Triassic sequences that otherwise remain difficult to date. Moreover, together with other geochemical proxies, it may provide constraints on global environmental changes. However, sulfur isotope stratigraphy of the Triassic is still in its infancy and carries large stratigraphic uncertainties, mainly because of the paucity of data and the difficulty of dating evaporite sequences. Here we present new highresolution stable sulfur isotope data from Northern Switzerland complemented with published data from the entire Triassic elsewhere. The new data were obtained on samples from drill cores penetrating two distinct anhydrite intervals in the wells Weiach and Schafisheim (Northern Switzerland) and recovered by NAGRA (National Cooperative for the Disposal of Radioactive Waste). An additional gypsum interval was studied in outcrop near Riepel in the Jura region. No comparable high-resolution data are hitherto available from other evaporite successions in the Germanic Triassic and S-isotope information from open marine Tethyan successions is rare, especially for the Anisian to Carnian time interval. The new results from the two sulfate sequences Anhydritgruppe (Middle Muschelkalk) and Gipskeuper (Middle Keuper) show in both cases rapid shifts upsection of more than 2‰ towards lower δ^{34} S values (Fig. 1). On a larger scale, these sulphur isotope shifts fall into a prominent decrease phase of sulfur values lasting from the late Permian up to the late Middle Triassic (Ladinian) that is followed by a stepwise decrease to apparently more stable values from the Carnian upwards (Figure 1). These very large and rapid sulphur isotope shifts testify significant perturbations of the global sulphur cycle during the Triassic.

On the basis of an improved geochronologic scale and correlation of Germanic and Alpine Triassic units, we propose a state-of-the-art comparison and integration of the new Swiss sulphur isotope data with results from the Southern Alps (Lombardy, Dolomites, Carnia) and the Northern Calcareous Alps.



Figure 1. Stable sulfur isotope curve with new data from Northern Switzerland (black lines) and data from literature.

Using Dickinson's method for a better understanding of the origin of the Voirons Flysch (Gurnigel nappe, Haute-Savoie, France)

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Grain counting of sandstone samples collected from the Voirons flysch following Dickinson's model shows that these sandstones originate from a continental area, as sandstones from the other portions of the Gurnigel nappe. Composition variations further demonstrate that it is possible to distinguish distinctive petrofacies within this flysch. The latter observation contradicts the classic idea that such differentiation was impossible.

Silicoclastics sedimentary successions of the Voirons flysch in the Gurnigel nappe (Haute-Savoie, France) have not been much studied from a sedimentological and petrographic viewpoint. Therefore, lithological unit descriptions and subdivisions are based on empiric criteria (occurrence of sandstones, conglomerates, or marls) rather than on tangible elements. Additionally, field experience demonstrates that it is difficult to observe facies variations. Our study consists in a sedimentological, petrographical and mineralogical analysis of this flysch based on several tools.

In the Chablais Prealps, the Gurnigel nappe is represented by the Voirons flysch which is exposed in the Voirons and Vouan massifs and some minor reliefs. This flysch is subdivided into three units: (1) the Voirons sandstones (VS), basically constituted by a thick-bedded sandstone series punctuated with some conglomeratic interbeds; (2) the Vouan conglomerates (VCg) forming metric-thick beds of matrix supported conglomerates with subordinate sandstones; and (3) the Saxel marls (SM) represented by a series of metre-thick marl layers separated by thinly bedded sandstones. This succession is interpreted as a turbiditic sequence from intermediate (VS) to proximal (VCg) and possibly distal (SM) facies. Ongoing biostratigraphic investigations have rejuvenated this flysch from the Middle Eocene to the Late Eocene - Early Oligocene.

More than 250 thin sections have been elaborated for the three members. Each thin section has been stained in order to differentiate alkaline feldspars, plagioclases and quartz. Counting of 300 points per section was done following the Gazzi-Dickinson protocol. Feldspars and plagiolcases from granite or volcanic lithoclasts have been identified. Other constituents have also been taken into account as extra-counting.

All samples have been classified as quartzo-feldpathic sandstones with variable composition. They are lithoclasts depleted. Most of them plot in the "Stable Craton" and in the "Transitional Continental" fields of the Dickinson ternary diagram. This result is comparable to that obtained from analogous analyses performed in other areas of the Gurnigel nappe and confirms a similar provenance for these sediments.

P 7.7

The last deglaciation of the northern Alpine Foreland: Evidence from the Reuss Glacier

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The Last Glacial Maximum (LGM) advance of the Reuss glacier to the northern Alpine Foreland built lateral moraines on the slopes of Mount Rigi (Canton of Schwyz) and terminal moraines at its frontal position near Lenzburg (Canton of Aargau). In order to establish the timing of deglaciation of the Reuss glacier starting after the LGM, we exposure dated erratic boulders with cosmogenic ¹⁰Be and ³⁶Cl. On LGM- terminal position of the Reuss glacier, we sampled two erratic boulders: "Grosser Römerstein" and "Kleiner Römerstein". We also collected samples from the lateral Alpine border position at the Rigi. The minimum exposure ages on the terminal position at around 22 ka and on its lateral maxima position at around 20 ka show that the beginning deglaciation of the Reuss glacier is comparable with other lobes in the northern Alpine Foreland. An erratic boulder next to the "Erdmannlistein" (Wohlen, AG) which is situated at approximate-ly 12 km in behind the maximal extent yielded the first exposure age from a retreat stadial position ("Stetten Stadium" sensu Jäckli 1966) in the northern Alpine Foreland, which indicates a deglaciation age of no later than around 19 ka. Based on our results, the melt back from the position in Wohlen at around 19 ka ago up to the high Alpine valley at the position of the next advance (Gschnitz s.l.) must have been extremely fast.

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The Middle Triassic (Anisian) marine transgression in the Tödi area, Central Switzerland

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During the basal Triassic, a shallow sea flooded the crystalline basement in central Switzerland. The knowledge on this transgression, i.e., stratigraphic allocation, depositional environment and paleogeographic setting, has been refined by numerous geologists since the end of the 18th century (e.g., Brunnschweiler, 1948; Widmer, 1949). Still, chronology, dynamics and direction(s) of this transgression remain unclear. First efforts based on palynological data (Gisler et al., 2007) indicated a marine transgression direction from the Tethys towards the Jura Mountains at lowermost Anisian time.

This study presents four different stratigraphic sections in the Tödi area, i.e., Limmernsee, Val Punteglias, Obersand and Hüfihütte, where lack of vegetation, well-exposed rocks and little tectonic deformation allowed detailed logging. The first sediments deposited on the weathered crystalline basement consist of conglomerats and sandstones with a fining-up trend. Numerous sedimentary structures such as ripple marks or channels can be observed in this siliciclastic unit. Following-up section, the clastic beds become thinner and dolomite layers appear randomly until they dominate. In the uppermost 20 m of the sequence, dolomite beds become massive and show a well-developed stacking pattern. The tops of the Triassic sections are erosive surfaces followed by black shales of Lias to Dogger in age. The thickness of these sedimentary deposits vary from one section to another. The Val Punteglias section is 54 m and thicker than the Limmernsee section (45 m), the Obersand section (32 m) and the Hüffihütte section (27m). Thus, the Triassic deposits thin towards the north and the west.

Facies and microfacies determinations, sedimentary structure analyses as well as stable isotope analyses (δ^{13} C, δ^{18} O) have been carried out. Preliminary results show that the sedimentary record displays several depositional sequences implying that high-frequency relative sea-level fluctuations were superimposed onto the general transgressive trend. These observations allow to correlate the four locations and to give indications about the depositional system and paleotopography.

Additional palynofacies analyses will be performed to reinforce these correlations and to determine more precisely the timing of the transgression. Several other sections will be logged in the Windgällen area (Ronenegg) and close to Erstfeld (Scheidnössli). This last section has already been well documented and will act as an anchor for the corelation. In a next step, these results will be compared with those of the Weiach borehole (Jura mountains) to get a better understanding on the Alpine realm at middle Triassic times.

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From "black shales" to red beds in the northern Helvetic Seewen Formation (Cenomanian – Turonian)

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Several Cenomanian – Turonian pelagic limestone sections were studied at high resolution to gain a better understanding of the highly variable sedimentation of the Late Cretaceous along the northern Tethyan margin. Two expanded sections in the Churfirsten Mountains (Chäserrugg, 32 m and Strichboden, 8 m) and another in the Alpstein (Kamor, 18 m) were sampled in 10 cm spacing. Both sections belong to the northern Helvetic Seewen Formation (Churfirsten-Säntis nappe). Samples were analysed for stable carbon- and oxygen-isotopes.

Westermann et al. (2010) showed that the onset of the δ^{13} C positive excursion of the Ocean Anoxic Event 2 (OAE2) is characterised by glauconite grains and even a small hiatus. The same characteristic layer can also be found 40km more to the east in the Churfirsten. The condensed beds comprise the first δ^{13} C excursion of the OAE2 (peak "a" 4.1‰) of the positive excursion. There are also some karstic features visible, which were sometimes filled by a glauconite-quarz sand. The following darker and more marly interval can be seen as evidence deposition near or within an expanded oxygen minimum zone. This succession can be traced into the Alpstein area (Zwinglipass) and further to the location "Kamor" (Appenzell) and into the Vorarlberg region. In the Kamor section, the condensed interval shows a δ^{13} C value of 4.8‰. An 80cm thick glauconite sand layer, the so called lower "Götzis bed" (Föllmi and Ouwehand, 1987), forms the top of this condensed interval. Based on C-isotope data, this condensed interval is correlated with OAE2.

The new C-isotope stratigraphy established in eastern Switzerland contrasts with the stratigraphy proposed by Westermann et al. (2010). These authors propose that sediments corresponding with OAE2 have an overall thickness of the about 11 meters. This study shows that OAE2 has a thickness of only 2-3 meters in the Seewen Limestone successions of Eastern Switzerland. A chemostratigraphic correlation of the Latest Cenomanian and Earliest Turonian intervals is possible if sampling resolution is in the order of around 10 centimeters.

Roughly 10m above the described δ^{13} C excursion the sediment colour of the Seewen limestone becomes reddish. The red variety of the Seewen Fm consists of several red intervals. The first and most distinct Oceanic Red Bed (CORB) occurs always in the *H. Helvetica* total range zone (Bolli, 1944). This Oceanic Red Bed was also described by Neuhuber et al. (2007) in the Ultrahelvetic units of the Eastern Alps of Austria and Bavaria. With the new chemostratigrapy these 3 CORB's intervals can be linked with sharp negative shifts of the δ^{13} C record of the Middle and Late Turonian.

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8. Palaeontology – in memoriam of Jean-Pierre Berger

Lionel Cavin, Damien Becker, Christian Klug

Schweizerische Paläontologische Gesellschaft Kommission des Schweizerischen Paläontologischen Abhandlungen (KSPA)

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- P 8.4 Schaefer K.: Variability of the dental morphology in marine crocodilians (Thalattosuchia) from the Kimmeridgian of Ajoie (Jura, Switzerland)

Pore morphometrics applied to Oligocene planktonic foraminifera : a method to disentangle phylogeny ?

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The Late Eocene is a time of general warm conditions. During this time planktonic foraminiferai assemblages are dominated by strongly specialized species (K-strategists) such as hantkeninids, morozovellids and acarinids. The Eocene-Oligocene transition marks the passage from « greenhouse to « icehouse » conditions in the Paleogene (Coccioni et al. 2000) and witneses the establishment of the Antarctic ice sheet (Coxall and Pearson 2007).

The entire Oligocene underwent a period of cool conditions (Zone P19 to P21) during which the warm and specialized K-strategist Eocene species were replaced by the cold simple r-strategist planktonic foraminifera possessing a high evolutionary potential. This climatic trend culminated in a strong climatic instability at its end corresponding to the Oligocene/ Miocene boundary (equated to the major period's boundary Paleogene/Neogene).

It is only with the warm pulse from Zone P21b to the end of Zone P22 that the tendency reverses and K-strategists panktonic foraminifera re-appear in the world oceans. In particular, a new genus of planktonic foraminifera, the genus *Globigerinoides* first occurs during this time of climatic instability (Spezzaferri 1995). Species of this genus radiate and evolve starting from the Oligocene-Miocene boundary. They are still among the most important and abundant species in modern oceans.

Despite their present diversification, the early appearance and development of this lineage is still poorly known. The evolution of the early *Globigerinoides* represents the passage from r- to K-stratgists by the appearance of supplementary apertures on the spiral side. However, their general morphologies are still not well defined, species cannot be clearly distinguished and therefore their lineage is difficult to trace.

We suggest here that pore density and diameters can be linked to different species and we propose to apply to the Late Oligocene and Early Miocene Globigerinoides a morphometric method previously applied to recent genera by Bé et al. (1969).

It consists in accurately measuring the diameter of pores from the internal wall texture and plot them versus the number of pores counted in a given shell surface.

We apply a statistical appraoch to test the method. As a result, we expect to link different species in a coherent lineage according to size and density of pores.

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The pachypleurosaurs from the Ducan area, southeastern Switzerland – validation of the species *Neusticosaurus staubi*?

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The Ducan region near Davos in southeastern Switzerland (Austroalpine Silvretta nappe in Canton Graubünden) provides an important site for Middle Triassic vertebrate fossils, excavated systematically since 1996. Beside numerous fish fossils only a few marine and terrestrial reptiles were discovered in the early Ladinian Prosanto Formation: pachypleurosaurs, nothosaurs, a placodont, two protorosaurs, and a rauisuchian (Furrer 2009). The first postcranial skeletal fragment of a pachypleurosaur was formerly classified as *Neusticosaurus staubi* (Kuhn-Schnyder 1959), however it was considered to be non-diagnostic at the species level (Sander 1989; Rieppel 2000). New findings of six nearly complete specimens allow a detailed reinvestigation of the pachypleurosaurs from the Ducan area.

Based on morphological and morphometric analyses, a species level classification is attempted. The specimens from the Ducan area are compared to the four species occurring in the classical section at Monte San Giorgio in southern Switzerland (late Anisian – early Ladinian). A review of the pachypleurosaurs from the Middle Triassic in Germany and the Netherlands gives insight into the temporal and geographical distribution of these animals.

The specimens from the Ducan area combine several characteristics of *Serpianosaurus mirigiolensis* and *Neusticosaurus pusillus* known from Monte San Giorgio. However, classification is complicated due to differences related to sex and age of the individuals. A preliminary parsimony analysis including all European pachypleurosaurs places the Ducan material between *Serpianosaurus mirigiolensis* and *Neusticosaurus pusillus*, within the clade of the Monte San Giorgio species.

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Unusually diverse bivalve assemblages from the Early Triassic (Griesbachian) of South China

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Early Triassic (Griesbachian) microbial limestone commonly overlays the latest Permian thick-bedded peri-reefal/shallow water limestone in the Guangxi part of the Nanpanjiang Basin (South China). Several fossiliferous lenses were discovered within the microbial limestone during two field campaigns.

These shelly accumulations form distinct intercalations between domes of microbial limestone. Such coquinoid lenses are interpreted as material washed in and trapped between the domes. They contain bivalves, gastropods, brachiopods and occasional ammonoids and ostracodes. Lenses from the new Wuzhuan section are dominated by bivalves; however the subordinate fauna contains gastropods, brachiopods and ostracodes.

Thirteen species of bivalves were recovered from the Wuzhuan lenses. *Towapteria schyhtica* is one of the dominant species. Other bivalves include *Bakevellia* sp., *Claraia* cf. *liuqiaoensis, Astartella* sp., and *Streblopteria* sp. nov., among others. At the genus level, five are long-ranging survivors, four are late Permian holdovers and four first appear in the Griesbachian.

From Shanggan, an unusually diverse mollusc fauna of Griesbachian age with high evenness of species abundances was first described by Kaim et al. 2010 and Hautmann et al. 2011. There, eleven bivalve species were obtained from a single lens.

Among the thirteen bivalve species from Wuzhuan, only a single one is shared with the Shanggan fauna, thus yielding a total of 24 species of bivalves for the benthic faunas of the microbial limestone in this area. This reflects a high diversity and evenness of the benthic fauna from the microbial limestone in China already in the Griesbachian. Sediments enclosed within the basal Triassic microbial limestone documents the first recovery episode of benthic ecosystems in the immediate aftermath of the end-Permian mass extinction.

Phylogenetic and ecological impact of Eocene climatic events on European artiodactyls

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We present here the objectives and first results of a project launched by the late Professor Jean-Pierre Berger. Aim of the project is to test if there is a causal link between the evolution of European artiodactyls and Eocene climatic events.

Numerous significant climatic events were recorded during the Eocene including the Paleocene-Eocene Thermal Maximum (PETM), the Eocene Thermal Maximum (ETM), the Early Eocene Climatic Optimum (EECO), the Middle Eocene Climatic Optimum (MECO), and finally the Terminal Eocene Event (TEE) (Berger 2011). Extinctions and apparitions of land mammal communities, and in particular of the European artiodactyls, occurred during those climatic events (e.g. Erfurt and Métais 2007). The first European Diacodexids appeared during the PETM. Most of the representatives of this group disappeared during the EECO. This time also witnesses the appearance of European Dichobunidae and probably of Xiphodontidae. A strong turnover can be noticed at the MECO in almost all the families. At the TEE, most of the species disappeared, replaced by taxa with major components of Asian origin. Additionally, in the middle Lutetian several families such as Anoplotheridae, Choeropotamidae and Dichobunidae diversified. Likewise, the family Anoplotheriidae eudured drastic changes around the Bartonian-Priabonian boundary: almost all Dacrytheriinae disappeard and the Anoplotheriinae diversified. Analogous turnovers happened in the other families in the same time.

The enhancement of knowledge about the phylogeny of Eocene artiodactyls, which is still controversial, is an essential requirement to better understand the effect of the climatic changes on their evolution. The genus *Robiacina*, for example, is sometimes considered as the oldest Cainotheriidae and sometimes as a primitive Anoplotheriidae (Erfurt and Métais 2007). Within the Anoplotheriidae, the phylogenetic link between the subfamily Dacrytheriinae and the more recent subfamily Anoplotheriinae is unknown. Also, tracing the relationships between the families Cainotheriidae, Anoplotheriidae, Xiphodontidae and Mixtotheridae is essential to understand the evolution of the classic group of Tylopoda.

Referring the ecology, the progressive emergence of some particular adaptations within several families such as the selenodonty and the elongation of limbs occurred also during Eocene climatic events. Therefore, a better description of the ecological adaptations of the Eocene artiodactyls can bring significant insight about the European terrestrial palaeoecosystems. In particular, the cranial and mandibular morphologies, the teeth shape and an analysis of teeth meso-wears may give relevant information about their diet (e.g. Fortelius and Solounias 2000). An analysis of dental cementum may relate to seasonality (Lieberman 1994) and the analysis of postcranial remains allows identifying some strategies of locomotion and of adaptations to environments (e.g. Christiensen 2002).

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8.5

Soft-part preservation in heteromorph ammonites from the Cenomanian-Turonian Boundary Event (OAE 2) in the Teutoburger Wald (Germany)

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Excellent preservation of ammonites in Cretaceous rocks has been documented several times already. For instance, Lebanese Plattenkalke have yielded heteromorph ammonites with phosphatised soft tissue (Wippich & Lehmann 2004) and, more recently, US-American baculitids (also heteromorphs) were published showing a perfectly preserved radula *in situ* (Kruta et al. 2011).

Several decades ago, WR extracted 17 flattened individuals of baculitid ammonoids with carbonised and partially also phosphatised soft parts from thin laminated marlstones belonging to the OAE 2 of the Late Cenomanian Hesseltal Formation of Lengerich in the Teutoburger Wald mountains (Westphalia, Northwestern Germany). The advantage of these specimens is that the shell is dissolved. However, it appears like the shell has been deposited with the soft parts because the shell outline is still visible as well as such shell structures that were not carbonatic like the siphuncle and melanin-rich parts of the shell (megastriae, aperture).

Several of these ammonites preserve remains of the buccal mass including jaws (more or less articulated) and radulae. Additional remains which were not mineralised *in vivo* have been found. Most of which are much more difficult to homologise with organs of their Recent coleoid or nautilid counterparts. For example, behind the mouth parts, two specimens display two lateral, symmetrically arranged more or less oval structures. In one of the two specimens, these two are linked with each other and this connection covers the supposed oesophagus. According to this arrangement, these oval structures have been interpreted as remains of the cephalic cartilage with the eye capsules, which were previously unknown from ammonoids. Further soft-parts include structures, which we interpret as digestive tract including oesophagus, crop, stomach and (?) the caecum as well as remains of what might have been the oviduct.

In the same horizon, patchy occurrences of numerous isolated upper and (less abundant) lower jaws (probably also from baculitids) as well as radulae occur (Wippich 2005). These jaw-accumulations may represent regurgitates or droppings of larger predators. According to the facies and associated microfossils, the here portrayed cephalopod remains were probably deposited in an epicontinental setting, perhaps at a palaeodepth between 200 and 600 metres. In this Late Cretaceous fossillagerstätte, ammonite upper jaws and anaptychi are among the most abundant fossils.



Figure 1. Reconstruction of the baculitid from northern Germany. Note the large eyes. Their swimming orientation is according to Hauschke et al. (2011), but a more or less vertical shell orientation is also conceivable, at least when the distribution of shell mass and phragmocone-gas is take into account. The arm morphology and positions are speculative.

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8.6

Morphological evolution of *Globorotalia menardii* and related forms during the past 8 million years at ODP Site 925B (Ceara Rise, western tropical Atlantic)

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"Evolutionary prospection" was initiated with the goal to investigate the morphological evolution of Neogene menardiform globorotalids from selected time-slices and key-locations in the world ocean as a case study for morpho-logical speciation in calcareous plankton (Knappertsbusch, 2011). For this purpose downcore studies of changes of menardiform globorotalid shells during the past 8 million years was carried out at the western tropical Atlantic ODP Site 925B. A total of 5976 specimens from 33 isochroneous time-levels to previous studies at DSDP Sites 502 and 503 were measured. Taxa include lineages of *G. menardii-limbata-multicamerata, G. menardii-pertenuis-exilis,* the *G. miocenica-"pseudo-miocenica"* group and the *G. menardii-G. tumida* morpho-plexus. Using our robot AMOR (Knappertsbusch et al, 2009) and MorphCol software shell parameters from digitized outlines were obtained. Special attention was given to the evolution of spiral width (Dx) versus axial length (Dy) of tests in keel position, but other parameters were collected as well. Results show a dominating gradual increase of shell size in *G. menardii*, but a prominent expansion to large forms after 2.72 Ma (normalized time of -0.34 in Figure 1), which is surprisingly similar to trends observed at remote Caribbean DSDP Site 502 (Knappertsbusch, 2007).

In Figure 1 shell variability of *G. menardii*, transitional *G. limbata* and *G. multicamerata* is shown in form of surfaces of equal specimen frequency in the bivariate morphospace of Dx versus Dy and ranging from 0 through 8 Ma. These iso-surfaces enclose specimens of equal frequency throughout the Dx, Dy morphospace across the studied time span. The philosophy behind is, that populations belonging to a particular taxon would appear as clusters, that through time connect together to form a "phylophenetic" tree. Such trends were visualized with Voxler software from Golden Software, Inc. (Knappertsbusch and Mary (2012).

The combination of visual taxonomy and morphometric measurements from ODP Site 925B allowed to visualize the transition from ancestral, extant *G. menardii* to the extinct *G. limbata-G. multicamerata*. Without resolving along the time-axis, these three morphological groups would strongly overlap and distinction would not be possible without extra information.

In these volume-density representations high iso-values indicate frequent specimens (occurring in the central part of bivariate frequency contour diagrams). In contrast, low iso-values indicate rare specimens and form the outermost "skin" of a distribution through time. Because innovative specimens are usually rare at their first appearance, low-frequency isosurfaces (arbitrary iso-values of 0.4665 of sample normalized frequencies) were chosen to illustrate evolutionary progress in *G. menardii, G. limbata* and *G. multicamerata*. *G. menardii* (4 to 6 chambers in the final whorl) slowly increases in size until about 2.7 Ma, when it suddenly expanded to large shells in the Dx versus Dy plane. *G. limbata* (which was recognized by 7 chambers in the final whorl and by a somewhat shiny surface texture) falls almost completely inside the distribution of *G. menardii* but shows a slow increase in size. *G. multicamerata* (8 or more chambers in the final whorl) appears as two clusters within the Pliocene and morphologically shows strong overlap with 5 to 6 chambered *G. menardii* from after 2.7 Ma.

Further statistical analysis must be carried out including all the remaining measurements in order to develop a numerical classification, that is independent from visual species identification.



Figure 1. Volume-density diagrams of the variation of Dx (spiral height, red axis) versus Dy (length in keel view, green axis) through time (blue axis) for *G. menardii* (yellow), *G. limbata* (purple, and *G. multicamerata* (red) at ODP Site 925B (Ceara Rise) during the past 8 million years. Left figure in front view, right figure in back-view. Axes are normalized to values between 0 and 1, while the time axis ranges from 0 (Recent) to -1 (8 Ma).

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8.7

Paleontology and stratigraphy of the North- Middle Upper Rhine Graben (N-Middle URG): relationships between rift system, alpine orogeny and paleoclimate

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Located between Strasbourg (France) in the south and Landau (Germany) in the north, the North- Middle Upper Rhine Graben (N-Middle URG) was the site of an intense lacustrine, brackish and marine sedimentation from the middle Eocene to the Late Oligocen

The traditional stratigraphic succession (Schnaebele 1948) is, in stratigraphic order : the Transition zone, in contact with the underlying Jurassic limestone, the Dolomitic zone, the Red Bed, the Lower- Middle- and Upper Pechelbronn Beds, and the "Série Grise".

There are very few outcrops in this area, mainly the old quarry of Bouxwiller, consisting in lutetian marls and limestones, marls from the Upper Pechelbronn Beds, as well as the Série Grise (Isselbaechel), but many boreholes and seismic lines exist because of the oil industry, especially GPK4 Soultz-sous-Forêts, covering the whole series, and the borehole of Preuschdorf 01983X2854, which is a complete cored drilling corresponding to the Upper Pechelbronn Beds with a small part of the Middle Pechelbronn Beds at the base. These localities provided heavy minerals, lithological, micro- macro- and nanopaleontological data.

Using these data and the previous publications, a stratigraphic correlation will be exposed, with a datation of the Red Bed based on charophytes, showing that these layer are different from the Red Bed found in the South Upper Rhine Graben (Schwartz1997), and a datation of the Upper Pechelbronn Beds based on nanofossils in contradiction with Martini and Reichenbacher (2007).

The previous paleogeographical and paleoclimatic reconstitutions (Berger et al. 2005 a, Pirkenseer 2007) will also be discussed, with a focus on the predominance, in the North-Middle Upper Rhine Graben, of local tectonic on global sea level changes.

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Micro-dissection reveals inner structure and ontogenetic growth of Pliocene menardellids (planktonic foraminifera)

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Planktonic foraminifera are marine protists that build a calcareous shell. They are widely used as biostratigraphic markers and as tools for paleoceanographic reconstructions. Recently, molecular approaches have targeted critical aspects of their classification, revealing the existence of genetically distinct cryptic species within the traditionally established morphospecies (Darling and Wade, 2008), calling for extra morphological studies of extant and fossil foraminifera.

Discrimination between species by shell morphology remains, however, still difficult, many planktonic foraminiferal species showing convergent morphologies and clinal intergradation. Morphological plasticity is strongly influenced by ontogeny (Hemleben et al., 1985; Brummer et al., 1987), which has important implications for the morphological characterization on the population level and in the preserved assemblages. The present work investigates the possibility of distinction between morphologically convergent morphospecies by the study of their ontogenetic growth.

Although micro-CT techniques nowadays allow for studying foraminiferal shell growth of individuals, this novel technique is still at infancy for routine application in larger amounts of specimens, which draws us back to traditional shell dissection techniques. Such techniques, however, are difficult, very labor intensive, and documented studies were limited to a few of largest individuals (Huber, 1994). We have developed microdissolution as an alternative and more efficient protocol to study ontogenetic shell growth of foraminifera on a statistically significant number of specimens (up to 350 individuals). For this we use concentrated hydrochloric acid to dissolve the umbilicall side of the test under the binocular, while the dorsal side of the test is mounted on multicellular faunal slides using a mixture of water soluble glue and sodium hydroxide to protect the spiral side from dissolution. This method proofed very fast and allowed the study of ontogenetic growth and internal ultrastructural features.

Using SEM pictures of microdissected specimens, we could measure the ontogenetic growth of Pliocene menardellid foraminifera. We show the relationship between shell morphology and growth rate within three morphological convergent groups, e.g. - *Globorotalia menardii*, *Globorotalia limbata* and *Globorotalia multicamerata*. Our study confirms the occurrence of a strong size dependent variation caused by differences of maturation between species within this genus (Schmidt et al. 2006). In addition, we identified several internal structures, that serve as primary taxonomical criteria to discriminate the different Pliocene menardellid morphospecies.

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Figure 1: Examples of a microdissected menardellids : A: Specimen overview B: Magnification of the first whorl exhibiting the proloculus. C: Differences in growth rate between specimens of *G. limbata* and *G. multicamerata*.

8.9

Ruminantia ecomorphology and the complexity of the phylogenetic signal

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The covariation of an organism's morphology (or a part of it) and its ecology corresponds to the ecomorphology. The shape of a bone is strongly influenced by its function and the physical requirement of this function. In the present study, two specific bones of ruminants (the astragalus used for locomotion and the mandible used for mastication) have been analyzed in order to define ecological pressures and phylogenetic trends.

Nowadays, the ruminants are the most diversified group of large mammals in having more than 200 extant species. They occupy numerous ecological niches covering many different types of environment such as deserts, grasslands, savannas, forested areas, and mountains. Their feeding habits vary from selective browsing to pure grazing. Their evolution is deeply anchored in the Paleogene of Laurasia (Mid to Late Eocene). However, extant families only appeared during the Mid-Miocene.

Numerous ecomorphological studies on postcranial bones have recently demonstrated that the ruminants, especially Bovidae, that cover the largest range of ecological variability among the ungulates, are good ecological proxies. Using the Support Vector Machine (SVM) method, associated with a Principal Component Analysis (PCA), we greatly improved the ecomorphological model of the Bovidae astragalus, with around 85% of good prediction based on 4 different environments: open habitats, lightly covered habitats, heavily covered habitats, and forests (Fig.1A, Hiard et al. in prep). Testing this method on a dataset containing all the families of extant ruminants, the result is still significant but drops to 73% with a lower robustness. Introducing old ruminant taxa from the Oligocene, the distribution becomes unpredictable. Testing the phylogenetic signal on the shape of the astragalus, based on a dataset of Cervidae and Bovidae, we obtain a replacement of 88%, proving a very high impact of the evolution of a clade on the shape of this bone.

The Geometric Morphometrics analysis based on the shape of the mandible provided good results on the phylogeny and ecology of fossil (until the Burdigalian) and extant ruminants. Within extant Pecora, Giraffidae differ by having an extremely elongated *diastema*. Cervidae are generally more slender than Bovidae, but an overlapping area between these two families groups together the most massive Cervidae and the most slender Bovidae (Mennecart et al. 2011, in press). Superimposing the phylogeny on the plots of the analysis permits us to prove (with a permutation test) that the phylogeny is supported by the graph, and the mandible shape possesses a strong phylogenetic signal (Fig. 1B).

Regarding the feeding habits, we used a canonical analysis, which defines *a posteriori* the possibility of easily separating feeding habits as a function of the mandible shape and to predefine some feeding characteristics of the mandible (Fig. 1C). A modularity test, using the minimum of covariance between the two anatomical complexes, completes the morphofunctionality of the mandible, depending on the feeding habit. Moreover, the well-diversified extant Bovidae show that an unambiguous trend from selective browser to grazer relates to the variation of these anatomical complexes. The terminal state of this trend shows the combination of a high hypsondonty index, an elongated molar row compared to the premolar row, an enlarged *corpus mandibulae*, a stockier mandible, and a more efficient lever arm of the mastication muscles (masseter and temporalis) that permits feeding on tough food such as grass and more efficient biomechanics of the jaw (Mennecart et al. in press). This trend is also roughly observed within non-Bovidae Pecora, but to a lesser extent. On the other hand, confident feeding category discrimination for fossil taxa cannot be clearly identified.



Figure 1. A. Results of the resubstitution and the Jacknife tests of the environmental and taxonomical prediction models based on the astragalus morphology. LDA: Linear Discriminant Analysis, QDA: Quadratic Discriminant Analysis, Rpart: recursive partitioning, SVM: Support Vector Machine. B. Phylogeny superimposed on the PCA of a geometric morphometrics analysis based on the mandible morphology of extant ruminant genera. Permutation test against the null hypothesis (no phylogenetic signal), with 10000 randomization rounds, provides a P-value inferior to 0.0001. C. Canonical analyses based on the feeding habit and the shape of the ruminant mandible

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From beachboys to river rafters – The sedimentary environment of the vertebrate tracksites of the autochtonous Triassic of the Aiguilles Rouges Massif (SW Switzerland)

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The autochthonous Triassic sediments of the Aiguilles Rouges Massif in SW Switzerland were last extensively studied by Amberger (1960). On the basis of lithological sections he concluded that the siliciclastic sequence unconformably overlying the Carboniferous/Permian basement was part of the Alpine Buntsandstein and were deposited in a shallow marine/sandy beach environment. Later on, Demathieu & Weidmann (1982) concluded that this unit was of Carnian age because of the presence of dinosaur footprints. This age and track assignment was challenged by several authors (e.g. Lockley & Meyer 2000). Most tracks, if not all, belong to indeterminate chirotheriids and dinosaur footprints are absent.

Reinterpretation of the main site at Vieux Emosson and the analysis of nearby newly discovered trackways reveal the presence of the ichnotaxa *Isochirotherium soergeli* and *Chirotherium barthi*. These ichnotaxa represent a "Chirothere assemblage" and indicate an older, Late Olenekian to Early Ladinian, age (Cavin et al. 2012) confirming earlier interpretations (Lockley and Meyer, 2000; Meyer & Thüring, 2002).

The present study focuses on detailed analysis of the sedimentary sequence of the Triassic between the Col du Jorat in the North to the Col del la Terasse in the South.

The sequence consists of a basal conglomerate that fines upward to medium- and coarse-grained sandstones with trough cross bedding, and capped by rippled surfaces with thin mudstones beds with mudcracks. The rippled surface at the top of the sandstone-dominated sequence is the main track level, as seen at the Vieux Emosson and Cascade d'Emaney localities. It is overlain by red and green mudstones interbedded with thin rippled sandstones. The latter show two additional trackbearing levels near the base. Consequent prospection have led to the discovery of eight new track localities between the Col du Jorat and the Col de la Terrasse during the field season 2012 confirming a recurrent track association that forms a megatracksite.

Fining upward sequences, truncated by channel-fills, texturally immature conglomerates, and unimodal paleocurrents indicate deposition in shallow bedload-dominated streams. Fine-grained facies are interpreted as floodplain and possibly playa lake deposits. The northwest paleoslope supports drainage into the Germanic Basin, and not to the Tethyan realm as postulated by others. Consequently the original idea of Amberger (1960) that these deposit form part of the "Buntsandstein" is corroborated by the present study, however the archosaurs were not beach boys but river rafters.

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Empirical 3D-models of Palaeozoic ammonoids and the ontogeny of septum- and chamber-volumes of three major ammonoid-clades

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Ammonoids belong to the cephalopods and are of a great importance in stratigraphy. Although they are well studied, some aspects of their palaeobiology and evolution are still unexplored. For example, empirical studies of changes in shell and chamber volume through ontogeny of the major clades have never been carried out. 3D-modelling offers new perspectives to provide new insights in their shell properties. The aims of our present work consist in documenting (1) volumetric growth of septa and phragmocone chambers in detail and (2) ontogenetic changes between major ammonoid-clades from the Palaeozoic.

This is achieved by 3D-reconstructions (see figure 1) based on actual specimens, which were subjected to grinding tomography. For those specimens, CT-scans cannot be used because of the insufficient contrast between the calcitic replacement shell and the carbonatic sediment matrix. Therefore, three specimens of three major clades have been investigated using grinding tomography: the Middle Devonian agoniatitid *Agoniatites clariondi*, the Middle Devonian anarcestid *Diallagites lenticulifer*, and the Early Carboniferous goniatitid *Goniatites multiliratus*. The sections were then traced manually for each fourth slice, and lastly processed for the 3D-reconstruction using VGstudiomax[®] 2.1, which allows direct volume calculations. The chamber volumes are plotted *versus* shell diameter, which is used as a proxy for growth while the septum volumes are plotted *versus* aperture height through the ontogeny of the respective specimen.

The obtained volume data allow both intra-specimen comparisons through ontogeny and inter-clade comparisons, i.e. through phylogeny. Further specimens from both older and younger ammonoid clades are planned to be investigated to provide more information on volumetric changes through ontogeny and phylogeny. Additionally, these first volumetric data provide the possibility to empirically test the existing mathematical models for neutral buoyancy of ammonoids.



Figure 1. 3D reconstructions of Agoniatites clariondi: complete (left) and clipped (right)

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Comparative skull anatomy of placodonts (Diapsida: Sauropterygia) using µCT scanning - implications for palaeobiogeography and palaeoecology

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Placodontia are a basal group of durophagous and often heavily armoured sauropterygian marine reptiles that inhabited shallow marine environments of the Tethys Ocean from the early Middle to the Late Triassic (e.g. Rieppel 2000). They are well known from Europe, especially Switzerland, Germany and Italy, and have recently been discovered in southern China, with four new taxa being described in the last twelve years (Li 2000; Li & Rieppel 2002; Jiang et al. 2008; Zhao et al. 2008). However, detailed phylogenetic and palaeoecologic analyses that go beyond the primary osteological descriptions have not yet been conducted for all of these new taxa.

As part of an on-going project to create a comprehensive phylogeny of the Placodontia, placodont skulls from both Europe and China were scanned using micro-computed tomography (μ CT). This exposed many important details that were previously obscured or unclear in previous descriptive works, such as braincase anatomy, as well as allowing the reconstruction of structures such as the endocranium and inner ear (e.g. Neenan & Scheyer in press; Fig. 1). The inclusion of a new skull from the middle Triassic of the Netherlands also sheds light on the origins of the clade, with implications for their dispersal and subsequent diversification throughout the Tethys.

These results are not only significant for the understanding of placodont relationships and dispersal but, due to the plesiomorphic position of Placodontia within Sauropterygia, also have implications for our understanding of sauropterygian palaeobiogeography as a whole.



Figure 1. Reconstructions from a skull of the placodont *Placodus gigas* as an example of what can be achieved with the use of µCT scanning. A, Braincase reconstruction, highlighting how elements that are usually obscured can be modeled. B, Virtual model of the endocranium (blue), inner ear (pink) and cranial nerves (yellow) in right lateral (top) and dorsal (bottom) views. C, Virtual model of the inner ear in right lateral (top left), caudal (top right) and dorsal (bottom) views. Modified from Neenan & Scheyer (in press).

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Stratigraphic Studies In The Sivas Basin (Central Anatolia, Turkey). 1- The Role Of The Charophytes.

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The Sivas Basin is one of the Central Anatolian Basins in Turkey which developed after the closure of the North Neotethys ocean in Late Cretaceous times. This basin mainly Cenozoic records the geodynamics of the collisional and post-collisional history of the Alpine belt in Central Anatolia. It covers the eastern and southeastern parts of the Kirsehir Massif to the North and the northern part of the Taurus belt to the South. It can be subdivided in several sub-basins which present rather different lithostratigraphic successions. However all include an alternation of marine and continental formations (with evaporites in some sub-basins) which interfinger together. Synsedimentary tectonic (especially the salt tectonics) and magmatic events led to a very complex tectono-lithostratigraphic successions. In such a context the precise knowledge of the chronology is of prime importance for the reconstitution of the imbricated paleogeographies and paleoenvironments. If the marine sequences (Paleocene-Eocene; Upper Oligocene-Lower Miocene) are rather well dated due to their fossiliferous facies it is not the case for the continental series in which only a few number of sites have been previously dated by different methods such as vertebrates in lacustrine layers (Uppermost Oligocene; Mid and Upper Miocene; Pliocene); spores and pollens in lignites (Middle Miocene); K/Ar in basaltic lavas (13 to 15 Ma). Despite these punctual well dated sites the main part of the thick (one to three km thick), continental sequences (including the evaporites) remained undated until the discovery of charophytes in lenses of lacustrine marls and limestones intercalated in the red clastics, or above the evaporites, in several sites over the western half of the basin. We present here preliminary results of a study of these charophytes.

The following assemblages have been found in several sites located in the Western part of the basin (Malak, Kabasakal, Apa), or in the central part (the others):

Malak: Rhabdochara praelangeri-major, Rh. stockmansi-major, Chara microcera, Sphaerochara hirmeri?, Nitellopsis sp., Gyrogona sp. (Rupelian-Chattian)

Kabasakal: Charites minutissima, Tolypella sp., Chara sp., Rhabdochara major?. (Lower Oligocene: Rupelian)

Apa: Chara notata, Sphaerochara hirmeri gr., Lychnothamnus sp., Rectangulochara sp. (Lower to Middle Miocene according to the other data such as K/Ar age at 13Ma)

Egribucak: Lychnothamnus (Stephanochara) ungeri-rochettiana gr., Rhabdochara sp. (Upper Oligocene)

Emirhan: Nitellopsis (Tectochara) meriani gr., Lychnothamnus (Stephanochara) cavalieri, Chara notata, Sphaerochara hirmeri (Upper Oligocene-Lower Miocene)

Karayün-1: Lychnothamnus (Stephanochara) cavalieri, Chara notata, Sphaerochara hirmeri gr., Lychnothamnus (Stephanochara) ungeri-rochettiana gr. (Upper Oligocene-Lower Miocene)

Karayün-2: Charites minutissima, Lychnothamnus (Stephanochara) cavalieri, Nitellopsis (Tectochara) meriani gr., Chara notata, Sphaerochara hirmeri gr., Lychnothamnus (Stephanochara) ungeri-rochettiana gr. (Upper Oligocene-Lower Miocene) **Karayün-3**: Chara notata, Ch. praeberdotensis-berdotensis. (Burdigalian)

Inkonak-1: *Chara microcera-notata* gr., *Sphaerochara hirmeri* gr., *Tolypella* sp., *Rabdochara major* (Lower Oligocene) **Inkonak-2**: *Nitellopsis meriani*, *Lychnothamnus ungeri* ?.

Discussion. In the absence of a Tertiary calibrated reference section for Central Anatolia the ages are tentatively attributed here on the basis of the western European zonation for the charophytes. These ages are generally in more or less good agreement with other chronological data (K/Ar ages and biochronology), but an uncertainty subsists in some cases. For instance the Notata zone covers the uppermost Oligocene and the Lower Miocene (perhaps up to Langhian). This is not precise enough for dating the synsedimentary events such as the tectonic events (salt tectonics), nevertheless these data show that an important period of deformation occured before the Notata zone, which mean during the Upper Oligocene.



Evenements climatiques MMCO : Middle Mocene Gimatic Optims TE: Terminal Ecose Event MECO : Middle Ecose Gimatic Optimum

(modifié d'après Zachos et al. 2001, Pälike & Hilgen 2009)

Symposium 8: Palaeontology - in memoriam of Jean-Pierre Berger

Symposium 8: Palaeontology – in memoriam of Jean-Pierre Berger

8.14

Taxonomy and phylogeny of the turtle Tropidemys langii Rütimeyer, 1873 based on new specimens from the Kimmeridgian of the Swiss Jura Mountains

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The fossil turtle Tropidemys langii is a representative of Plesiochelyidae, a traditionally recognized group of Late Jurassic turtles (Joyce 2007) diagnosed by the presence of three cervical scutes (Fig. 1) and adapted to life in the sea. Tropidemys langii was only known from fossilized carapaces and, possibly, plastra from Europe, most notably the famous 'Solothurn Turtle Limestone' of Switzerland (Rütmeyer 1873; Bräm 1965; Meyer 1994). Due to the sparse fossil record of Tropidemys langii, several questions concerning its taxonomy and phylogeny have remained unanswered.

Here, new material of Tropidemys langii is reported from the Kimmeridgian of the region of Porrentruy, Canton Jura, Switzerland. In addition to three well-preserved carapaces (Fig. 1), associated plastra and limb bones (humerus and femur) are described for the first time. The type specimen of 'Tropidemys valanginiensis' and 'Pelobatochelys blakii' lack diagnostic characters, but can nevertheless be referred to Tropidemys (Püntener et al., submitted). A potential extension of the lineage into the Early Cretaceous is uncertain, however, as the type locality of 'Tropidemys valanginiensis' is dubious. A cladistic analysis shows that Tropidemys langii is sister to Plesiochelys solodurensis, thereby tentatively confirming for the first time the monophyly of Plesiochelyidae using cladistic arguments (Püntener et al., submitted).



Figure 1. Specimen CRE985-1 of Tropidemys langii (Kimmeridgian, Porrentruy, Switzerland). Carapace in dorsal view. A, photograph; B, illustrative drawing showing bone sutures (zigzag line); scute sulci (double line); the preserved outline of the carapace (thick line); and fractures (thin line). Abbreviations: co, costal; ne, neural; nu, nuchal; per, peripheral; sp, suprapygal; CE, cervical; MA, marginal; PL, pleural; VE, vertebral. Photograph by Palaeontology A16.

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New insights on the stratigraphic distribution and phylogeny of foraminifers from the study of a Panthalassan terrane

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On account of their abundance, diversity, rapid evolution, wide distribution, and ease of use and recovery in both modern and fossil environments, foraminifers are routinely used to reconstruct environmental changes. Excellent markers of decline and diversification through time, they are also widely used as biostratigraphic indicators. Multiple unknowns, however, still remain as far as their phylogeny, global distribution over time, and ability to survive and recover from major biological crises is concerned.

During the Triassic, the earth was divided into two distinct marine worlds, namely the Tethyan and the Panthalassan domains, which connections were limited. Whereas the foraminiferal distribution has been thoroughly studied in the Tethys, only few investigations have been lead in the Panthalassa, where several million years of the foraminiferal evolution are unknown. Our study of the Late Triassic Wallowa carbonate platform (Wallowa Terrane, NW USA) of Panthalassan affinity has provided significant contributions to the understanding of the global diversity, distribution, and evolution of foraminifers.

In the Panthalassa, the stratigraphic distribution of foraminifers differs significantly from that of the Tethys. As indicated by a stratigraphic shift of several million years, Late Triassic foraminifers were not able to disperse easily across the open sea and have evolved independently in the two domains. The finding of numerous missing links reveals that a large part of the foraminiferal evolution occurred in this disregarded oceanic domain and greatly improves previous phylogenetic frames. As suggested by the strong similarities existing between Late Triassic Panthalassan foraminifers and complex Early Jurassic Tethyan foraminifers, the Panthalassa was probably a refuge for foraminifers during the Triassic-Jurassic biotic crisis.

These discoveries have important implications for the use of foraminifers in biostratigraphy, paleobiogeography, taxonomy, and molecular phylogeny. Further studies of the spatial and temporal evolution of Panthalassan foraminifers should provide a solid basis to understand processes controlling the foraminiferal speciation, diversification, extinction, dispersion, and recovery before, during, and after major extinction events.

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Palaeogeography and evolution of the Triassic basal ray-finned fish *Saurichthys*

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Saurichthys was a Triassic lower actinopterygian (ray-finned fish) with a global distribution. It is distinguished from contemporaneous fishes by its garfish-like body shape – in fact, *Saurichthys* was the first actinopterygian that developed such a highly derived bauplan. Its elongated rostrum and body and specialised squamation pattern enabled *Saurichthys* to become one of the top predators among Triassic fishes, both in marine and freshwater environments. The specialized morphology of *Saurichthys* makes even fragmentary material easily identifiable at least at the genus level, thereby reducing the risk of being overlooked in the field and in collections. Hence, the fossil record of *Saurichthys* can be considered as wellknown. We review the global fossil record of *Saurichthys* and use it for a case study of trends in morphological adaptations as well as changes in palaeogeographic distribution and diversity dynamics of Triassic fishes. The results are compared to patterns observed among other osteichthyans (bony fishes) during the Triassic, especially in the context of recovery after the end-Permian mass extinction. 207

Embryos in Deep Time - Palaeontology and the Study of the Evolution of Biological Development

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If the expanded evolutionary synthesis places development as a key subject, then the role of palaeontology to address developmental evolution becomes a central issue. Palaeohistology and the occasional embryos or growth series provide means of examination of what is otherwise rare: the direct study of development in fossil vertebrates. A web-database provides a bibliographic listing covering all major groups of vertebrates (www.developmental-palaeontology.net). Fossil phenotypes provide an indirect but rich source of data for developmental evolution. Collaborative works in my lab provide examples of different approaches. The resolution of the homologies of the interparietal bone and its dual embryonic tissue origin would not be possible without early synapsid (stem-mammals) data. The study of palaeohistology in fossil deer demonstrates how gigantic and dwarf forms grew. Fossils can expand the morphospace of a clade which otherwise would be considered to be biased negatively by some developmental pattern of that clade. Examples can be found in the size and dental morphological range of fossil marsupials. Studies of development also provide models and predictions which serve to interpret the fossil record. This is exemplified by the study of the potential molecular bases for the morphological diversification of a ray-finned fish from the middle Triassic of Switzerland. Another example is the application of the 'inhibitory cascade model' to predict molar proportions and its examination in a large radiation of extinct and endemic ungulate mammals from South America. Finally, palaeontology together with comparative morphology can provide the questions that developmental studies should address. This is exemplified by the investigation of the apparent extradigit in talpid moles among mammals. The partial preservation of fossils and the impossibility of performing experiments on them put major limits on what can be achieved in developmental palaeontology. But the direct evidence fossils provide of development in geological time make them a central subject of an expanded evolutionary synthesis.

Taphonomy and palaeoecology of the green pentamerid Devonian brachiopods from the Aferdou el Mrakib, eastern Anti-Atlas, Morocco

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On the large reef mound Aferdou El Mrakib in the Maïder Basin (Anti-Atlas, Morocco), thick-shelled pentamerids occur in a locally high abundance. Like *Stringocephalus* from shallow water limestones of Germany, these Moroccan brachiopods of the genera *Devonogypa* and *Ivdelinia* often display greenish shells. By EDX analyses of the shells, it turned out that the colour was caused by impurities of Fe^{2+} -ions. Their concentration varies strongly between the samples, indicating that the colour is less dependent on the iron-concentration than on shell thickness. Indeed, only the thickest parts of the shells appear green. There is also some indication that the Fe-content increases towards a deeper shell layer (further away from the surface).

Additionally, we examined the quality and spatial distribution of sublethal injuries in over 200 specimens of *Devonogypa* and *Ivdelinia* in order to find indications for their origin. The results support the hypotheses that (1) the injuries had several causes, (2) some of which were inflicted by predators, probably cephalopods, and (3) many fractures might have been caused by the brachiopod shells hitting each other in dense populations in agitated water. Numerous such dense clusters of these pentamerid brachiopods were examined in the field. They consisted of the association of members of both brachiopod genera or of only one taxon, occasionally accompanied by other brachiopods, some trilobites, corals and a few other groups.

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Alpha diversity and palaeoecology of invertebrate associations of the Early Devonian in the Moroccan Anti-Atlas

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The Moroccan Anti-Atlas is famous for its highly fossiliferous and well-exposed Palaeozoic rocks. These include Lower Devonian outcrops in the Maïder and the Tafilalt of the eastern Anti-Atlas. The superb exposures, local abundance of fossils and their sometimes excellent preservation provide the possibility of studying Early Devonian faunal associations in their stratigraphical context.

A rich fauna with well-preserved macrofossils of Pragian age (411- 407 Ma) and five more faunas of different Early Devonian ages (Lochkovian-Early Emsian) are under investigation and will be included in a study on alpha-diversity. The fossils were collected from the south-west of Jebel Ouaoufilal in the Tafilalt.

The taxonomic composition of every fauna has been examined and all taxa grouped according to their habitat and feeding behaviour. In combination with abundance data, this information will be evaluated with respect to palaeoecology. First analyses of the data show an increase in alpha diversity from the Silurian/ Devonian boundary to the early Emsian.

Orthoconic nautiloids are abundant in all faunas included in this study, but they become more diverse during the Pragian. The diversity of bivalves gradually increases during the Lochkovian and is highest during the Early Emsian. Other benthic organisms such as gastropods and brachiopods appear during the Lochkovian and have high diversities in the Pragian and Lower Emsian. Tabulate and rugose corals first occur in the Pragian and Emsian sediments. Sclerobionts colonizing the nautiloid shells include auloporid corals, cornulitids and a new hederelloid (?phoronid) genus.

The increase in species diversity and the change in species composition reflect a regional environmental change during the Early Devonian. In particular, the increase in benthic species leads to the supposition that a steady rise of oxygen content near the seafloor occurred in combination with a sea-level fall. This is in accordance with existing Devonian sea level curves (Kaufmann 1998). Further investigations may reveal relationships with the end-*pesavis* Event at the Lochkovian/ Pragian boundary, and the corresponding regional regression evident in eastern Australia (Talent *et al.* 1993).

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Comparing intraspecific variability of ammonoids

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Heritable phenotypic variation is usually thought to be the raw material for evolution and natural selection. Knowledge of the intraspecific variability of any taxon is therefore essential for systematics and diversity studies. Heritable variation is, however, hard to separate from morphological variation resulting from a plastic response to the environment, especially in extinct groups. For instance, a large part of the intraspecific variability in shelled molluscs could be caused by differences in growth rates, which could also explain certain recurrent patterns in intraspecific variability in the shells of coiled mollusc shells. Probably because of a low amount of specimens, poor preservation of study materials and/ or the lack of time and/ or motivation, intraspecific morphological variability has been poorly studied in ammonoids (as it is the case in most other groups of fossil and extant organisms). In ammonoids, this might lead to biases and problems such as, e.g., overlooking the influence of coiling on the intraspecific variability, oversplitting of taxa, and insufficient knowledge of taxa.

We have finished first studies on variability in relation to coiling with loosely coiled ammonoids of the genera *Anetoceras* and *Erbenoceras* from the early Emsian (Early Devonian) of Morocco and could demonstrate high degrees of intraspecific variability in both genera. We compared the morphometric data of the Moroccan material with published specimens of the same age worldwide. This led to the conclusion that the current amount of valid ammonoid species of the studied interval (> 20) is not supported by differences in the classical dimensional shell characters. Since the suture lines of these ammonoids are extremely simple, they are insufficient to base species exclusively on their suture line courses. This led to the conclusion that the existing wealth of species with loosely coiled shells has originated from oversplitting and has no profound scientific base. Estimates of ammonoid diversity are thus probably too high for the early Emsian.

In the past decade, we have collected and measured many Palaeozoic ammonoids, predominantly of Early and Middle Devonian age, but also of Late Devonian and Carboniferous age. These included species that have the advantages that several of which originated more or less close to the origin of the respective clade and that several show traces of ancestral characters especially in the early parts of ontogeny. An important plesiomorphic trait is the loose coiling, which is seen in several early Emsian ammonoid species. Our material of these very early forms led to the hypotheses that (1) intraspecific variability (at least of some characters) is intimately linked with coiling and therefore, (2) earlier forms are more variable than more derived forms with more tightly coiled shells.

To test the relation of the degree of intraspecific variability of conch parameters with coiling, we measured additional datasets of ammonoids from the late Emsian, the Eifelian, and the Carboniferous; the representatives of which have more or less tightly coiled shells. We used the coefficient of variation as a measure of the range of variability. Preliminary tests appear to support the two hypotheses, but further tests are needed before drawing a conclusion.

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P 8.3

New coastline morphology in Western France during the Miocene

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Classically, no Miocene deposits are recorded in the Poitou-Charentes region (Central Western France). Previous authors suggested the existence of a hill forming a peninsula during high sea level periods (Aquitanian, Burdigalian, Langhian and Serravallian) in this area. This relief seems to be highly linked to the general Alpin orogen and the formation of the "Seuil du Poitou". However, the absence of such sediments could also be linked to secondary erosion of them due to a late uplift between the Paris Basin and the Aquitaine Basin.

A first outcrop lies directly on a Cenomanian reefs, it is small and 6 meters thick. It is located in the Aix island (Charente Maritime, France). Sediments composing the outcrop are layered and slightly tilted following Cretaceous deposits. A long-ranging unconformity separates the Cretaceous from the Tertiary layers, the Cretaceous being highly karstified. The base of the Tertiary deposits is mainly composed of sandstones with some thin marly layers (probably paleosoils). On the top of the outcrop, a very dark marly layer finely litified, contains marine fossils: calcareous dinocysts and foraminifera. The dinocysts are not described in the literature and probably belong to a new species of *Alasphaera*. A preliminary analysis of the foraminifera (possibly a *Dentoglobigerina langhiana*) gives a Miocene age to these deposits.

A second outcrop consists of several fissure fillings documented in a Coniacian and Santonian quarry from Grezac (Charente Maritime, France). The fossiliferous assemblage from these pockets is peculiar: it comprises Cretaceous varanid and shark teeth, Miocene shark teeth (such as *Megalosuchus megalodon, Cosmopolitodus hastalis*, and *Hexanchus primigenius*), marine (dolphin and manatee) and terrestrial Miocene mammals (*Micromeryx* sp., Suoidea, Proboscidea, Carnivora, etc.). Our present hypothesis is that these fissures were Miocene coastal caves where terrestrial and marine fauna was mixed by various taphonomic processes; the Cretaceous fauna deriving from the dissolution of the karsts (similarly to the Burdigalian deposits in Jurassic limestone from La petite Morée in Glovelier, Switzerland). The presence of *Micromeryx* in this locality gives an age comprise between MN5 and MN11. These deposits could correspond to the Serravallian transgression.

The description of these new outcrops could change the datation of a late uplift of the "Seuil du Poitou" during the Late Miocene and the French Miocene coastline shape. On both localities, further investigations will be done to precise the age and the environment based on micro-, nannofossils, and the sedimentology.

P 8.4

Variability of the dental morphology in marine crocodilians (Thalattosuchia) from the Kimmeridgian of Ajoie (Jura, Switzerland)

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Discoveries of Thalattosuchia (Crocodylia, Mesosuchia) are common in the Mesozoic, notably in the Late Jurassic of Europe. During the nineteenth and the beginning of the twentieth centuries, many species or genera were erected. Due to the dental renewal in crocodilians, the most frequent remains are isolated teeth. For example, *Machimosaurus hugii* (Teleosauridae) was originally based solely upon isolated teeth. In the nineties, Vignaud (1995, 1997) established a synthesis of thalattosuchian dental morphotypes and associated them to known species. Between 2000 and 2009, more than 500 isolated teeth and about 10 jaw remains of Thalattosuchia were discovered in the Kimmeridgian of Ajoie (Canton Jura, Switzerland). They have been excavated during controlled excavations on the future path of the A16 motorway (Transjurane). Those remains have been initially ascribed to two genera of Teleosauridae (*Steneosaurus* and *Machimosaurus*) and to one genus of Metriorhynchidae (*Dakosaurus*).

In this work, dental morphotypes were defined based upon morphology, ornamentation and size of teeth, in order to identify the thalattosuchian fauna from Ajoie. In order to complete the dataset, additional material of thalattosuchians from the Kimmeridgian of Swiss and German localities was included. Four dental morphotypes, one including two sub-morphotypes, were defined. By comparison with the literature, especially Vignaud's morphotypes (1995, 1997), they were ascribed to four genera represented by five species: two genera of Teleosauridae (*Steneosaurus*, including two species, and *Machimosaurus*) and two of Metriorhynchidae (*Metriorhynchus* and *Dakosaurus*) (Table 1). Furthermore, a bivariate synthesis diagram "height/diameter" grouping all the taxa was compared to the dental morphotypes defined by Massare (1987). It indicates that the dental morphotypes from Ajoie correspond to five feeding guilds with five types of preferred prey. This shows that coexistence of the five species (*Steneosaurus* cf. *jugleri*, *S*. cf. *bouchardi*, *Machimosaurus* sp., *Metriorhynchus* sp., *Dakosaurus* maximus) in an open coastal marine environment was possible. In addition, there is a correlation between the distribution of thalattosuchian teeth and sea level variations, the metriorhynchids matching with transgression phases.

Isolated teeth of Thalattosuchia are useful to estimate the palaeobiodiversity of these marine crocodilians in a deposit. They are numerous and have more discriminant characters than postcranial elements for the identification at the genus level. However, it is tricky to assign isolated teeth to particular species. Results gained by this work may be used as reference for the identification of future discoveries of thalattosuchian teeth in the Kimmeridgian of Europe. Finally, an assemblage of isolated thalattosuchian teeth can contribute to the reconstruction of marine palaeoenvironments.

	Morphotype 1		Morphotype 2	Morphotype 3	Morphotype 4
	Sub-morphotype 1A	Sub-morphotype 1B			
Family	Teleosauridae			Metriorhynchidae	
Genera	Steneosaurus	Steneosaurus	Machimosaurus	Metriorhynchus	Dakosaurus
Species	cf. jugleri	cf. bouchardi	sp.	sp.	maximus
Number of isolat- ed teeth	355		74	24	1
Percent of isolat- ed teeth	78.19%		16.30%	5.29%	0.22%
Nature of the presence in Ajoie	Autochthonous	Autochthonous	Autochthonous	Parautochthonous Autochthonous?	Allochthonous?
Habitat	Coastal	Coastal	Coastal Pelagic?	Pelagic Coastal?	Pelagic
Type of prehen- sion	Piercing	General	Crushing	Piercing/Cutting	Cutting
Estimated size	~ 3 meters	4 - 5 meters	Up to 9 meters	~ 4 meters	>4 meters

Table 1: Synthesis of the thalattosuchian dental morphotypes from the Kimmeridgian of Ajoie (Jura): systematics, distribution and palaeoecology.

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Quaternary environments: landscapes, climate, ecosystems, human activity during the past 2.6 million years

Olivier Heiri, Christine Pümpin

Swiss Society for Quaternary Research (CH-QUAT)

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- 9.3 Hippe K., Ivy-Ochs S., Kober F., Zasadni J., Wieler R., Wacker L., Kubik P., Schlüchter C.: Chronology of deglaciation and Lateglacial ice flow reorganization in the Gotthard Pass area, Central Swiss Alps, based on cosmogenic 10Be and in situ 14C
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- P 9.8 Schälli L., Schnellmann M., Fischer U. H., Haeberli W.: Solid-rock surface model of the Rhine and Seez valley
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Swiss aquatic ecosystems in medieval times: A combined archaeozoological and biomolecular approach

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This interdisciplinary investigation focusses on the evaluation of archaeological fish remains to receive information about the anthropogenic influence on aquatic ecosystems. Fish bone material from 22 sites in Switzerland, covering a time span from the 9th to 16th centuries, has been analysed. Besides the use of classical archaeozoological methods which evaluate osteomorphological criteria, certain fish remains were selected for ZooMS (Zooarchaeology by Mass spectrometry) and stable isotope analysis. The combination of those three methods can inform us about the composition of the fish stocks and the ecological conditions in their habitats.

In particular, this interdisciplinary approach enables new perspectives for the identification of species of the carp family (*Cyprinidae*). Cyprinids are well suited as bioindicators, but are hard to differentiate osteomorphologically. In this case we use ZooMS for species identification. The analysis of peptide masses in fish bone collagen creates a molecular fingerprint (Richter et al. 2011). Until now 286 cyprinid bones have been analysed (Hounslow 2011). The comparison of the medieval fish species spectrum constructed by classical archaeozoological analysis with the preliminary results of the ZooMS analysis revealed a refinement in species composition. The numbers of cyprinids living in eutrophic water bodies, such as tench (*Tinca tinca*) and bream (*Abramis brama*), has increased.

In addition to species identification, we try to find out whether effects of anthropogenic activities on water quality can be assessed through carbon, nitrate and sulphur stable isotope analysis. While sulphur isotope analysis seems to represent the tool best suited to detect the onset of "industrial" activities in water, nitrogen has potential for documenting eutrophication as a result of organic waste disposal (Van Neer et al, 2009). In a next stage of the research project, stable isotope analysis will be conducted on fish bone samples to assess for possible influences and impacts on medieval aquatic ecosystems.

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Wauwilermoos, located at the north-western rim of the former Reuss-Glacial, provides a range of complex postglacial and colluvial sediments. The profile Mattenhof in a lacustrine terrace of the former Lake Wauwil, which periodically flooded the space between the two ridges of the terminal LGM moraines, consists of sediments spanning the period since the LGM until current times. From bottom to top this profile consists of 5 major sedimentary units: a) two layers of grey, middle-grained sand with frost wedges on tops, identified as proglacial sandur, b) reddish-brownish layers of medium- to coarse-grained sand and gravels laminated with sand and silt, identified as a lacustrine terrace sequence; it is cut by an erosional discordance, c) lower colluvium containing mixed sand, silt, clay and gravels, intermittent laminated, also cut by an erosional discordance brought out by a stone line, d) upper colluvium made of very compact mixed layers of sand, silt, riddled with clay nodules and gravels, e) black mixture of sand and peat, with irregular bottom and downward eversions penetrating into the underlying layers, which might have developed due to tree roots or diggings, in the recent past.

While attempting dating of this sedimentary sequence, discrepancies of the resulting burial ages were observed depending whether small aliquots (SA), large aliquots (LA) or single grains (SG) were used to measure the output of the optically stimulated luminescence (OSL). While SG measurements yielded age estimates supporting the palaeo-environmental and archaeological expectations, revealed e.g. by Nielsen (2009), the aliquot measurements failed, with SA yielding the worst results. In addition, the wide spread of the OSL results made the application of age modelling problematic and age components that could not be supported by the geological records, appeared in the statistical calculation. Application of the new OSL approach, first described by Wang et al. (2012), significantly improved the final results of the OSL dating, indicating that sandur with the frost wedges may represent the intra-LGM oscillation and ice recession. The overlying sands and gravels were deposited during the subsequent lake phase coinciding with the second LGM ice advance (Starnberger et al. 2012) and the build-up of the West-Mauensee moraine. The overlying colluvial beds are related to human occupation during the Younger Dryas and Mid-Holocene. The age of the upper part of the profile is well constrained by estimates obtained from archaeological artefacts and radiocarbon dating of a neighbouring profile Wauwil Obermoos (Nielsen 2009).

This contribution presents the results of the application of both approaches of evaluation of the OSL data – the traditional one and that of Wang et al. (2012) - and discusses the consequences for understanding of the LGM palaeo-environmental changes.

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Chronology of deglaciation and Lateglacial ice flow reorganization in the Gotthard Pass area, Central Swiss Alps, based on cosmogenic ¹⁰Be and in situ ¹⁴C

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The onset of the Alpine Lateglacial is marked by massive downwasting of the large piedmont glaciers in the Alpine foreland due to the beginning of gradual climate warming after the Last Glacial Maximum (LGM). While the chronology of ice decay and glacier readvance is relatively well known for the foreland and the inner Alpine valleys, the timing of the breakdown of the large high Alpine ice cap(s) is less well constrained. To improve the understanding of the effect of climate change on the high Alpine mountain glaciers, we have performed surface exposure dating using cosmogenic ¹⁰Be and *in situ* ¹⁴C analysis of bedrock surfaces on the Central Alpine Gotthard Pass, Switzerland.

Dating was combined with detailed mapping of glacial erosional features (e.g. crescentic gouges, glacial striae). These show a progressive downwasting of ice from the maximum LGM ice volume and a gradual reorganization of the ice flow pattern with a southward migration of the ice divide. Although the decay of the LGM ice can be identified from field evidence, it was not recorded by the bedrock exposure ages. The oldest exposure ages obtained by ¹⁰Be (~16-15 ky; snow corrected) are interpreted to reflect the decay of the large Gschnitz glacier system, which post-dates deglaciation of the foreland by a few thousand years. In agreement with published ages from other Alpine passes, these data support the concept of large transection glaciers that persisted in the high Alps after the breakdown of the LGM ice masses and possibly decayed as late as the onset of the Bølling warming. Our results indicate that the timing of glacier recession and climate change in the high Alpine regions cannot easily be correlated with the chronology obtained for the Alpine lowlands.

A younger phase of local glacier readvance is evident from the erosional features and is consistent with another group of ¹⁰Be exposure ages of ~12-13 ky. These are correlated with the decay of glaciers associated with the Younger Dryas Egesen stadial. Erosional markers and the distribution of exposure ages consistently imply that Egesen glaciers were of comparatively small volume and were following a topographically controlled paleoflow pattern. Dating of a boulder close to pass elevation that was probably deposited during the late stage of glacier readvance gives a minimum age of ~11 ky for final deglaciation by the beginning of the Holocene. *In situ* ¹⁴C data are overall in good agreement with the ¹⁰Be ages. This consistency excludes the presence of significant glacial ice (including non-erosive ice patches) for any time on Gotthard Pass during the Holocene and points to a continuous exposure of the pass area since the end of the Younger Dryas. From the combination of both nuclides, we were able to evaluate the necessity of a snow shielding correction and gained detailed constraints on the amount of Holocene snow cover for each sampling site.

The application of optically stimulated luminescence to overdeepened valleys in northern Switzerland

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Overdeepened valleys and basins are commonly found below the present landscape surface in the North of the Alps, and the major control for their development is ascribed to glacial processes during the Quaternary. The extent of these troughs and their sedimentary fillings is an important aspect of applied geology with regard to the geotechnics of deep foundations and tunnelling, and groundwater resource management. Moreover, the sites under investigation for the installation of deep geological repositories for radioactive waste are located in the vicinity of some of these troughs. With the need for them to remain stable for up to 1 Ma, both the timing and nature of the overdeepening processes are being investigated.

One aspect of this investigation is the application of optically stimulated luminescence (OSL) dating to the filling of the valleys to at least identify a minimum age for their formation. This presents a considerable challenge as the valleys are the result of more than one glacial cycle and so a dating method is required that extends beyond 200 ka. OSL dating offers this potential and can be applied to sedimentary deposits to identify the last time they saw light and so, effectively, the age they were buried.

A variety of OSL protocols can be applied to both quartz and feldspar grains, which act as luminescence dosimeters. The methods are constantly developed in order to improve their reliability and extend the age range. Several of these methods have been applied to deposits in Switzerland in order to identify the best approach to dating the infilling sediment of the overdeepened valleys. Some have been more successful than others, and the results of these are being used to determine how future sampling campaigns can be optimised. Work is also being done on the properties of the different mineral and grain-size fractions in the sediments available, in order to identify where the potential lays to extend the age range and reliability of the method. An overview of the work so far will be given, as well as an outlook on future investigations.

Paleoglacier chronology of the southwestern Black Sea Region

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Information of moisture transport during the cold periods and thus atmospheric circulation patterns during extreme climate conditions can be gathered by detecting glacier oscillations. As mid-latitude mountains often act as a weather divide, the comparison of timing and magnitude of the glacier oscillations in both sides of the divide can directly be correlated to the changes in circulation system. The orography of the Eastern Black Sea Mountains, located in the southwestern Black Sea region, forms a barrier to atmospheric circulation. In order to glean information on the change in circulation patterns during the Last Glacial cycle in this region, we studied the glacial oscillations in two valleys located to the north and the south of the weather divide.

The magnitude and chronology of these oscillations were determined by mapping different glacier advances and surface exposure dating of erratic boulders. Our first results show that there may be a difference between north and south of the weather divide, based on the volume and timing of maximum extent of the glaciers in these two valleys. The glacial chronology reveals an earlier stage before MIS-2 during which the moisture seems to dominantly be transported from south to north causing more extensive glaciations in the south. In contrast during the MIS-2, the direction of moisture transport should have changed and as a result, the glaciers should have advanced to lower altitudes in the north.

9.6

An 'Older Little Ice Age' ~3 kyr ago? Evidence from the Steingletscher, central Swiss Alps

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The 'Little Ice Age' (LIA, 1300-1860 AD) has been identified in many climate records in the Northern Hemisphere and is widely seen as the culmination of a multi-millennia cooling trend throughout the middle and late Holocene. This cooling trend is commonly related to the astronomical forcing represented by decreasing northern summer insolation. Less is known about the extent and duration of LIA-type cold-excursions earlier in the Holocene, mostly due to missing historical evidence and low-resolution climate records.

Based on precise cosmogenic ¹⁰Be surface exposure dating, we here present surveys of Holocene fluctuations of Steingletscher, central Swiss Alps (46°N), which is highly sensitive to regional climate changes and in particular, to summer temperature variations. Our results show that the most extensive Holocene glacier culminations in the Alps occurred during the earliest Holocene. No moraines are preserved from the mid-Holocene, consistent with the scenario of small glaciers during this time. However, we dated moraine fragments close to the LIA moraines to the period between ~3.2 to 2.8 kyr ago, indicating LIA-type climate conditions as early as 3 kyr ago. This finding from the Steingletscher is in agreement with our record from Tsijiore Nuove in the Western Alps, and also with unpublished moraine records from the Western US as well as with existing glacier studies in Alaska, British Columbia and Greenland. Beyond, north Atlantic bottom water temperature records indicate an abrupt, 'LIA' level cold excursion around this time. Taken together, we discuss this 'older LIA' phenomenon in a hemispheric climate context, challenging the view that Holocene climate was quasi-continuously cooling over several millennia prior to the LIA cold peak.

A model-data comparison of Holocene mountain vegetation dynamics in the Bernese Alps, Switzerland

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Treeline ecosystems are highly sensitive to environmental change, because trees grow at their lower limit of thermal tolerance (Körner 1999). Climatic shifts or disturbance and land use can alter the elevation and species composition of the vegetation at treeline. With an expected temperature rise of 2.7 - 4.8 °C by the end of this century (CH2011 2011) and increasing land abandonment in the Swiss Alps, the treeline will shift upwards. Rates and extent as well as reaction of individual tree species to the different triggers are still largely unknown. To disentangle the effects of climate and human land use on mountain forests, we combine vegetation and climate records from sedimentary archives with a climate and disturbance driven dynamic vegetation model.

We present new pollen and macrofossil-inferred reconstructions of Holocene vegetation from a series of lakes at, above and below the present treeline in the Northwestern Swiss Alps, which span the entire Holocene.

Analyses of pollen and plant macrofossils show that during the rapid warming at the onset of the Holocene treeline reached the first site at 1381 m a.s.l. within 100 years (ca. 11,400 cal BP). The second site at 2065 m a.s.l. however, was unforested until 1700 years later (ca. 9,700 cal BP), even though reconstructed summer temperatures were sufficient for forest growth (Heiri et al. 2003). We use LandClim, a dynamic vegetation model to explore the effects of different climatic scenarios (e.g. increased seasonality or severe frosts) on the subalpine forest.

The model-data comparison shows that the vegetation at the treeline was in equilibrium with climate until humans started to use the alpine meadows as pasture around 6500 cal. yr BP. The highest position of treeline in the Northwestern Swiss Alps was around 2300 m a.s.l. in the Holocene, ca. 300 m higher than during the 20th century (Berthel et al. 2012). Paleovegetational and modeling results agree well with archaeological remains from Schnidejoch, a pass is in the study region (Grosjean et al. 2007, Hafner 2009). During the Bronze Age, mountain forests were repeatedly cleared to expand pastures and finally treeline reached its present position in the Middle Ages. Cross-correlation analysis shows that the expansion of *Picea abies* and the demise of *Abies alba* was strongly supported by human fires and animal grazing since the Neolithic. We hypothesize that future climate change and land abandonment may lead to forest compositions and positions similar to those in the mid-Holocene. Warmer conditions, less moisture availability and/or the decline of land use may disrupt the current monospecific *Picea abies* stands and promote *Abies alba, Pinus cembra* and *Larix decidua* up to at least 2300 m a.s.l.

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Die Fundstelle "Abri Unterkobel". Ein wichtiges siedlungs- und landschaftsgeschichtliches Archiv im St. Galler Rheintal.

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Die archäologische Fundstelle "Abri Unterkobel" liegt am der Westseite des Alpenrheintales, auf dem Gebiet der Gemeinde Oberriet. Die archäologischen Schichten befinden sich unterhalb einer am Fuss leicht überhängenden, etwa 120 m hohen Felswand, die einen witterungsgeschützten Abri bildet. Dieser prähistorische Siedlungsplatz liegt ca. 30 m über der heutigen Talsohle, auf einer Höhe von 445 m.ü.M.

Die Fundstelle wurde im Winter 2011 wurden bei Baggerarbeiten, im Gelände der Bauschuttdeponie Unterkobel angeschnitten und im Frühjahr der Kantonsarchäologie St. Gallen gemeldet. Vom Juli 2011bis Juni 2012 konnte im zentralen Bereich der Abrifundstellen eine Ausgrabung durchgeführt werden, anschliessend wurde die Fundstelle mit Bauschutt überdeckt und ist nicht mehr zugänglich.

Insgesamt wurde auf einer Höhe von etwa 4.5 m eine Abfolge von archäologischen Schichten ausgegraben und dokumentiert. Die Besiedlung der Fundstelle beginnt im Frühmesolithikum und dauert bis in römische Zeit. Eine erste Serie von Radiokarbondatierungen ergaben Alter zwischen 9230 ± 45 C14 BP und 2145 ± 35 C14BP. Diese Datierungen entsprechen den in den Fundschichten gefundenen Artefakten. Im Fundmaterial ist das Mesolithikum, das Neolithikum und die Bronzezeit besonders gut vertreten, Spuren einer eisenzeitlichen und römischen Begehung des Abri sind ebenfalls vorhanden.

Über die ganze Höhe der Fundschichten sind eine Vielzahl von gut erhaltenen Feuerstellen sowie dazu gehörende Ascheund Holzkohlepakete vorhanden. Der Grossteil der Feuerstellen sind einfache, muldenförmige Strukturen, die eine stark brandgerötete Basis aufweisen. Vereinzelt sind auch stärker eingetiefte oder mit Steinen befestigte Feuerstellen zu erkennen. Mehrere Pfostenlöcher sowie verbrannter Hüttenlehm weisen auf bauliche Strukturen zumindest im jüngeren Abschnitt der Stratigraphie hin. Diese anthropogenen Strukturen liegen in wechselnden, natürlich abgelagerten Sedimenten, die erste Rückschlüsse auf lokale Umweltverhältnisse erlauben.

Eine enge archäobiologische und geoarchäologische Begleitung der Ausgrabung erlaubt es nun verschiedene Aspekte der Umweltentwicklung im Alpenrheintal auch in Bezug auf das Verhalten der damaligen Menschen während des ganzen Holozäns vertieft zu untersuchen. Zusätzlich konnten in der näheren Umgebung der Fundstelle verschiedene Proben aus Bohrungen entnommen werden, die weitere Informationen zur Entwicklung der Landschaft und des Klimas während dieser Zeitspanne liefern können.

P 9.1

Past vegetation and land-use of the páramo in southern Ecuador

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Ecuador is a country of very high biodiversity, long cultural history and very different landscapes. However, not much research has been devoted to it so far. Being a developing country, the use of the land is increasing at a high rate, as well as its population and their economic needs. It is, therefore, very important and urgent to understand the ecosystems present in Ecuador, their natural variability and the impact humans could have, as a support for decision makers in developing suitable management techniques that preserve biodiversity, ecosystem services and the life quality of the people.

For this purpose, we use palaeoecological techniques to better understand the vegetation that would be present under natural conditions and to see what impact humans have had since the beginning of the Holocene. We studied a new highaltitude site, the infilled lake Laguna Vendada at 3640 m asl, lying in the southern part of Ecuador, where only few studies have been done so far. We especially focussed on treeline fluctuations and forest dynamics, so we selected this site lying above the actual treeline but within the potential reach of forest. We studied pollen, microscopic charcoal and macrofossils. Much effort was put in finding terrestrial macrofossils for radiocarbon dating, because until now only few well-dated pollen sequences in Ecuador were published in which the radiocarbon dating was not based on the less reliable bulk sediment. As a result, it has so far been difficult to temporarily constrain potential climatic signals and to compare the reconstructions of vegetation amongst each other (Hansen 1995). In addition, plant macrofossils are essential for reconstructing local treeline fluctuations (Tinner and Theurillat 2003).

We found several vegetational shifts during the last ca. 18'200 years (calibrated). Pollen and macrofossils show that especially around the mid-Holocene (7000 to 3000 years ago), forests of mainly *Polylepis*, *Weinmannia* and Asteraceae trees were reaching the study site and were generally more widely distributed than today. Indications for human transformation of the landscape are apparent since about 8000 years ago, when there was a marked increase in charcoal and dung-inhabiting spores. A major decline of forests and treeline lowering below the study site is apparent around 1000 years ago, coinciding with unambiguous signs of intensified land-use in the region in the form of the first occurrence of *Zea mays* pollen and peaks in charcoal and dung-inhabiting spores.

In conclusion, forests would today be much more wide spread if it wasn't for the influence of man. We have clear evidence that grasslands are not the climax vegetation up to ca. 3800 m asl, where they dominate today and only small, isolated patches of forests are found. In contrary to the European Alps, where it is well known that treeline was significantly lowered by man, this is still subject of debate in South America.

As the Andean highlands are very important in their function of gathering and redistributing water to the lowlands, as well as being globally important as a hotspot of biodiversity, we recommend that much care be taken in preserving this ecosystem, especially regarding trampling pressure by cattle and fire utilization as a means to create palatable grass for husbandry animals. Marginal areas should be taken aside to allow the recovery of natural vegetation, while still allowing people to use great parts of the land.

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Water isotope signature of fluid inclusions in speleothems

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Fluid inclusions are common in speleothems and they are natural repositories of cave drip waters (Scheidegger et al., 2010). Therefore, the hydrogen (δD) and oxygen ($\delta^{18}O$) isotopic composition of fluid inclusions can yield direct information on the isotopic composition of paleoprecipitation which can then be combined with isotopic analyses of speleothem calcite to either directly calculate paleotemperatures (McGarry et al., 2004) or to reveal changes in the source of moisture (Fleitmann et al., 2003). To liberate speleothem fluid inclusion water and to measure its isotopic composition, a new method was developed. It consists of a simple hydraulic crushing device similar to that one used to extract noble gases from fluid inclusions. Prior to crushing, the sample tube is conditioned by heating and flushing with nitrogen in order to release adsorbed water. Thereafter, the speleothem sample (approximately 1g of calcite) is crushed and the released water from fluid inclusions is transferred by a nitrogen gas stream to a Picarro L1102-i isotopic liquid water and water vapor analyzer. The measuring principle is based on wavelength-scanned cavity ring-down spectroscopy (WS-CRDS) technology that allows us to simultaneously monitor hydrogen and oxygen isotopes (Gehre et al., 2004). Manual water injections of small amounts of water ranging between 0.3 µl and 0.9 µl showed that the reproducibility of measurements is the key parameter for routine measurements and depends on the amount injected, i.e. on the water amount released by the speleothem. The main task we would like to address with this method is a comparison between the isotope signals of the fluid inclusion and calcite to reduce uncertainties associated with the interpretation of calcite δ^{18} O values in speleothems in Switzerland and Turkey.

Currently, we are mainly focusing on a stalagmite (M6) from Milandre cave, Jura, Switzerland. We decided to monitor the drip water rate at the sampling site and to collect drip water, which was originally dripping and precipitating on the M6 stalagmite. In parallel, we collected rainfall water at the MeteoSwiss station "Le Mormont" located close to the cave. In this way we are able to compare δD and $\delta^{18}O$ isotopic composition of drip and rainfall water. At the same time, we installed a high precision drip logger ("Stalagmate", Driptych instruments), which continuously counts the number of water drops per time unit using an acoustic technique. This will help us to characterize the water transfer through the soil zone and bedrock into the cave and to understand the fractionation process that can precede the calcite production and the formation of fluid inclusions.

This study is part of STALCLIM – Multi-proxy climatic and environmental reconstruction from stalagmites from Switzerland, Turkey, Arabia and India – a Sinergia project financed through the Swiss National Science Foundation.

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Symposium 9: Quaternary environments

Geomorphology and landscape evolution of the Chironico landslide (Leventina valley, southern Swiss Alps)

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A pulse in landslide activity seemed to have occurred during the Lateglacial and Holocene in the European Alps, as the valley flanks became unstable due to postglacial landscape modification and slope adjustment. This work investigated the Chironico landslide located in the Leventina valley in the southern Swiss Alps. It comprises about 530 million m³ of crystalline granitic gneiss belonging to the Lower Pennic nappes that detached from the eastern valley wall, slid along valleyward dipping exfoliation joints and fractures of 25-30 degrees and was deposited into the Ticinetto stream mouth. The slide mass consists of a northern and a southern lobe separated by the canyon of the Ticinetto stream.

Already existing radiocarbon ages from three pieces of wood found in a borehole drilled in deposits of an upstream-dammed lake, north of the landslide, yielded an age of about 13500 cal yr BP (Antognini & Volpers 2002). Since these ¹⁴C dates represent only a minimum age and originate from a secondary deposit, a direct age determination of the landslide was performed using surface exposure dating on fourteen boulders with the cosmogenic nuclides ¹⁰Be and ³⁶Cl. A mean age of 13.38 ± 1.4 ka resulted, thus revealing the failure of the landslide in one event during the Bølling-Allerød interstadial.

The runout distance and lateral expansion of the Chironico landslide could be reproduced by runout modeling. The potential failure scenario could thus be identified. The geologic and geomorphologic investigation of the study area enabled to understand the landscape evolution history of the Leventina valley around Chironico. From this, it could be concluded that the landslide was triggered around 3000 years after deglaciation. This time gap between deglaciation of the valley and failure of the landslide suggests that the landslide was not directly triggered by the glacial unloading. It however prepared the failure by undercutting and oversteepening the steep SSW-dipping eastern valley slope, creating a dip-slope on this flank.

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P 9.4

Erosion control and steep slope on the Quaternary soils of Chandab area-Iran

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So soil conservation can be very important regarding to production factors. Soils in deep slopes are very sensitive to degradation. Erosion has always been one of the major sources of damage to both the natural environment and the manmade structures and is caused by different factors and can be avoided only if protection measures are properly selected according to its cause. Erosion on slopes may be caused by rainfall, runoff or wind. These days geosynthetic reinforced soil structures belong to the most economically attractive construction methods due to their flexibility and versatility. Also under the ecological point of view, as e.g. CO_2 reduction, further positive impulses for this type of application can be expected in future Khaksar et al. (2011).

This paper is derived from a research on slope stabilization using geogrid in the Quaternary alluvial sediments of Chandab region in southeast of Tehran. The objective was to study the efficiency of geogrid materials in technical and economical aspects for high slope stabilization and decrease of soil erosion. It shows that they can present soil degradation and soil erosion plots of 12×2 meters were chosen in the research. At the end of plots, runoff is caught and measured and sediment amount in the runoff was measured. Different treatments along with replications were chosen. Nine events were measured. The data were analyzed with the Spss program. The results showed in both slope types: a) in the 110% slope the erosion was much more than the 85% slope b) the treatment plots which were stabilized with geogrids. Conclusions and analysis proved that it is very economic compared to other treatments. The Chandab basin is situated in the southern slopes of the Alborz range, 60 km south eastern of Tehran province in the northern part of Iran, in the latitude 35° 24' 31" N and Longitude 51° 55' E situation (Figure 1). The project has been effectuated on quaternary alluvial fan. Quaternary Alluvial fan is composed of coarse material, including coarse gravel, boulders, and pebbles with ~ 1000 meter of thickness in the study area. In this study the geogrid with bellowed characteristics to soil conservation and soil stability (Table. 2) has been used.

The collected data were analyzed. Different treatments along with replications were chosen. Conclusions and analysis proved that it is very economic compared to other usual used methods. Two slopes rate and there replication were among the treatments 6 sampling in the 6 season were recorded (18 months). These data during the operation of project is shows variations in the vegetation covering in the different plots. Also the together influence of slope and soil covering type with %95 of probability is not significant. For evaluation of amount soil losses for Hectare, produced sediments has been extended to hectare. Importance of this subject for this reason is important that erosion and soil losses evaluation in the each area explain erosion situation and sensitivity to erosion of the area. In the table 6, the quantity of sediments that each treatment can produce in each Hectare has been presented. The most of sediments produced related to plots without geogrid with seeding aboriginal grassland species have been most of soil losses. In the two another treatments: A and B the quantity of soil losses are very fewer than the others. So geosynthetics can be used with geogrid in comparison with other protective methods like to gabion, retaining wall, pitching and terracing decreased expenses respectively 450, 490 and 219 percent to hectare. The results could be applied for stabilization of slopes next to dam reservoirs or trenches resulted by road construction.

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C Without geogrid and with natural grassland covering

D Without geogrid with seeding aboriginal grassland species

Table 2. Characteristics of used geogrid

0 0	
Aspect	nets or grids in rolls or boxes
Solubility in water	insoluble
Polymer	Polypropylene- HDPE
Ecotoxicity	Non toxic.
Measure	690 g/m ²
Measure of gates	27×27 mm.
Tensile strength	8.5 Kn/m
Applications	Stabilization and
	reinforcement of
	weakly soils



Fig. 2: Sediments produced related to plots with and without geogrid

GEMAS: A harmonised geochemical dataset for soils in Europe and in Switzerland

(Peter Hayoz, swisstopo)

Introduction

Geological Surveys have been documenting the natural geochemical background of chemical elements in a variety of sample materials for more than 50 years. However, the existing exposure data at the national and regional scale are often not comparable at the European scale (different sampling strategies, different materials and equipment used for sampling and sample preparation, different sample preparation protocols, different analytical protocols, etc.) and are thus not able to provide a harmonised pan-European geochemical "background" variation. A reference network is therefore established, where local data can be tied to continental (European) and finally to global scale data (Darnley et al., 1995).

Thus, the EuroGeoSurveys Geochemical Atlas of Europe (FOREGS dataset, Salminen et al., 2005) has demonstrated that low-sample density geochemical mapping can provide the required information about the geochemical background in natural soil, stream water and sediments of streams and floodplains.

The most recent GEMAS-Data are the result of a harmonised sampling project executed in more than 30 European countries, under the lead of the Geological Surveys from Norway, Germany and Greece and of Eurometaux. Soil samples are taken from Agricultural and Grazing Lands on a 50 km grid. A well-defined sampling procedure and harmonised sample preparation as well as analysis guarantee comparable data all over Europe.

Similar to the IUGS/IAGC Global Geochemical Baselines Programmes, the main objectives of this European

survey are: 1) to apply standardised methods of sampling, chemical analysis and data management to prepare a geochemical baseline across Europe and 2) to use this reference network to level national baseline datasets.

Procedure and Analysis

A regular grid of 50 km was established across the European continent (Fig. 1). Within every cell of the grid a composite sample was taken on Agricultural (Ap, depth 0-20 cm) and on Grazing Land (Gr, no farming since >10 yrs; depth 0-10 cm). Samples were taken from subsites at the centre and at each corner of a 10 m square and numbered with a unique code. Duplicate samples were taken every 20 sites or according to the requirements. All in all more than 4300 samples were prepared in just one laboratory (air dried and sieved to <2mm). Following an international tender, parameters and sets of elements were determined in one laboratory:

- pH, TOC, Loss on Ignition (LOI), Cation Exchange.
- Aqua regia extraction (ICP-MS): Ag, Al, As, Au, B, • Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Fe, Ga, Ge, Hf, Hg, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Pd, Pt, Rb, Re, S, Sb, Sc, Se, Sn, Sr, Ta, Te, Th, Ti, TI, U, V, W, Y, Zn, and Zr.
- Total element concentrations (XRF) : SiO₂, TiO₂, Al₂O₃, Fe₂O₃, MnO, MgO, CaO, Na₂O, K₂O, P₂O₅, SO₃, Cl, F, As, Ba, Bi, Ce, Co, Cr, Cs, Cu, Ga, Hf, La, Mo, Nb, Ni, Pb, Rb, Sb, Sc, Sn, Sr, Ta, Th, U, V, W, Y, Zn, and Zr.
- Total extraction and REE on Agricultural Soils: Al, Ba, Be, Ca, Cr, Cu, Fe, K, Li, Mg, Mn, Ni, P, Sc, Sr, Ti, V, Zn, Ag, As, Bi, Cd, Ce, Co, Cs, Dy, Er, Eu, Ga, Gd, Ge, Hf, Ho, In, La, Lu, Mo, Nb, Nd, Pb, Pr, Rb, Sb, Sm, Sn, Ta, Tb, Th, Tl, Tm, U, W, Y, Yb, Zr.
- Pb-isotopes (Agricultural Soils) and Sr-isotopes (Grazing Land Soils).

The most important differences between the FOREGS and the GEMAS datasets are the higher density of sampling, the standardised methodologies, analysis in one laboratory and



Fig. 1: Distribution of the sampling sites (Agricultural Soils) and sampling configuration. Setting for the Grazing Land Soils is identical.



Fig. 2: Distribution of the sampling sites in Switzerland from the FOREGS and the GEMAS projects.

the higher detection limits. It has to be stressed, that the FOREGS data keep their entire importance as a baseline dataset. In Switzerland 17 samples (+ 1 duplicate) were taken from Ap- and 17 (+1) from Gr-Soils by Agroscope (Reckenholz) in autumn 2008.

Results (Aqua Regia)

The main aim of the dataset is to provide a geochemical baseline. This paper briefly demonstrates the content of the Swiss data. Results from the Aqua Regia extractions are presented as an example. Even with the relatively weak density of available data, some interpretations are possible.

The data are generally well comparable between Ap and Gr soils. Some elements such as Cu, P, S, etc. however tend to show a dependency from the agricultural use of the soil. On the other hand it was difficult to sample Ap soils (farmed land) at higher altitudes. The relationship with the geological lithology is thus very important. A comparison between the sampling sites as a whole seems to be much more interesting at the Swiss scale e.g. with synoptic maps (Fig. 3).

Dataset

The entire European dataset will be available as of January 1, 2013, Au and PGE will follow in 2015. If interested please contact the author: peter.hayoz@swisstopo.ch.

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Fig. 3: Statistical overview. The quintiles on the map are calculated for the entire dataset (34 samples), concentrations in mg/kg. GEMAS-Median from the European dataset.

A new pollen-based gridded Holocene climate reconstruction for Europe: multi-proxy evaluation, data-model comparisons and the role of climate modes.

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We present an updated and improved (from Davis et al. 2003) pollen-based seasonal gridded climate reconstruction for Europe for the entire Holocene (0-12 ka). Fossil pollen site density has been increased by more than 50% (to 879 sites) representing almost 60,000 individual pollen samples, while the modern pollen calibration training set has been increased by 81% (to 4287 sites). Further improvements include a series of quality control checks and full-error accounting of transfer function and interpolation errors, as well as the reconstruction of seasonal (winter/summer) temperature and precipitation, and the inclusion of changes in past elevation due to post-glacial isostatic re-adjustment. As well as the internal evaluation of errors, the gridded reconstruction has also been evaluated against other published reconstructions of Holocene climate at individual site locations that have used the same pollen-proxy but different methodology, as well as reconstructions based on different proxies such as chironomids, diatoms, isotopes, and glacier mass balance.

Our new reconstruction shows much greater spatial resolution and a clearer spatial pattern of anomalies, as well as reduced errors at the grid-box scale. Comparison with mid-Holocene climate model simulations demonstrate the same datamodel discrepancies as identified in previous studies, but we are able to more clearly demonstrate the role of atmospheric circulation modes and teleconnections in explaining these discrepancies.

In particular the reconstruction shows that the pattern of temperature and precipitation anomalies is consistent with a strong zonal circulation associated with a positive NAO or AO in the mid-Holocene in winter, and weak zonal circulation associated with blocking (e.g. SCAND or EU1) in summer. Neither of these patterns is shown in mid-Holocene climate model simulations, while comparison with transient model simulations shows that this problem extends throughout the Holocene.

These results may help reduce current uncertainties about the role of climate modes in modeled scenarios of future climate change, as well as help understand what drives these modes since climate forcing during the Holocene was relatively simple at low frequency time-scales.

Sediments size characteristic of Jazmurian playa as an important source of dust production in the world and harmful effects of dust on human health

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Jazmourian playa (Hamun Jazmourian) is an ephemeral lake located in the South East of Iran. During the last 10 years this playa was dried because of drought condition and build of dam on the Hirmand River (the major water source of playa). Jazmourian playa sediments are formed mainly of fine grain particles that are in the silt and clay size in the center of basin, sand and slightly granule in the around of playa, unconsolidated sediments due to high muddy cracks networks in the surface sediment.

This study executed because the dust particles smaller than 2 microns are formed of clay minerals that are very harmful for human health. In this investigation 26 surface sediment samples were taken from surface sediment of playa . Sedimentology investigation and grain size analysis, calcimetry and mineralogy (XRD) have been done in Geological Survey of Iran. The results show that mean of sediments sizes are between 0.42 to 4.3 millimeters. Clay sizes particles are between 1.03 to 78.78 percent. Value of silt is between 0.88 to 64.17 percent, sand is 0.77 to 96.5 percent and a few gravels exist in the sediments. The most important minerals are clay minerals, quartz, feldspar, calcite and halite. Also hematite in the East and gypsum in the south of playa have been observed. Montmorilonite, chlorite and Illite are major and Kaolinite is minor clay minerals. Carbonate minerals are 17.3 percent contain 15.6% calcite and 1.7% dolomite.

Major source of sediment in playa are fluvial, eolian and chemical (due to high evaporate and precipitation of Gypsum and halite.

Due to dry climate condition, strong wind system, no flora cover on the playa, fine grain and unconsolidated sediments this area has huge potential for create huge and catastrophic dust storm.

Dust especially smaller than 2microns (clay minerals), pose a risk on our health and adverse effects on respiratory function, cardiovascular system, nervous system and increases the risk of cancer. Respiratory tract are cough, nose, throat and eye irritation, shortness of breath, exacerbation of allergic symptoms.

Key words: Jazmourian playa, Dust storm, Sedimentology, Health

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Solid-rock surface model of the Rhine and Seez valley

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The elevation and morphology of the solid-rock surface and the associated thickness and distribution of Quaternary deposits are of practical and scientific interest. They provide opportunities for studying subglacial erosion and other glacial processes at the glacier bed and provide boundary conditions for geo-engineering tasks, groundwater resource management and the siting of deep geological repositories for radioactive waste.

Digital elevation models of the solid-rock surface are e.g. available for northern Switzerland (Jordan 2010), for the region around Bern (Dürst Stucki et al. 2010) and for western Switzerland (Fiore 2007). Here we present a bedrock model constructed for the Rhine and the Seez valley in eastern Switzerland. This region is of special interest because little is known about the glaciological and geomorphological processes operating at glacier diffluences, like the one of the ice-age Rhine Glacier at Sargans. However, such diffluences likely have a strong influence on the dynamics and hydrology of ice masses and, hence, might play an important role in the formation of valleys and landscape evolution.

Following the methodology of Jordan (2010) and Dürst Stucki et al. (2010) we constructed the digital elevation model (DEM) of the bedrock surface at a 25 m grid cell spacing based on existing topographic maps and elevation models, extensive borehole data, seismic profiles and gravimetric information. With the help of the "topo to raster" function in ArcGIS, elevation contour lines were interpolated to obtain the bedrock topography. The model (Fig. 1) reveals that the Rhine and the Seez valley are deeply incised into the bedrock. Furthermore, two pronounced overdeepenings reaching below sea level exist south of Lake Constance and close to Sargans.

The overdeepened feature at Sargans is located in a region of ice diffluence during LGM and earlier glaciations. While ice confluences have been suggested to favour the formation of overdeepenings (Fischer 2009), such a causal link is not known for ice diffluences. In fact, the formation of an overdeepening at Sargans can be explained by the local geology, i.e. the locations of nappe boundaries, major faults and weak lithologies.

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Figure 1: Digital elevation model (DEM) of the bedrock surface of the Rhine and Seez valley.

Calculation of shielding factors for production of cosmogenic nuclides in fault scarps

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For the last 30 years, Terrestrial Cosmogenic Nuclides (TCN) have successfully been used for geochronology. TCN dating relies on independently calibrated production rates, on semi-empirical scaling factors and on geometrical shielding factors. The computation of scaling factors includes the neutron monitor measurements and requires therefore the use of tabulated data. The geometrical complexity of surrounding environment also forces the use of numerical methods. Special programs were developed to ease the calculation of TCN scaling, shielding and production rates.

One of the most challenging TCN applications is the reconstruction of past earthquake histories. In this method, limestone normal fault scarps are used to reconstruct past seismic events that have exposed the foot wall of the scarp. In the simplest case, there is a footwall of infinite height and accumulated colluvium that covers the lower part of the footwall. During an earthquake footwall is moving upwards and exposing a new segment. The complexity of the exposure geometry limits the computation of the geometrical scaling factors analytically. Only one discussion dedicated to this computation was recently published. Unfortunately, the average TCN users would need to spend significant time applying the published material to particular case. Therefore, we aim with our contribution to provide the reader with a clear protocol and an easy-to-use tool for fault scarp geometrical scaling factors computation.

This study consists of a theoretical basis with a reference to previous works and a MATLAB computation code which can be used as stand alone software or as a MATLAB M-file. Geometrical scaling factors are calculated by the program for fast neutron spallation and include all general shielding geometries: topographical shielding, sloped surface, fault scarp surface, colluvium cover, snow cover, self-shielding and erosion.

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10. Geomorphology

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Swiss Geomorphological Society

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Symposium 10: Geomorphology

10.1

Electrical Resistivity Soundings on a Stabilized Slope of a Subalpine Catchment: A new Approach to Detect the Spread of Root Systems

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Intense rain fall events considerably increase erosional processes and the risk of mass movements in general and, in particular on steep slopes in mountainous areas lacking a protecting vegetation cover. Consequently, such events are jointly responsible for an increasing natural and socio-economic damage potential. In view of hazard prevention, soil bioengineering measures, e.g. slope and soil stabilisation with living plants, gain more and more in importance.

In order to estimate the plant's influence on the stabilization processes, the observation of the aboveground plant development is a common practice. In contrast, the near subsurface is invisible, difficult to address and, therefore, often neglected. Soil samples, sensors (e.g. soil moisture) or rhizotrons allow for some information on the belowground plant/root development. These methods, however, provide only limited point-by-point data, alter parts of the study site, and are often time-consuming and expensive. In contrast, geophysical methods, e.g. electrical resistivity tomography (ERT) provide minimally-invasive and spatial information of the near subsurface. Unlike in mountainous and steep environments, this approach is often used in lowlands by soil scientists.

In May 2010, we established three new research plots at an erosion-prone talus slope (inclination: ~40 - 45 °; elevation 1220 - 1360 m a.s.l.), located in the Arieschbach catchment area (Eastern Swiss Alps). The slope, consisting of moraine and denudation-derived substrate, shows high geomorphic activity (e.g. debris flows, rill erosion). Two of the plots were stabilized with 1200 plants each. Additionally, mycorrhiza inoculum was added to one of these plots (INOQ Forst, 40 ml/plant). A mixture of eight saplings was planted per running meter in 15 rows of 10 m length. The assortment included four saplings of Alnus viridis and two of Salix purpurea as well as one further tree (Acer pseudoplatanus, Betula pendula, Fraxinus excelsior) and shrub species (e.g. Viburnum lantana/opulus, Lonicera xylosteum). Finally, both plots were hand-seeded with a site adapted seed-mixture. The third plot was not treated and serves as a control plot.

Data logging stations are installed on each plot, measuring soil moisture and soil temperature in 10 cm and 35 cm depth. Furthermore a climate station in between the plots records air temperature and humidity, precipitation and solar radiation. In September 2011 ERT monitoring lines (48 electrodes, 25 cm electrode spacing) were installed at all three plots.

At the end of the vegetation periods 2010 and 2011 all plants were counted and measured. In addition, soil samples were taken likewise, and analysed in respect to aggregate sizes and stability, (fine) root penetration and the degree of mycorrhization.

Aboveground, preliminary results indicate that the plot, which was mycorrhizal treated shows higher plant vitality. The ERT soundings provided plausible data and enabled the modelling of the rhizosphere. An obvious difference between the three plots is detectable, showing deeper and more spacious rooting in the inoculated plot compared to the non-inoculated one. The shape of the subsurface anomalies fits with the vitality of the plants next to the ERT lines.

Tectonics, Climate, and Mountain Topography

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By regressing simple, independent variables that describe climate and tectonic processes against measures of topography and relief of 69 mountain ranges worldwide, we quantify the relative importance of these processes in shaping observed landscapes. Climate variables include latitude (as a surrogate for mean annual temperature and insolation, but most importantly for the likelihood of glaciation) and mean annual precipitation. To quantify tectonics we use shortening rates across each range. As a measure of topography, we use mean and maximum elevations and relief calculated over different length scales. We show that the combination of climate (negative correlation) and tectonics (positive correlation) explain substantial fractions (> 25%, but < 50%) of mean and maximum elevations of mountain ranges (Figure 1A and 1B), but that shortening rates account for smaller portions, <25%, of the variance in most measures of topography and relief (i.e. with low correlations and large scatter). Relief is insensitive to mean annual precipitation (Figure 1C and 1D), but does depend on latitude, especially for relief calculated over small (~1 km) length scales, which we infer to reflect the importance of glacial erosion (Figure 1C). Larger-scale (averaged over length scales of ~10 km) relief, however, correlates positively with tectonic shortening rate. Moreover, the ratio between small-scale and large-scale relief, as well as the relative relief (the relief normalized by the mean elevation of the region) varies most strongly with latitude (strong positive correlation) (Figure 1E and 1F). Therefore, the location of a mountain range on Earth and corresponding climatic conditions, not just tectonic forcing, appears to be a key factor in determining its shape and size. In any case, the combination of tectonics and climate, as quantified here, can account for approximately half of the variance in these measures of topography. The failure of present-day shortening rates to account for more than 25% of most measures of relief raises the question: Is active tectonics overrated in attempts to account for present-day relief and exhumation rates of high terrain?



Figure 1: Pie charts of the relative contributions of each external variable – V_{h} (tectonic shortening rate), *precip* (mean annual precipitation), and *coslat* (cosine of the latitude)– to the observed variance of the topographic variables – E_{max} (maximum elevation of the topography average over a 10 km), E_{mean} –BL (mean elevation of the range above the base level BL), *GR1* and *GR15* (mean geophysical relief over 1 and 15km), *nGR1* (relative relief, i.e. geophysical relief normalized by the mean elevation of each range), *GR15/GR1* (Dimensionless ration between GR15 and GR1). The gray shading is the unexplained part of the variance that is due to unused variables and natural scatter.

Strong imprint of periglacial-environments dynamics on stream sediments seen trough a ¹⁰Be-budget of an alpine catchment (French Alps).

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The Ecrins-Pelvoux massif (French Western Alps), like most of the European Alps, has been extensively glaciated during Quaternary glaciations, leading to a strong morphological imprint and a related rejuvenation. This massif therefore provides a suitable area to study the effects related to this inheritance, and to quantify erosional processes in changing land-scape. To this extent, we sampled stream sediments in 12 catchments throughout the Ecrins-Pelvoux massif to measure in-situ produced ¹⁰Be concentrations and derive catchment-scale denudation rates for late-Holocene timescales. Our results show a clear correlation between denudation rates and mean catchment elevation, in the absence of any significant relationship with other morphometric parameters (Delunel et al., 2010). We thus propose that postglacial denudation of Ecrins-Pelvoux massif is climatically driven trough increasing frost-controlled processes with elevation, providing a mechanistic link for the inferred feedback between uplift, elevation and denudation rates observed elsewhere in the European Alps (Wittmann et al., 2007; Champagnac et al., 2009).

¹⁰Be concentrations of stream sediment alone cannot be used to identify potential about the intrinsic spatial variability of erosion and sediment discharge in a single catchment. Therefore we have measured ¹⁰Be concentrations (n = 19) on both different morphologic features and detrital materials resulting from high-altitude erosion that ultimately feed the sediment routing system. For this purpose, we focussed on the Etages catchment (~14 km² catchment, Ecrins-Pelvoux massif), located within the altitudinal range where frost-controlled processes are most efficient (Delunel et al., 2010). This catchment also hosts a small cirque-glacier, which is a relict from the Little Ice Age (LIA) glacial advance. This basin allows us to identify the glacial influence on stream-sediments ¹⁰Be concentrations.

The results show that ¹⁰Be concentrations vary strongly from ~0.1x10⁵ to 4.5x10⁵ atoms g-1 in the Etages catchment, while displaying consistent ¹⁰Be signature within each representative sources. ¹⁰Be contents of glacial materials vary from 0 (i.e., undistinguishable from procedural blanks) close to the present-day glacier position to ~0.3x10⁵ atoms g⁻¹ towards the LIA moraines. Debris-flow materials collected at different catchment levels have slightly higher ¹⁰Be concentrations (~0.4-0.7x10⁵ atoms g⁻¹). Regolith material collected close to the highest crests (morphologic features currently affected by frost-cracking processes) carries much higher concentrations (~1.3-1.8x10⁵ atoms g⁻¹), while bare rock surfaces are also characterized by relatively high and heterogeneous ¹⁰Be concentrations ranging from ~1.4 to 4.5x10⁵ atoms g⁻¹. Finally, stream sediments collected along the main stream and at the outlet carry ¹⁰Be concentrations of only ~0.2x10⁵ atoms g⁻¹, without any downstream trends either towards higher or lower concentrations.

We then interpret these ¹⁰Be concentration measurements combining a geomorphological map and surface ¹⁰Be production rates estimates within a mass-balance model (Brown et al., 1995; Granger et al., 1996). The model results evidence that the ¹⁰Be signature of sediments exiting the Etages catchment does not fulfil the steady-state equilibrium required for inferring catchment-wide denudation rates implying a strong transience. Most important, the ¹⁰Be concentrations measured in the alluvial sediments along the stream tightly reflect the glacial material signature, showing that the Holocene variability in denudation has not imprinted on the ¹⁰Be concentration of the trunk stream yet. In summary, we propose that periglacial dynamics need to be considered as important constituents in the erosional factory either through the effects of frost cracking, or the recycling of glaciogenic deposits.

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10.4

Geomorphological catchment parameters affecting bed load transport in mountain torrents

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Information on potential bed load and bed load transport is essential to conduct hazard assessments of torrents and their possible consequences on settlements and infrastructures. A variety of methods and formulae have been developed to predict and estimate bed load transport in mountain torrents ranging from simple regression to complicate multi-step and multi-parameter approaches. However, the possibilities to test these formulae using field data are limited by the challenges of measuring bed load and detailed hydraulics due to their high variability in space and time.

The presented study takes up these challenges by comparing estimated bed load values applying a transport formula for steep channels and accounting for high flow resistance (Rickenmann, 2012) (here called calculated values) and values derived from sediment traps at the water intakes for water power plants (here called observed values). The considered water intakes and thus the study area are located in the Valais (Switzerland). All water intakes are maintained by the Grande Dixence Hydropower Company. The observed bed load values are associated with some uncertainties (grain size distribution of deposits, filling degree of sediment trap, numbers of flushing events). The discrepancy ratio of calculated to observed values varies considerably between 0.1 and 1400. The main objective of the study is to find possible geomorphological parameters within the catchments, which may clarify the discrepancies and partly explain the general overprediction. To achieve this objective, catchment parameters which are supposed to influence bed load transport are deduced from maps or analyzed from the DEM in ArcGIS. Field work was deducted for validating map and DEM interpretations and the input parameters for the bed load transport calculation. The geomorphological parameters such as catchment area, channel length on rock, loose sediment or vegetation and distance between the water intake and the glacier were compared with the discrepancy ratio of calculated to observed values. The analysis includes XY-diagrams and multiple regressions. First results of the graphical comparison show channel length on rock and loose sediment to be most strongly related to the discrepancy ratio, with a coefficient of determination of 0.39 for a logarithmic function. The form factor according to Horton and maximum height for instance seem to have no influence on the ratio of calculated to observed bed load values.

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Cosmogenic nuclide denudation rates in the debris-flow dominated Haslital-Aare and Matter catchments

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We have continuously sampled river sand for cosmogenic derived catchment wide denudation rate analysis in the catchments of the Haslital-Aare (5 years under observation) and Matter/Saas (2 years). Both catchments are known for their highly active debris-flow torrents causing considerable damage, pose a natural hazard risk and are under high technical surveillance and protection constructions.

While the widely measured cosmogenic nuclide derived denudation rates in alpine catchments are commonly only measured ones, we opted a seasonal to monthly and event based sampling scheme to evaluate the degree of perturbation caused by episodic events to assumed steady state systems (as the method requires).

The cosmogenic ¹⁰Be and ¹⁴C results for the Haslital-Aare show that the localized admixture of sediment from high-magnitude and trunk-stream channel coupled debris-flows in 2009 to 2011 have a marked effect on long-term ¹⁰Be denudation rates compared to prior undisturbed years. Furthermore, though magnitudes were exceptional high in 2010 and 2011, a threshold was approached, where the higher sediment flux did not result in apparent higher denudation rates (Kober et al., 2012). This suggests that with time sediment-remobilization in the lower parts of the debris-flow torrents dominates that has no different cosmogenic signature than the material delivered from previous years or, that similar reservoirs were tapped. Individual torrent measurements and field observation support these results.

The Matter catchment has been observed for 2 years so far only, with rates obtained that are similar at all sites suggesting (i) mixing of sediment and (ii) no perturbation by large magnitude events that are coupled with the trunk stream. Field observation confirm these data where debris-flows were only of small volume and did run out in tributary systems. Furthermore, no significant perturbation by the Randa landslide/rockfall is observed, suggesting that the slope deposits and the modern channel are decoupled.

Overall, all apparent denudation rates fit current mean Alpine denudation rates of about 1 mm/yr, unless perturbed by events. This highlights the fact that a careful knowledge of the pre-sampling catchment process history is necessary in order to interpret data correctly.

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10.6

Alpine Cambisols and their genetic implications for eolian influence on karst soil development (Northern Calcareous Alps)

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This study focuses on striking Cambisols on the karst paleosurface of Reiteralpe (Trias, Cretaceous) (Figure 1).

Distinct B horizons forming Chromic Cambisols are not exclusively related to autochthonous residues. In contrast, pedology and mineralogy indicate a strong eolian addition (silt, fine sand, mica, feldspars) to the topsoils, underlining that recent dust influx is an ubiquitous phenomena in high-mountainous karst. The related mineralogy of both dust and soil samples reveals a heavy mineral spectrum congruent with detritus derived from Central Crystalline Alps. These results go along with dust deposited periodically by southerly foehn winds. More than exiting are special features (e.g. rounded quartz, hematite, gibbsite), implicating accessorily far-traveled Saharan dust.

Although apparently common, the addition of allochthonous silicate-rich dust is still a neglected factor for mineral soil development. Thus, it is for the first time that influx measurements upon the soil profiles face this challenging problem. What is also quite new is the combination of winter and summer deposition by using firstly the snow surface method (Thorn and Darmody, 1980) and secondly a simple construction of dust boxes near the soil surface.

The data of a meanwhile five-year-record yield in dust influx rates producing a mineral layer of 9.0cm per 10,000years. This is a multiple (factor 2 to 11) of the accumulated thickness of Holocene residue production out of limestone weathering only. These findings indicate that eolian dust is a major contributor to alpine karst soil genesis.

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Figure 1. Germany and the location of the study area (Maps of Germany, Munich 2007).

Río Mamoré - Holocene river dynamics in the Bolivian lowlands

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The Llanos de Moxos, which are located in the lowlands of north eastern Bolivia (Beni), are one of the largest seasonally inundated savannahs in the world (150.000 km²). The region is characterized by a complex fluvial drainage pattern, where large-scale river migrations have been reported for the Río Grande, Río Beni and Río Maniqui (e.g. Allenby 1988; Dumont 1996; Plafker 1964). So far little is known however with regard to causes and timing of these river shifts.

Based on previous results, the Río Mamoré shift (Plotzki et al. 2011) has been investigated in more detail and results will be presented here. Remote sensing was used to analyse dimensions of palaeo meanders, which were then used for palaeo discharge calculations. Discharge of the modern Mamoré is 3-8 times that of the former Mamoré. Three infilled oxbows of the palaeo meander belt have been investigated in 2008, 2010 and 2011 and sediment cores have been taken. OSL and radiocarbon dates indicate that the Río Mamoré was at least active in its former meander belt until ~3 ka. Increase in discharge of the Río Mamoré resulted in a reduction of the channel's capacity to accommodate the increased amount of water, and ultimately caused the avulsion. However, other possible mechanisms resulting in avulsion, e.g. tectonic tilting of the basin, have to be considered as well. The increase in discharge may be attributed to increase in humidity from the late Holocene on due to strengthening of the South American Summer Monsoon (SASM), which is evidenced by several archives from the Bolivian altiplano and the lowlands (e.g. Baker et al. 2001; Mayle et al. 2000).

Irrespective if the river shift is correlated to the increase in discharge or not, it is evident that i) climatic conditions changed markedly from the mid-to late Holocene, as evidenced by discharge alterations. Our results represent the first attempt to correlate meander dimensions and increasing discharge in the Beni basin with climatic changes on Holocene timescales. ii) High variability of the fluvial system in the Beni basin is indicated by several river shifts, yet this is the first approach to put one of these shifts into a temporal frame.

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Paleo-erosion and sedimentation rates calculated for the Holocene in a formerly glaciated alpine catchment demonstrate a high variability of sediment supply during an interglacial stage. A combination of ¹⁴C data and ¹⁰Be-derived rates, allow interpreting the evolution of the Zielbach catchment (Venosta valley, Sudtyrol, Italy) in terms of sediment yield, sedimentation dynamics and landscape evolution. In addition, stratigraphic and seismic data allow us to interpret the relative importance of the Zielbach catchment and of the Adige River system (in the main valley) as a balance between sediment availability, supply and accommodation space in the Venosta valley. The two systems basically reflect the different response of the landscape to glacial retreat, highlighting the spatial and temporal variability of the deglaciation in the Venosta valley (Fig.1).

The ¹⁰Be data show that erosion and sedimentation rates experienced a decreasing trend from ca. 10'000 yrs B.P. until at present, testifying one order of magnitude higher sediment discharge immediately after the deglaciation of the main valley than at present. In particular, during the first phase of deglaciation (from ca. 12'000 yrs B.P.), the catchment was affected by an extremely high erosion and sedimentation rate, which caused the exhaustion of the sediment deposited by the LGM glacier on the slopes. Subsequently, the activity of the trunk stream decreased, but the ongoing movement of a re-activated landslide on the eastern slope of the basin contributed to the rapid sediment delivery (mainly through debris flow) also during the first mid-Holocene. The continuous accumulation of sediment in the main valley probably caused the stabilization of the slope and resulted in a reduction of sediment supply by debris flows. This was then accompanied by an increase in the relative importance of alluvial processes. This phase coincided with the Holocene climatic optimum.

More recently, between ca. 3'500 yrs B.P. and present, the debris-flow activity regained a more important role in the supply of sediment. This behavior may be related to the Holocene climatic deterioration when more variable climatic conditions could have affected the stability of hillslopes and related debris flow processes. If this hypothesis is correct, the future evolution of the Zielbach catchment will be strictly linked with predicted climatic changes that may affect the decreasing trend of erosion and sedimentation rates characteristic of the recent past.



Fig.1. Evolutional model of the Zielbach fan. The model shows the interaction between the main valley (Adige River) and Zielbach sedimentation processes, following the deglaciation of the Venosta valley.

Sediment transfer in the Southern Swiss Alps since the Last Glacial Maximum: evidences of paraglacial crisis

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Continental hillslope deposits – in particular talus slopes and alluvial fans – and valley floor deposits, can be read as important palaeoenvironmental archives for the reconstruction of the morphogenesis, the evolution and the morphodynamics of alpine valleys since the last deglaciation (Scapozza 2012). The study of these deposits it is of particular importance because, especially in the actual context of a warmer climate, a « geosystemical » approach focusing on the sediment transfer in a whole alpine hillslope – from the rockwall to the valley floor – is of great importance to understand and evaluate the past processes and to try to assess how they might evolve in the future.

In this framework, we would present the state of the art concerning the knowledge about sediment transfer in the Southern Swiss Alps, allowing defining the major morphoclimatic crisis that have occurred during the Lateglacial and the Holocene, and which is based on the:

- compilation of detailed Quaternary geological maps;
- definition of the timing of deglaciation of the Ticino glacier and of the main steps of progradation of the Ticino river delta (fig. 1-A);
- collection of morphometrical analysis of several alluvial fans and palaeodeltas allowing the reconstruction of depositional processes;
- quantification of the sediment transfer from rockwalls to talus slopes in high mountain areas (in particular in the periglacial belt) (fig. 1-B);
- definition of the infilling chronology of the Ticino valley floor, allowing the quantification of sedimentation rates (fig. 1-C).

These preliminary data allow to show, for the higher part of the studied catchments, the existence of "paraperiglacial rockfall phases" related to the permafrost degradation in rockwalls which coincides with rapid climate warming periods, as at the beginning of the Bølling, during the Preboreal or, maybe, since 1980 (fig. 1-B; see Scapozza 2012). A similar behaviour was found by the analysis of the fluvial sedimentation rates (fig. 1-C) and of the Ticino river delta progradation rates, with the erosion/sedimentation dynamic during the Lateglacial and the Holocene that was putted in relation with the paraglacial sedimentation model, which implies a major morphogenetical crisis at the beginning of the deglaciation (Scapozza *et al.* 2012).

In future, these results will be improved by investigation at the local scale, including for example the assessment of sediment transfer from glaciers and rockglaciers to the valley floors, the study of the relationship between mass movements and alluvial fan development and the detailed study of the stratigraphy of some talus and alluvial cones thanks to the presence of outcrops dues to sand and gravel quarries or archaeological excavations.

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Figure 1. Evolution of some natural parameters related to the sediment transfer in the Southern Swiss Alps. (A) Main deglaciation stadials of the Ticino glacier and mean altitude of the Lake Maggiore; (B) Rockwall erosion rates in the alpine periglacial belt based on talus slope volume evaluation; (C) Mean sedimentation rates in the valley floor of the Ticino plain; (D) Chronostratigraphical framework (in "roman") and main morphoclimatic subdivisions (in "*italic*"). LGM: Last Glacial Maximum; B/A: Bølling/Allerød; YD: Younger Dryas; HCO: Holocene Climatic Optimum. (A) and (C): data from Scapozza *et al.* (2012); (B) and (D): data from Scapozza (2012).

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P 10.1

Transient fluvial incision and active surface uplift in the southern India

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The Southern Peninsular India is characterized by anomalously high topography in passive margin settings. Throughout the globe the research devoted to the understanding of feedbacks among topography, tectonics and climate are focused on tectonically active settings. In the Western and Central part of Southern Peninsular India, mountains are as high as 2600m, slopes are steep, monsoon rain is heavy, and temperatures are tropical. All these conditions provide an unique opportunity to test the coupling between topography, tectonics and climate. We utilize topographic analysis of channel profiles combined with field measurements to explore the distribution of fluvial incision and landscape transience in Southern India. We analyzed fluvial channel profiles of both the east and west flowing catchment system covering an extensive area between 10-16°N latitude. The channel profile analysis revealed systematic differences in morphology between the east and west flowing catchments. The east flowing channels of Cauvery catchments are approximately 800 km long and flowing across the subcontinent down to the Bay of Bengal. The trunk channel and its tributaries are characterized by one or more major knickpoint that separate channel reaches with different channel steepness. From field survey, we found that channels downstream of the knickpoints are carving through narrow deep gorges. The catchments flowing westward, to the Arabian Sea, are short and of two types. Type A channels are marked by one or more prominent knickpoints and the downstream channels are steep and cutting through narrow V-shaped gorges. Type B channels are devoid of knickpoint and marked by concave upward valley shapes. These preliminary results highlight the transient state of the landscape in Southern India and provide evidence for variable amounts of fluvial response to the adjusting landscape. Further work is in progress using insitu produced cosmogenic nuclide and low temperature thermochronology to better understand the timing and magnitude of landscape adjustment and its relation with changing boundary conditions.



Figure 1. River profile along the Cauvery River. Grey and black lines (with area shaded between) indicate mean and maximum elevation values from the swath profiles.

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P 10.2

Climatic imprint on landscape morphology in the western escarpment of the Andes

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Over human timescales, the processes responsible for the long-term topographic evolution of a mountain range are typically not observable and hence, poorly constrained. Here we perform a space-for-time substitution with the western escarpment of the Andes between 10 and 20°S to identify the formative mechanisms.

We use this setting to propose that variations in the precipitation pattern play a primary role in setting hillslope relief in mountainous landscapes. We find that in dry climates topographic relief grows with increasing precipitation, independent of either the underlying lithology or prevailing rock uplift pattern. We proceed by differentiating between Andean land-scapes with generally low precipitation rates (80-500 mm/yr, Peruvian Andes 10-20°S) where local relief correlates positively with precipitation, from those with higher precipitation rates (400-1400 mm/yr, Chilean Andes 35-40°S) where increases in precipitation lead to topographic decay. We suggest that these trends result from dominant bottom-up processes giving way to increasing top-down processes. With low precipitation, relief growth is controlled by stream incision and knickzone retreat into a largely undissected plateau. With higher precipitation rates, relief is set by the steepness of graded streams and the rates of sediment production and transport on hillslopes.

Trends of topography can also be interpreted in temporal terms, in which the higher precipitation results in shorter response times, such that the Peruvian Andes are still responding to Miocene uplift while in the Chilean Andes, these knick-zones have already propagated through the entire fluvial network. We anticipate that such changes also operate during the formation and destruction of other mountainous plateau landscapes.

Dip direction controls of bedrock on channel morphologies and denudation rates in the eastern Swiss Alps

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The bedding orientation of bedrock exerts a prime control on the nature and the rates of sediment transfer on mountainous landscapes. Here, we address one particular situation, in which the dip angle of the bedrock is subparallel to the topographic slope (termed dip-slope). Such an arrangement results in the potential for large-scale deep-seated landsliding with bedding or jointing acting as glide planes. Hillslopes with the opposite situation (non-dip slope) have no such preconditioning, and will denude through standard mechanisms. The dip slope case is transport limited, with deep-seated landslides of up to tens of km² large transferring material towards the trunk stream. The opposing, non-dip slope, valley side is dissected by <150 m deep, supply-limited, bedrock channels.

Quantifying these effects is however difficult as surface sediment transfer rates in the dip-slope case may not reflect the depth integrated sliding rate. Likewise, in non-dip slope catchments, failure events tend to be episodic. We approach this problem with multiple methods, complementing geodetic surveys with morphometric analysis and ¹⁰Be derived hillslope and channel denudation rates. In particular, we analyse the relationship between upstream size of drainage basins *A* and channel gradients *S*. In case where channels are graded and actively shaping the landscape, then channels gradients *S* are directly related to the size to the contributing area *A* following Flint's (1974) law:

$$S = k_s A^{-\mathsf{q}} \tag{1}$$

where k_s and θ denote the channels steepness and concavity, respectively. The type, magnitude, and relative contributions of hillslope and channel processes can result in deviations from this relationship, which are readily identified by changes in the concavity and steepness values. Accordingly, we calculated these parameters from tributary streams on dip slope and non-dip slope valley sides. Tributary channels on dip-slope valley side are characterized by low concavity values ranging from 0.1 to 0.2, and equally display low steepness indices of approximately 100 m^{0.9}. Streams on the non-dip slope valley side have substantially higher concavity values between 0.3 and 0.8 and higher steepness indices, reaching maximum values of ca. 200 m^{0.9}. Surface slip rates derived from geodetic data exceed 10 cm/yr on the dip-slope valley flank, but are below detection limits (~1 m horizontal shift) on non-dip slope hillsides (Schwab et al., 2009).

The high steepness and concavity values of streams on non-dip slope valley sides support the interpretation of rapid dissection of the channel network into landscape where low hillslope slip rates allow the channel network to stabilize and actively shape the landscape. This is in contrast to the dip-slope valley side, where low steepness and concavity values suggest that the channel network is continually destabilized by rapid deep-seated landsliding. ¹⁰Be-derived denudation rates are expected to yield similar distinct relationships between landsliding, fluvial dissection and overall sediment yield.

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P 10.3

Bedrock surface model of Switzerland: indication for glacial erosion processes

Mirjam Dürst Stucki, Fritz Schlunegger

The bedrock topography without its quaternary sediments is an important archive for the indication of glacial erosion processes and evidence for the glacial impact on landscape. Based on stratigraphic investigations of more than 30,000 boreholes we generated a bedrock model of the entire Canton Bern. We combined our model with other models, which resulted in a map of the bedrock topography of nearly the entire area of Switzerland. Adapted on this map we calculated an erosion model based on the glacier velocity. Additionally, we were able to identify areas with high erosional potential of the subglacial meltwater. By analyzing hypsometry, slope distribution, lithology, and bedrock course and morphology of the different catchment areas, we characterized the history of the different glaciers within Switzerland.

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P 10.5

Quaternary geological map of Sheet Reichenau (Canton Graubünden): improvement of several GIS tools

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In the framework of the Geocover project, the Institute of Earth Sciences of the SUPSI has realized during 2012 the digital map 1:25'000 of the Quaternary landforms and deposits of the Sheet 1195/Reichenau and of a part of the Sheets 1174/Elm and 1175/Vättis, located in the northern part of the Canton Graubünden between Flims and Chur (Vorderrhein Valley).

The mapping of the Quaternary landforms and deposits was based on the directives of the Swiss Geological Survey (see OFEG 2003) and was performed thanks to the software ESRI ArcGIS and thanks to an extension of it, called ArcGDS. This tool is particularly adapted for the cartography of Alpine valleys and hillslopes because it allows collecting, editing and updating of 3D features using a stereoscopic 3D interface. In addition to 2D (X-Y plane) data, ArcGDS captures altitude data (Z) by continuously connecting points in superposed images.

The goal, concerning the mapping of Quaternary geomorphology, was reached by the analysis of a 2 m resolution Digital Elevation Model (DEM), orthorectified aerial photographs (orthophotos) and summary maps and sketches published in literature. The perimeter of the landslides was interpreted and mapped using the ArcGDS tool.

One of the purposes related with the realization of these digital maps was also to improve the quality of digitalization work by reducing the presence of typical topology errors and problems that are generated by the use of editing tools on polygons (e.g., cutting, reshaping and clipping tools). For this reason, we have chosen to work only through lines (which represent the geological construction lines, as a geological boundary or linear geomorphologic landforms) and points and to generate the polygons at the end of the work, instead of generate directly the polygons (Figure 1). The points allow attribute the polygons generated by the intersection of the lines (*point main* for deposits; *point aux* for instabilities; see Figure 1) and the punctual geological elements (e.g. erratic boulders, springs, etc.).

The mapped area is characterized by a complex event stratigraphy, well known in literature, which presents a large number of landslides (with, in particular, the famous Flims rockslide; e.g. Poschinger 2005, Ivy-Ochs et al. 2009), DSGSD (deep seated gravitational slope deformations) and different hillslope and alluvial deposits.

This bibliographic knowledge is very important and represents the base to a correct interpretation of the different deposits and landforms visible through the hillshade of the DEM.

In the studied area, the valley floor is characterized by different rockslide deposits. First occurred the Tamins rockslide, which blocked the Vorderrhein river and caused the formation of the Bonaduz paleo-lake. At about 8'900 ± 700 yr BP (Ivy-Ochs et al. 2009), the Flims rockslide came down and caused a new dam of the Vorderrhein river, with a reworking and a resedimentation of the Bonaduz gravel and the formation of the Ilanz paleo-lake. This lake increased rapidly its level and induced a flow caused through the breaking of the dam. The part of the lake that remained was filled up by sediments and finally the Vorderrhein river started eroding the valley floor down to the actual level (Poschinger 2005). In conclusion, the overlap of 2 m DEM analysis, orthophoto and cartographic information allow to collect a lot of information and also to recognize, correlate and map different type of Quaternary landforms and deposits.

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Figure 1. An extract of the Quaternary map of Reichenau: digitalization with points and lines (above) and the final result with polygons (below). See details in the text.

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P 10.6

Quantifying glacial erosion and relief evolution using luminescence thermochronometry (Granite Range, Alaska)

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Long-term exhumation and topographic evolution of mountain belts arise from complex coupling between tectonics, climate and surface processes. The recent development of luminescence thermochronometry (e.g., Herman et al., 2010; Guralnik et al., this volume) and its very low closure temperature (0-60°C) opens a new spatial and temporal "window" to study latest stages of rock exhumation, and address the nature of Quaternary topographic relief changes. We apply this new method in the Wrangell-St Elias National Park (Alaska), an alpine landscape that exhibits typical glacial features (U-shaped valleys, cirques, moraines). This setting provides an exceptional opportunity to study potential differences in relief evolution under a gradient of glacial forcing. We sampled four elevation profiles over an 80-km East-West transect across the Granite Range, where there is a consistent eastward increase in mean elevation, glacier activity, and topographic relief.

Feldspar separates from 15 bedrock surface samples were dated using the IR-50 protocol, and exhibit good internal reproducibility. Apparent ages vary from ~250 ka in the western part of the range, to younger ages of ~30 ka in the east, thus supporting the notion of amplified glacial activity on the east. Using a kinetic model to convert apparent ages into mean cooling histories, our work reveals spatially variable erosion rates during the late Quaternary, with preferential high-altitude erosion in the eastern part of the Granite Range and localized valley incision on its west. This represents the first quantification of relief limitation (so-called "glacial buzzsaw") in an active mountain range, and demonstrates the potential of luminescence thermochronometry in resolving topographic evolution and surface processes over 100-kyr timescales under high-frequency climate modulations (e.g., glacial-interglacial oscillations).

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P 10.7

Four years of avalanche erosion measurements in the Guggigraben catchment, Canton Valais

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Dense wet-snow avalanches breaking through to the base of the snowpack or overriding snow-free surfaces can entrain basal material and act as important agents of sediment transport in steep alpine catchments. Here we present results from four years of measurements quantifying the volume of coarse rock sediment transported by avalanches each winter. We then use these values to calculate catchment-wide erosion rates. The seasonal transported sediment load was estimated at the Guggigraben fan (Matter valley, Canton Valais) by measuring the debris content within a number of representative areas and then extrapolating the cumulative volume. Results reveal a total transported sediment volume of 150 m³ in 2009, 13 m³ in 2010, 13 m³ in 2011, and 41 m³ in 2012, which when distributed over the entire catchment area yield catchment-wide erosion rates of approximately 0.1, 0.01, 0.01, and 0.03 mm/year, respectively. Observed differences in transported sediment volumes are caused not only by varying total yearly snowfall, but also by the timing and rate of spring snowmelt. Sediment is sourced predominantly from within the main channel or one its four tributaries, originating first as rockfall or regolith landslides. Avalanches thus play an important role in the Guggigraben catchment in transporting loose sediment from temporary storages to the fan and main river system. As the avalanche deposits melt in spring, entrained sediment is set down gently, often resulting in precariously balanced boulders and rows of blocks perched on the walls of the fan's main channel. In flat lying areas, snowmelt results in sparse sediment deposits with no clear structure or sorting. Observations show that the fan surface is usually protected from erosion by snow and older avalanche deposits, which provide a smooth gliding plane for new events. Within the bedrock gully at the apex of the fan, and in the avalanche source region above, signs of abrasive wear were evident on exposed bedrock surfaces. These included rounded and scoured bedrock, fresh signs of boulder impacts, and scratch marks on the rock walls.

P 10.8

Quantifying rockfall hazards through injury counting on the bark of trees

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Introduction

Over the past decades, numerous studies revealed the great potential of dendrogeomorphic techniques for the analysis of natural hazards. In this contribution, classical tree-ring reconstructions were used to assess past rockfall activity focusing on conifers. This "classic method" allows a very accurate dating of historic events; however it represents a very time-intensive method. With the aim to reduce time and effort of tree ring studies dealing with rockfall, we suggest a new method requiring less effort and compare it to the classical approach. The new method is based on the counting of visible scars on the stem surface of Common beech (*Fagus sylvatica* L.).

The study site selected for analysis has a surface of 3ha, an inclination of 40° and is covered with a mixed forest composed of *Picea abies* (L.) Karst., *F. sylvatica* and *Pinus sylvestris* (L.). It is located in the Inn valley near the city of Innsbruck (Tyrol, Austria). A roughly 200m high, south facing limestone cliff is the release area for the rock fragments, which are generally stopped by the forest or by the rockfall nets above the railway line.

Methods

Increment cores were taken from 33 *P. abies* and 50 *F. sylvatica*. Different sampling strategies were applied for the different species: three to four cores (144 in total) were taken for *P. abies* and only one core per tree (50 samples) for *F. sylvatica*. Firstly, rockfall events in the spruce trees were identified by typical growth disturbances in the tree-ring series such as tangential rows of resin ducts, scars, callus tissue or reaction wood and dated with yearly precision. Secondly and as mechanical impacts remain clearly visible on the bark of beech trees, rockfall events in beech were derived by simply counting visible rockfall impacts on the stem surface. Recurrence intervals were calculated for each individual tree by dividing the age of the tree by the number of impacts. Results were visualized by spatial interpolation.

Results

The analysis of the spruce increment cores yielded a total of 431 growth disturbances corresponding to 277 rockfall events since AD 1819 whereas the systematic observation of injuries on the stem surface of the beech trees allowed the identification of 1140 rockfall impacts.

Significant differences in absolute numbers of rockfalls result in different return intervals of rockfall events. With the "classic" dendrogeomorphic approach used for the analysis of the spruce trees, a mean return period for the entire study area of 18.4 years was computed. In contrast, an average recurrence interval of 8.7 years was derived from the beech trees. Differences were less marked for observed average jump heights with 0.9m for spruce and 0.7m for beech trees, respectively.

Spatial patterns of return periods are comparable independently of the approach used (Fig. 1): in both cases, higher rockfall frequencies are observed in the upper part of the study area as well as a canalizing effect of activity stemming from the relief.

Conclusion

Both methods yield reliable data on the spatial distribution of rockfall frequencies and jump heights in the study area, but results vary for different reasons. Due to the bark properties of beech, smaller rocks or rocks with lower kinetic energy will not damage spruce trees but still leave scars in the thin bark of beeches. Differences in return intervals can be due to the differences in tree locations as well as to the fact that multiple impacts in the same year would only be counted one event in spruce whereas each injury in the beech trees would constitute an individual event. Hence, a reconstruction solely based on increment cores from spruce trees runs the risk of underestimating absolute recurrence intervals whereas impact counts on beech trees may lead to some overestimation of rockfall activity and resulting return intervals in case that the impact of individual rocks leaves multiple scars on the stem surface.



Fig. 1. Interpolated (inverse distance weighting) recurrence intervals (in years) for A) spruce trees and B) beech trees

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Detection of surface changes in a torrent channel and comparison of surveying techniques

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Debris flow events have threatened mountain communities for centuries. The knowledge of triggers and process behavior is essential for an effective risk management. Recent events have shown that due to efficient erosional processes within the channel the debris flow can strongly increase in volume and cause unexpected high damage in the runout area. During the event the channel morphology is strongly reworked and debris entrainment changes the flow dynamics. Both highlighted factors are not included in numerical simulations of debris flows and debris flow erosion and deposition are still poorly understood. Methods to study the highly variable processes are in their infancy and standardized approaches are still missing. The present study aims to detect surface changes and quantify erosion and deposition caused by debris flow and bedload transport. A further topic is the evaluation and comparison of surveying techniques. The study contributes to a research project on improving simulation of debris flows (cf. Bühler et al. 2010; Christen et al. 2010). Due to the lack of debris flow events during the field season the work focuses upon methodological problems.

Field work was conducted during the summer season 2011 in the Dorfbach in Randa. The debris flow channel was surveyed by means of cross sections measured with a laser rangefinder (TruPulse 360B) combined with a differential GPS (Trimble GeoXH6000). In addition, further measurements were carried out with a terrestrial laser scanner (Leica ScanStation C10). Geomorphological mapping and a photo documentation were established in order to integrate punctual surveying data into the overall situation. The data collected allows the comparison of at least three terms and an evaluation of continuous as well as event-based changes. Surveying methods are evaluated with regard to the analysis of erosion and deposition by debris flows. The applied surveying techniques are compared with further methods described in literature, which in this study results in a methodological recommendation.

A first assessment of the collected data highlights, that no major morphological changes occur in the channel without a debris flow or bedload transport event. Detected continuous changes may be caused by variations in the watercourse or the collapse of instable bank segments. The volumetric change due to erosion amounts to 30 - 100m³ and to 15 - 50m³ caused by deposition within a surveyed channel area of 2460m². Furthermore, the surface changes as a result of a flood in August 2011 are clearly detectable and verifiable with photos. For this event, erosion amounts to 520 - 560m³ and deposition to 680 - 730 m³ for the same channel area. The applied surveying methods both allow change detection with an accuracy of a few decimeters. Therefore the collected data is by far detailed enough to detect surface changes caused by debris flow events. When evaluating the applicability of different methods for the aims stated, data quality issues are considered as well as local preconditions, resolution requirements and logistic aspects. Further results as well as their discussion and a conclusion are presented in the poster.

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P 10.10

Hazard mapping and an early warning system for lake outburst floods in the Cordillera Blanca, Peru

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The Peruvian Cordillera Blanca is strongly affected by climate change impacts, like many other high mountain regions around the world. The combination of a high population density in close vicinity to steep slopes and retreating glaciers has led to some of the most devastating glacier-related mass movement disasters where thousands of people were killed during various events over the past decades (Carey, 2005). The main hazards include ice/rock avalanches, debris flows and glacier lake outburst floods (GLOFs), which are often parts of complex process chains. There are strong concerns that climate change favors such mass movements by destabilizing perennially frozen bedrock and steep glaciers, and that the frequency and magnitude of these events might increase in future (Huggel et al., 2010).

To prevent such disasters, an early warning system is currently being implemented in the Río Chucchún catchment above the city of Carhuaz (~9000 residents). At this site, successful prevention measures took place in the early 1990's, when the water level of the proglacial rock-dammed Lake 513 has been lowered by 20m (Reynolds et al, 1998). However, the changing thermal conditions in the steep and glacierized rockwalls above the lake is a probable trigger of a huge rock-ice avalanche, which occurred on April 11, 2010. Its impact wave in Lake 513 overtopped the freeboard and led to a debris flow and flood which reached down to the alluvial fan of Carhuaz. Fortunately, no victims were claimed, but a lot of agricultural land and several bridges have been destroyed. According to the current state of the glaciers, larger avalanches with more serious consequences cannot be excluded.

In a first step, the hazards have been analyzed and the hazard map elaborated by the 'Instituto Nacional de Defensa Civil' in 2004 has been updated (Figure 1). This has been done by applying an avalanche model (RAMMS::avalanche) for different scenarios, a lake impact and flood wave simulation model (IBER), and by using segment-wise varying frictional rheologies for a debris flow model (RAMMS::DEBRIS FLOW) to account for the complex flow transformations.

As a second step, a technical early warning system is currently being implemented in the field. It is composed by two main measurement stations, a repeater station to transmit the signal, and a communication and data center in the town of Carhuaz (Figure 1). The stations cover two aspects: (I) a long-term perspective that includes high quality climatic and discharge measurements by a new station at 3600m a.s.l., and automatic multi-temporal daily photographic monitoring of the steep glacierized flanks of Nevado Hualcán. This will enable to better characterize the local climatic characteristics, the water balance of the catchment, and to detect changes in the stability of the hanging glaciers. The system further comprises (II) a real-time early warning system for rock-ice avalanches and debris flows. It is based on 4 geophones near the avalanche source area at 4491 and 4752m a.s.l., which activate two cameras in the case of an event. To reduce the risk of false alarms the civil defence needs to verify the alarm based on the video images, and the event needs to be confirmed by other geophones and the discharge measurement sensor at the lower station at 3600m a.s.l. Despite of the redundancy of the sensors, an intense testing and calibration phase will be particularly needed for the geophones to achieve a high level of confidence in the system.

The next steps include instructing the responsible authorities, establishing the alarm chains, informing the population about the hazards, and finally the implementation of acoustic alarms at some sites within the flood path and the alluvial fan to alert the population in time in case of a hazardous event.



Figure 1. Río Chucchún catchment above the city of Carhuaz with the updated hazard map and the stations of the monitoring and early warning system (background: Alpenvereinskarte 1:100,000).

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P 10.11

Bewirkt ein Extremereignis eine Veränderung des Systemzustands in Wildbacheinzugsgebieten? Fokus: Auswirkungen auf den Geschiebehaushalt – Fallbeispiel Lötschental

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Aussergewöhnliche Witterungsbedingungen (langanhaltende Starkniederschläge, hohe Neuschneemengen und markantes Tauwetter) führten am 10.10.2011 an den Nordhängen des Lötschentals zu einem Extremereignis aus geomorphologischer Sicht. Während mehreren Stunden wurden ungewöhnlich grosse Mengen an Feststoff von den nördlichen Seitenbächen, insbesondere vom Golm-, Mili- und Tännbach, der Lonza zugeführt oder auf den Kegeln abgelagert. Dieses Ereignis führte zu Schäden hauptsächlich an der Infrastruktur und zur Unterbrechung der Strassenverbindungen im Lötschental. In den Einzugsgebieten wurde starke Tiefenerosion um mehrere Meter an den Bachsohlen sowie eine räumlich differenzierte Verbreitung des Gerinnebetts und Hanginstabilitäten festgestellt. Bemerkenswert ist, dass in direkt benachbarten Einzugsgebieten (Gafenbach, Gisentella) hingegen nur eine geringe Geschiebeführung beobachtet werden konnte. Spuren von geomorphologischer Aktivität fehlen in diesen Einzugsgebieten (Geoplan AG, 2012).

Ziel dieser Arbeit ist die Analyse der unterschiedlichen Reaktionen dieser Wildbacheinzugsgebiete auf die aussergewöhnlichen Witterungsbedingungen anhand des Konzepts der Disposition (Grunddisposition, variable Disposition, Auslöser; Zimmermann et al. 1997). Im Konzept der Disposition werden räumlich und zeitlich variable Aspekte, die zu Murgängen oder Geschiebeführung beitragen, beleuchtet und somit auch die Veränderung des Systemzustandes über die Zeit analysiert. Die Vergleichsanalyse erfasst daher räumlich und zeitlich differenzierte Informationen zu Relief, hypsometrische Flächenverteilung, Materialeigenschaften und -verfügbarkeit, Bodenbedeckung bzw. -nutzung und hydro-meteorologische Bedingungen in den fünf Einzugsgebieten. Das auslösende Ereignis (aussergewöhnliche Witterungsbedingungen) wird mit weiteren in der Vergangenheit erfassten Auslösebedingungen in diesen Einzugsgebieten verglichen. Zusätzlich wird mittels der Geschiebeabschätzungsmethode nach Lehmann (Lehmann 1993) das Geschiebepotential erfasst und jenen vor dem Ereignis gegenübergestellt. Ergebnisse der Studie werden aufzeigen, welche Unterschiede hinsichtlich Grunddisposition, variable Disposition und Auslöser in den Einzugsgebieten vorherrschten. Zudem sollen die Ergebnisse Auskunft geben über die Auswirkung des Extremereignisses vom 10.10.2011 und deren Bedeutung zur Beurteilung der aktuellen Disposition (mögliche gravierende Veränderungen der Grunddisposition oder der langfristigen variablen Disposition).

Eine ausführliche Beschreibung des Konzepts, inhärente Schwierigkeiten und Herausforderungen sowie erste Ergebnisse werden präsentiert.

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P 10.12

Process interactions during damage-relevant torrent events in the Swiss Alps

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Research on single geomorphological processes during damaging events has a long history; however, comprehensive documentations and analyses of the events have been conducted not until the late 1980ies. Thus, for high damaging events insights about triggering, the evolution and the impacts of processes during an event and the resulting damage were produced. Though, in the majority of cases the processes were studied in a well-defined procedure of one disciplinary focus. These focused studies neglect mutable influences which may alter the sequence of the process or the event. During damaging events multiple geomorphological processes are active which leads to the assumption, that they have a certain impact on each other and the course of damaging effect. Consequently, for a comprehensive hazard and risk analysis all processes of a catchment have to be analysed and evaluated quantitatively and qualitatively (MARZOCCHI, 2007). Although the demand for a sophisticated risk management is increasing, the research on interactions as well as on physical vulnerability to multiple hazards, including the different processes impact effects, is still very limited (KAPPES ET AL., 2010, 2011). The challenges in this field are the quantity of data needed and furthermore to conduct this kind of analysis is very complex and complicated (GREIVING ET AL., 2006, KAPPES et al. 2012). Yet, knowledge about possible interactions and resulting impact effects could significantly contribute to the reduction of risk in a region (DI MAURO ET AL., 2006).

The objective of this study is to analyse, i) how geomorphological processes interact with each other and with other factors of the surrounding during a damaging event, ii) what influences those interactions have on the resulting damage of the event and iii) whether or not different events are comparable in terms of those interactions and their impacts. To meet these objectives, 15 torrent damage events, which occurred between 2000 and 2011 in the Bernese Oberland or the Pennine Alps, were analysed on the basis of the event reports. The interactions were classified into different categories regarding a process and the interacting counterpart (another process, with structures or disposition) and the temporal and spatial extent in which these interactions occurred. Additionally positive and negative feedbacks of the processes were considered.

First results highlight that some types of interaction can be extracted in several events and that their temporal and spatial extent is comparable. However, the analysis (so far) indicates that single interaction exhibit multi-path consequences which complicate to educe general propositions for interactions influencing damage from event documentation. In the further step of this study, clusters of interactions which could occur in different events in similar ways are analysed in more detail.

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11. Cryospheric Sciences

J. Alean, A. Bauder, B. Krummenacher, J. Nötzli, C. Lambiel, M. Lüthi,

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- 11.1 Girard L., Gruber S., Weber S., Beutel J.: Continuous monitoring of near-surface damage in a freezing rock-wall
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11.1

Continuous monitoring of near-surface damage in a freezing rock-wall

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The formation of ice within rock is believed to be an important driver of rock damage near the surface and up to several meters depth. In steep terrain, this process may be crucial for the slow preconditioning of rock fall from warming permafrost areas. Large thermal gradients than can occur close to the rock surface can yield thermal stresses that are also a potential source of damage.

So far most knowledge about these processes stems from theoretical studies or laboratory experiments. However, the transfer of corresponding theoretical insight and laboratory evidence to natural conditions characterized by strong spatial and temporal heterogeneity is nontrivial.

In order to address this problem we have developed a measurement system to investigate in-situ rock damage using acoustic emissions, rock temperature and liquid water content. The measurement system has been deployed on a rock-wall at Jungfraujoch, at 3500m.a.s.l. in the central Swiss alps, and has been continuously monitoring for a year-long period.

The results suggest that frost damage occurs (i) on a wide range of sub-zero temperatures, rejecting the concept of a frost cracking window proposed in previous studies, (ii) with intermittent dynamics (i.e. it is not a continuous process), and (iii) with a strong dependance on the local water saturation level of rock.

Symposium 11: Cryospheric Sciences

On the sensitivity of different mountain permafrost occurrences to climate change

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To evaluate the sensitivity of mountain permafrost to climatic changes and to assess its future evolution, not only climatic variables such as air temperature, radiation and timing and duration of snow cover, but also subsurface characteristics such as ground ice content, porosity or hydraulic properties have to be considered. In general, simulations with physically-based coupled heat and water transfer models for the subsurface (in the following referred to as 'pf-model') can be used to investigate the impacts of climatic changes on permafrost on the local scale of specific field sites. Using observed atmospheric and subsurface data for calibrating the pf-model one can simulate the evolution of ground temperature, ice content and the future variability of the depth of the active layer by forcing the pf-model with plausible future time series taken for example from Regional Climate Models (RCMs) downscaled to a specific location (Engelhardt et al. 2010, Scherler et al. submitted).

In order to transfer these site-specific results to the sensitivity of different mountain permafrost landforms in general, it is necessary to determine the permafrost conditions, which are most susceptible to (for example) degradation in the context of climatic changes, i.e. radiation, air temperature and precipitation changes. The "permafrost conditions" mentioned above may hereby comprise subsurface variables such as ground temperature, ice content, active layer depth, porosity, thermal and hydraulic conductivity of the host material, but also topographical factors such as slope angle and altitude.

Starting with 100-year projections from combined RCM-permafrost model simulations for two different permafrost sites in the Swiss Alps, we will focus in our contribution on the dominant influencing variables at mountain permafrost sites that determine whether a specific site is endangered to rapid permafrost degradation or exhibit a more stable thermal regime. Additionally, observations from various field sites are used to analyse further permafrost landforms and surface characteristics (Isaksen et al. 2011, Schneider et al. 2012). The sensitivity is hereby quantitatively expressed as the amount of active layer deepening per year per %-change of the respective variable, e.g. air temperature change. Alternatively, a multiple linear regression between active layer depth and the various influencing factors can be performed to find the dominant variables, at least in a statistical sense (Scherler et al. submitted).

The results indicate that the evolution of summer temperatures are dominant for high altitude stations with long-lasting snow cover and low ground ice contents, whereas autumn/early winter temperatures and the specifics of the snow cover evolution are dominant for sites at lower altitude and with smaller snow cover thickness. Coarse blocky sites have usually higher ice contents and are less sensitive to climate changes due to the combined effect of thermal insulation by the air voids in the ice-free near-surface layer and of the energy sink through increased demand of energy for the melting of the high ice contents in the permafrost layer. Consequently, for the currently projected future climate in Switzerland as simulated by RCMs from the EU-Ensembles programme, largest increases in active layer thickness may be expected for fine-grained (or low-porosity), low-ice content sites with substantial snow cover and without the presence of a surficial blocky layer.

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11.3

Intermittent snow drift - experimental study and analysis

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Snow drift due to wind is important and has been studied for many years, for example Clifton et al. (2006), who studied threshold wind speeds for snow drift, or Gordon & Taylor (2009). The redistribution of snow by wind has been shown to be important for small scale snow variability in the alps (Mott et al. 2010) and also has an impact on the mass balance of sea ice.

After several experiments with a particle counter type measurement technique a two-dimensional high speed imaging system was installed in the SLF wind tunnel in Davos. The drifting particles are illuminated with a bright lamp and the camera is positioned so that the shadows of those particles are recorded. An example image with size 30 mm × 50 mm is shown in figure 1a.

This technique was used to study drift of fresh naturally fallen snow by recording 10 images with separation of 0.3 ms. These sets were recorded every 2 s. Therefore it was possible to detect particle size (based on equivalence diameter), velocity and the total particle mass flux at a rate of 0.5 Hz with the software DAVIS (LaVision).



Figure 1. a) Shadowgraphic image (original size . b) Time series of particle number per image.

Figure 1 b) shows distinct peaks in the number concentration of particles approximately one order of magnitude larger than the mean value were observed. Since snow behaves different than solid spherical particles, one set of experiments was conducted with sand, which did show much less pronounced peaks with maximum values a factor three larger than the mean.

These maximum drift events have a duration of less than 10s. An analysis of the dynamics was performed and found that there is a negative correlation of particle streamwise velocity and particle mass flux, indicating the momentum coupling of snow mass flux with the wind. Inspection of the films showed that small structures as in figure 1 a) grow and finally break and a large number of particles is released instantaneously. This intermittent behavior might have important consequences for the modeling of total snow mass flux, since the momentum coupling between wind and particles is highly non-linear.

An additional variation of drift had been observed also on a much slower scale of the order of 5 min, see figure 1b), which shows that the drift becomes very low and becomes larger again. On a beach, Davidson-Arnott & Bauer (2009) have observed that sand particles had to be dried first before removed at a considerable rate, leading to increased sand flux with time. Hence, in our experiment the bonding between that particles could create a drift pattern which shows increased drift after elapsed time of several 10 min. To support this suggested mechanism, we estimated the surface sublimation rate by assuming a fully developed boundary layer flow (relative humidity during the experiment was 77%) which results in reduction of bond size by a factor of two within the order of 10 min. Hence, this estimate indicates that the changing bond size between single snow particles could lead to strongly time dependent drift rates at a slow scale. To clarify this, experiments with (nearly) saturated air are planned in the wind tunnel for the coming winter season.

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11.4

A fiber bundle damage model for viscoelastic ice

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We consider a damage model for viscoelastic ice which is inspired by the widely-used fiber bundle approach. Starting from a one-dimensional model, we develop a multiaxial constitutive model. Viscous deformation is considered as an intermediate configuration in addition to reference and present configuration, which are all three embedded into vector spaces by a local-convected approach. This allows to consistently define the delayed-elastic deformation as the local displacement between viscous and present configuration, and damage as a function of it. Furthermore, we briefly discuss thermodynamic aspects of our theory.

11.5

Storage and release of persistant organic pollutants (POPs) from glaciers

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Glaciers accumulate solid precipitation in form of ice, and with it materials ranging from chemical species to dust and stones. Only under steady climate conditions the release rate of these materials, and water, is constant. Under a varying climate there exist cold periods with reduced release of accumulated water and chemical species, as well as warm periods when water is released at high rate. During the warm periods, high concentrations of chemicals and sediments are released from the glacier. We present results from a transient glacier model which allows us to quantify these processes. In case studies for Oberaargletscher and Silvrettagletscher we show that persistent organic pollutants (POPs) emitted to the atmosphere in the 1950-1960s were stored in the glacier and are released at high rate during the last decade. Consequently, the concentration of toxic POPs in the proglacial lakes are as high as during the time of atmospheric impact, which agrees with measurements in sediment cores.

11.6

Future sea level rise contribution from Greenland's local glaciers and ice caps; the impact of predicted high Arctic precipitation changes.

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Glaciers and ice caps (GIC) on Greenland have yet received limited attention, mainly because a complete glacier inventory was missing until recently. According to the new Greenland glacier inventory published by Rastner et al. (2012) local glaciers and ice caps cover an area of ~89000 km2, about 1.5 to 2 times the values of previous estimates.

Based on the new inventory we calculated future sea level rise contribution (2000-2098) from surface mass balance of all of Greenland's GICs using a simplified energy balance model which is driven by two different climate scenarios from the regional climate models HIRHAM5 (forced from ECHAM under the A1B scenario) and RACMO (Hadgem2-forcing under RCP4.5 scenario). Glacier extent and surface elevation are modified during the model run and mass balance as well as glacier surface change is calculated on a 250 m resolution digital elevation model. Yielding unprecedented level of detail in the modelling of very large glacier samples, this ensures that important feedback mechanisms such as the influence of changing surface elevation on mass balance are considered.

Mass loss of all Greenlandic GICs by 2098 is calculated to be 2050 Gt with HIRHAM5 forcing and 2650 Gt using RACMO. This corresponds to a total contribution to sea level rise of 0.59 or 0.76 cm by the end of the century. The calculated rates in mass loss are nearly identical to observed 2003-2008 values (Bolch et al., subm). However, in contrast to the observations, the modelling does not yet address dynamical mass loss from calving. Total mass loss of Greenland's GICs by 2098 is thus likely to be larger when calving loss is considered.

For the north-east of Greenland it is shown that increasingly negative summer mass balances are largely compensated by a distinct increase in precipitation. Thus glaciers change their characteristics towards greater activity and mass turnover; an observation of considerable importance to modelling efforts of glaciers and ice caps. Modelled future glacier mass balances in the southern half of Greenland are dominated by increasingly negative summer mass balances with no significant change in winter mass balance. HIRHAM5 and RACMO forcing both indicate a similar pattern of precipitation change over Greenland, possibly related to the forecasted continued decrease in Arctic sea ice cover.

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Figure 1. Volume change relative to the initial volume for six selected regions. The applied RCMs are abbreviated with HIR (HIRHAM) and RAC (RACMO) (Figure modified from Machguth et al., subm.)

11.7

Monitoring of Ice Sheet Dynamics in Greenland Using Seismological Techniques

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The Greenland ice sheet contributes about 0.67 mm per year to global sea level rise (Spada et al., 2012). In order to project trends in ice sheet mass balance into the future, interaction between changes in surface melt and ice flow has to be reliably modeled. In this context, a profound understanding of subglacial drainage system is crucial, since its influence on basal motion are critical for ice sheet dynamics (e. g. Zwally et al., 2002; Bartholomew et al., 2010; Sundal et al., 2011).

In order to investigate controls on basal motion, influence of melt water, and subglacial drainage system, the ROGUE¹ (Real-time Observations of Greenland's Under-ice Environment) project was initiated as an international collaboration between ETH Zurich and several institutes in the US. Combining in-situ measurements with numerical modeling, the main project goal is to analyse the drainage system of the Greenland ice sheet and its influence on the dynamics of ice flow. The two main field study sites were located in Western Greenland's ablation zone near Swiss camp, some 30 km north of Jakobshavn Isbræ.

The main field component of the ROGUE project consisted of the 2011 deep drilling campaign and subsequent borehole instrumentation to monitor englacial deformation and temperature as well as subglacial water pressure. Additionally, GPS instruments measured surface flow velocity, while atmospheric and melt conditions were monitored with an automatic weather station and pressure sensors in surface streams and a prominent moulin.

For the duration of 1.5 months a passive seismic network complemented the glaciological point-measurements with the main goal to monitor englacial dislocation sources down to glacier bed. The network consisted of 17 stations including 11 short-period (1 Hz) seismometers at the surface, 3 short-period (8 Hz) borehole sensors (150-350m deep) and 2 collocated broadband seismometers.

The seismic monitoring produced a rich data set including waveforms of icequakes from within the ice sheet and from surface crevasse formation, iceberg calving from nearby Jakobshavn Isbræ, and water-induced tremor.

In this presentation we focus on seismic signatures of englacial water transients and hydrofracturing. These signals are particularly interesting in view of the englacial and subglacial drainage system and its capability to adapt to changes in surface melt. Specifically, we report long-term (>1 hour) tremors induced by englacial water flow during the afternoon hours of days with high melt rates (Figure 1). The tremor signals exhibit different intensities throughout the network indicating a source location near a major moulin. Centered around 4 Hz, the tremor frequencies undergo minor variations, which correlate well with recorded water level in the moulin (Figure 1). We plan to study tremor frequency spectrum in more detail to reveal geometry and temporal evolution of englacial water-filled cavities and conduits.

Finally, we report on icequakes as strong evidence for hydrofracturing at around 100 m depth near the tremor-generating moulin. The icequake shows a typical impulsive, high-frequency (>30 Hz) onset and is followed by a brief 4 Hz tremor signal. As this is close to the frequency of the long-term tremor, we suggest that both water passage as well as hydrofracturing stimulate resonance of the same or similar water-filled englacial channels.

Our results demonstrate that investigations of ice sheet seismicity ideally complement conventional glaciological and geophysical measurements.

¹ http://www.ig.utexas.edu/people/staff/gcatania/rogue.html http://www.vaw.ethz.ch/people/gz/luethim/projects/data/gz_rogue_seismic

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Figure 1. Spectrogram (bottom, unfiltered) and waveform (top, bandpass filtered 1-10 Hz) of the vertical component of the seismic signal during 24h of observations for a 1Hz LE-3D seismometer. The moulin water level (middle) correlates with the occurrence and shape of the seismic tremor.

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11.8

Tracking wetting of a snowpack using upward-looking ground-penetrating radar

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Percolating melt water combined with snow stratigraphy are thought to be the dominating drivers for the formation of wet-snow avalanches. It is, however, difficult to model or measure water flow in a sloping snowpack. For modeling, results highly depend on the type and availability of input data and the parameterization of the physical processes; in the case of sensor deployment, problems with snow gliding and avalanches will arise. In addition, if sensors are placed within the snowpack they will influence the flow of water. Radar technology allows scanning the snowpack non-destructively and deducing internal snow properties from its signal response. If the radar is buried in the ground, it cannot be destroyed by avalanche impact or snow creep.

During the winter seasons 2011-2012 we recorded continuous data with an upward-looking pulsed radar system (upGPR) operating at a frequency of 900 MHz which was placed next to a well-known wet-snow avalanche path. At the same time, we recorded the avalanche activity by observing the avalanche path with time-lapse photography.

We showed that it is possible to operate a solar-powered radar system in a remote site under harsh conditions. Following the signature representing the transition from dry to wet snow, we successfully monitored the advance of percolating water. We determined the bulk volumetric liquid water content and tracked the position of the first stable wetting front. Concurrent wet-snow avalanche activity tended to be high when the water penetrated deeper into the snowpack. Avalanches released when the wetting of the snow reached the bottom of the snowpack. This correspondence suggests that improving the prediction of wet-snow avalanche activity with the help of remotely operating upGPR systems buried in representative starting zones might be feasible.

11.9

Measuring and understanding winter mass balance and snow depth distribution on alpine glaciers from LiDAR DEM differentiation, GPR and snow soundings

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End-of-winter snow distribution is the key factor for the winter mass balance of alpine glaciers and is thus fundamental for understanding and modelling glacier changes. Measuring the winter mass balance using the direct glaciological method provides point measurements only. A better understanding of processes controlling deposition and redistribution of snow, however, requires spatially distributed information on snow depth and its variability. In this study we present simultaneous measurements from 2010 using not only the glaciological method but ground penetrating radar (GPR) and Light detection and ranging (LiDAR) digital elevation models (DEM). Our study site is Findelengletscher, Valais, Switzerland, a large alpine valley glacier (13.4 km²).

The glaciological survey provides snow depth data from 463 soundings and density measurements at 13 snow pits across the glacier (Figure 1). Spatially distributed snow depth and snow water equivalent are gained through extrapolation in the same way as it is done when using the glaciological method for mass balance evaluation.

Differentiation of LiDAR DEMs (Joerg et al., in review) has previously been used to assess snow depth distribution. Usually,

the influence of the vertical component of glacier flow is neglected. In the case of Findelengletscher, however, this leads to a strong misfit with glaciological in-situ measurements. The required correction is based on the 5-year mass balance record and observed geometry changes. This estimation of annual average vertical velocity is then scaled to fit the subannual time span between the two LiDAR scans. Since glacier dynamics vary throughout a year this is done by minimising the RMSE with in-situ measurements.

The 500 MHz GPR survey was carried out from helicopter as done previously (Machguth et al., 2006). It covers 12.7 km of linear tracks with 12'000 radar traces. Travel times are converted to depth using a constant velocity estimation based on the measured snow density.

The corrected LiDAR-differentiation and the glaciological method show good agreement in the mean specific winter mass balance of 0.73 m w.e. and 0.78 m w.e. respectively. They disagree in crevassed areas and in the accumulation area where firn compaction affects the LiDAR-derived snow depth. The quality of the distributed mass balance that is used to obtain the correction for glacier flow directly limits the quality of the distributed snow depth data set. However, this data set allows analysing the relation of snow depth to surface topography such as elevation, slope and curvature. The performance of a multiple linear regression using these variables varies strongly within the glacierized area. So far, no simple model was found that could explain snow depth on the entire glacier with reasonable correlation.

Comparison with the GPR snow depth measurements indicates that the glaciological method is affected by a systematic bias that comes from non-representative sampling sites. Thereby, GPR proves to be an attractive tool for snow depth measurements with relatively small uncertainties. Unlike LiDAR-differentiation it is not affected by glacier dynamics and firn compaction in the accumulation area. However, LiDAR provides truly distributed data with high resolution that is not directly achieved by GPR or conventional glaciological measurements. The simultaneous availability of all three data sets is unique and their comparison and combination draws a detailed image of winter snow accumulation that benefits from each method's advantages.



Figure 1. Snow probings, GPR profile lines and difference between corrected LiDAR-derived snow depth and extrapolated snow probings in April 2010 on Findelengletscher, Switzerland.

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11.10

Climate change impacts on glaciers and runoff in Tien Shan (Central Asia)

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Climate-driven changes in glacier-fed streamflow regimes have direct implications on freshwater supply, irrigation and hydropower potential. Reliable information about current and future glaciation and runoff is crucial for water allocation and, hence, for social and ecological stability. Although the impacts of climate change on glaciation and runoff have been addressed in previous work undertaken in the Tien Shan ('water tower of Central Asia'), a coherent, regional perspective of these findings has not been presented until now.

In our study, we explore the range of changes in glaciation in different climatic regions of the Tien Shan based on existing data. We show that the majority of Tien Shan glaciers experienced accelerated glacier wasting since the mid-1970s and that glacier shrinkage is most pronounced in peripheral, lower-elevation ranges near the densely populated forelands, where summers are dry and where snow and glacial meltwater is essential for water availability. The annual glacier area shrinkage rates since the mid-twentieth century are 0.38-0.76% a⁻¹ in the outer ranges, 0.15-0.40% a⁻¹ in the inner ranges and 0.05-0.31% a⁻¹ in the eastern ranges. We used glacier change assessments based both on direct data (mass balance measurements) and on indirect data (aerial and satellite imagery, topographic maps). The latter can be plagued with high uncertainties and considerable errors, which highlights the need for continued *in-situ* mass balance and ice thickness measurements. Efforts should be encouraged to ensure the continuation and re-establishment of mass balance measurements on reference glaciers, as is currently the case at Karabatkak, Abramov and Golubin glaciers (Figure 1).

Although in the first instance shrinking glaciers supply ample quantities of water in the form of increased glacial runoff, reduced glacier volume will ultimately result in a decrease in both glacier-fed and total runoff, if there are no increases in water amount from other sources. Accordingly, long-term average annual runoff in Kyrgyzstan has increased from 47.1 km³ (~1947–1972) to 50 km³ (1973–2000) and the current level of total runoff is likely to remain stable in the near future or could even further increase slightly. By the end of the 21st century, however, total runoff is projected to be smaller than today. Analysis is still hampered by compensating effects such as changes in precipitation and evaporation as well as an-thropogenic influences, rendering an appropriate identification of factors controlling discharge difficult. For instance, decreasing runoff during the ablation season can be compensated for by higher winter runoff from increased liquid precipitation. More integrative studies addressing changes in all runoff components (precipitation, groundwater, and meltwater from snow, glaciers and permafrost) are therefore required for better appraisal of the degree of glacial depletion and subsequent changes in glacial runoff. The impact of snowcover changes, black carbon and debris cover on glacier degradation needs to be studied in more detail. Only with such model approaches, reflecting transient changes in climate, snowcover, glaciation and runoff, can appropriate adaptation and mitigation strategies be developed within a realistic time horizon.

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Figure 1. Cumulative mass balances (solid lines) and reconstructions (dashed lines) of selected Central Asian glaciers. The horizontal black line indicates the level at first measurement. Source: WGMS 2009 and earlier volumes.

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P 11.1

Micro-computed tomography of salted snow

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High salt amounts (between 8-40 t salt per km) are applied during wintertime to maintain the safety of the national road network. A typical day of maintenance costs about 1mio Swiss Francs [1]. In addition, the melt water with high salt concentration is harmful for soil and groundwater [2, 3].

Although salt has been used for the treatment of snowy roads in wintertime for many years there is only limited understanding of the effect of salt to snow regarding thermodynamic and especially mechanical processes. The thermodynamics of salted snow, its sintering process and mechanical properties have not yet been systematically investigated or measured. Up to now there exist only little empirical data (e.g. [4]). Most of the theory on snow sintering and metamorphism is based on dry snow. Wet snow is mainly investigated for its hydraulic properties, but again little data exist for mechanical properties.

To understand the physical properties of salted snow information about microstructural properties is crucial. By microcomputed tomography (microCT), the three phases air, ice and brine (salt solution) can be distinguished due to their different X-ray absorption coefficients (Figure 1). All three phases can be observed in-situ. This opens the possibility to use time-lapse methods. Changes in size and distribution of air, brine and ice can be extracted afterwards.

Samples with increasing amount of NaCl-solution were mixed with snow and compressed under a load of ~2 bars for 2 h. Afterwards, the samples were analyzed by microCT. Results of the microCT evaluation will be shown.



Figure 1) 2D micro-CT images of a salt-snow mixture with 45 w% NaCl measured at -18°C. *Left*: Sample immediately after adding and mixing with salt solution. *Right*: Same sample 21 days later.

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Orientation of snow crystals: Evolution of orientation during temperature gradient metamorphism

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The physical properties of snow are tied to its microstructure. Especially for the slow, plastic deformation of snow, the crystal orientation could be an important factor in addition to the geometry of the ice matrix. Micro-CT measures precisely the snow microstructure, but gives no information about the orientation of the ice crystals. In this study, we applied a temperature gradient of 40 K m⁻¹ to two large blocks of undisturbed decomposed snow during 3 months. The absolute temperature at the sampling location was -20°C. Two closely spaced snow samples were taken before heating, then every week during the first month and afterwards every month. From each sampling period, one sample was analyzed in the micro-CT and the other was used for thin sections preparation. The thin sections were analyzed using a G50 fabric analyzer. The results show that not only the shape and size of the crystals change, but also the orientation. In our experiment, the orientation of the crystals change in one snow group from a predominantly vertically oriented c-axes fabric to a fabric where the c-axes are mainly horizontal, but randomly oriented in plane. In the other snow group, no evolution was observed. These preliminary results suggest that several factors impact the evolution of the crystal orientation, such as density, pore space and the initial snow crystal fabric.



Figure 1. Depth hoar thin section analyzed with the Fabric analyzer G50. Each color corresponds to a different c-axis orientation of the snow crystals. C-axis orientation and color are related through a color wheel (bottom left).

Acoustic emissions related to avalanche release

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We intend to find acoustic precursors within the snowpack prior to avalanche release. The acoustic emission technique is commonly used to study the rupture of brittle materials (see, e.g. Johansen and Sornette, 2000). The rupture events are observed to obey power-law distributions (with exponent β). A change in the rupture process (transition from a stable to an unstable regime) can be associated with a change in the exponent β of the size-frequency distribution of the event energy and of the waiting time distribution of the events (Pisarenko and Sornette, 2003). Within natural hazards this behaviour was shown for icequakes prior to a glacier break-off by Faillettaz et al. (2011).

We performed laboratory experiments where we loaded snow samples containing a weak layer and measured acoustic emissions. Preliminary results suggest that prior to the catastrophic failure of the snow samples the change in exponent was observed as well.

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Tracer-LIF (Laser-Induced-Fluorescence) measurements of water flow through snow

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Many wet and gliding snow avalanches caused several accidents during the winter 2011/2012 in the European Alps, demonstrating the need for a better understanding of the formation of these events. Predicting regional wet snow avalanche danger depends on factors like the structure of the snowpack, the energy transferred from the atmosphere and the ground into the snowpack and the rate of water percolation through the snow. A lack of knowledge exists on the micro-scale water flow through snow. Most studies mainly quantify the total flow through the snow matrix for different snowpack layers neglecting the micro-scale flow dynamics and preferential flow path generation. A detailed description as a basis for quantitative understanding, however, requires investigations of the microscopic velocity fields in the pore space.

We present spatiotemporally highly resolved Tracer-LIF measurements of the water flow in the pore space of a wet snow sample driven by gravitational and capillary forces. For the experiments, cooled water seeded with fluorescent micron-sized particles (tracers) is carefully sprinkled onto the top of the snow sample, which is placed behind a Plexiglas window. The snow sample is illuminated with laser light and the fluorescent light of the tracers is filmed with a high-speed camera. The measurement resolution is 15 µm × 15 µm per pixel.

Fig. 1 shows the resulting, with tracer-LIF measured particle trajectories. Each velocity vector is labelled with a colour indicating the particle velocity at a specific location. The travel time of a relatively long particle track is included ($\Delta t = 0.84$ s). The total measurement time was 1.35 s. The path of this particle shows a strong deflection around a snow crystal of a size of about 1 mm. A wider flow path with a relatively high particle density and high particle velocities occurred around {*x*, *z*} = {5 mm, 7 mm} in Fig. 1. Another interesting feature is found at {*x*, *z*} = {4 mm, 2 mm}. Particles enter a small pore space with a relatively high velocity, get deflected by the snow matrix performing almost a 360° loop at a lower velocity and leave the pore space again at a higher velocity. This flow loop and all other trajectories show that the flow within the snow sample is highly 3-dimensional.

LIF measurements were extensively used for investigations of the flow fields in porous media and fills, however, this is the first study applying LIF to snow. LIF measurements in snow will open a wide range of possible investigations like analysing capillary effects or the transition from water filled pores to melt water percolation.



Figure 1. Particle trajectories for a gravity driven, saturated water flow in a wet snow sample. Colours of arrows indicate particle velocities.

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P 11.5

Towards the automatic detection of seismic signals generated by snow avalanches

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Snow avalanche activity data represent the most direct instability data for avalanche forecasting. Avalanche activity is usually estimated based on visual observations, which are imprecise and impossible at night or when visibility is limited. To overcome this limitation, seismic monitoring has been developed over the last 20 years to detect snow avalanches. While it holds great potential, seismic detection of avalanches is not widely used due to a lack of accurate classification algorithms to detect avalanche events from passive seismic data. To tackle this problem, we used seismic data from a geophone directly inserted in an avalanche start zone. By visually analyzing the spectrogram of the seismic data, over 380 avalanches were identified for the winter of 2010 over an area of about 2 km2. To automatically detect these avalanche events in the seismic data, a pattern recognition workflow was developed. It consisted of three steps: 1) event selection, 2) feature extraction, and 3) classification. The results are quite promising: our workflow achieves 93% overall classification accuracy with 13% precision for detecting avalanches for the entire season. Though we obtained successful classification accuracies, the low precision rates of our model indicates that there is still room for improvement. In the coming winter, we therefore intend to deploy an array of geophones to allow for the localization and characterization of avalanches with the goal to improve the automatic avalanche detection workflow.

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P 11.6

SNOWPACK model uncertainty and future trends of the Swiss snowpack

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Snow is a key feature of mountainous environments because of its high implications on hydrology, vegetation and economics, such as winter tourism or hydropower (Beniston et al. 2003, Marty 2008). In particular, snow depth, the stored snow water equivalent, the snow load on a roof or the duration of the snow on the ground are all important parameters for services like road maintenance, avalanche warning, water management, hydro power, flood prevention or building code regulations. The measurement of these snow parameters is either not always possible or too expensive. To overcome this problem, snow models are often used, such as the complex one-dimensional, physically based snow model SNOWPACK, which numerically solves the partial differential equations governing the mass, energy and momentum equation within the snowpack (Lehning et al. 2002).

In order to make meaningful statements considering the Alpine snow cover under future climatic conditions, it is very important to verify SNOWPACK in its ability to correctly model snow characteristics such as snow depth or duration of snow cover. As input data, SNOWPACK needs air temperature, relative humidity, wind speed and direction, incoming short- and long-wave radiation, and precipitation intensity. As most stations do not provide incoming long-wave radiation data, it needs to be parameterized, for example using methods described in Flerchinger et al. (2009). Moreover, due to wind-induced errors, it is not meaningful to take precipitation measurements directly as input into SNOWPACK, so they need to be calibrated or corrected.

The aim of this poster is to highlight the abilities of SNOWPACK in modeling various relevant snow parameters, as well as showing future trends of the Swiss snowpack at selected sites in Switzerland. Therefore we concentrate on the ability of SNOWPACK in modeling climatological characteristics of the snow cover, such as snow depth, maximum snow depth, length of snow season, and so on. For the assessment of the future trends, scenario data of the recently released CH2011 report will be used in order to perturb the observed time series of temperature and precipitation.

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Estimation of snow cover distribution in alpine catchments by application of airborne laser scanning

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The storage of winter precipitation in the snow cover is a substantial source for runoff generation in high mountain catchments. The spatial distribution of snow accumulation is influenced by topographic parameters, such as slope, aspect and wind exposure. In high alpine catchments complex relations exist between the glacier surface and the snow accumulation, and vice versa.

Measuring the snow cover distribution by in situ measurements in terms of snow probing and snow pits delivers spatially limited data due to the restricted accessibility in the rough terrain. Airborne laser scanning (ALS) is a remote sensing technique to record point information of the surface elevations with a high spatial density of several points per square meter. From these points digital elevation models (DEM) can be produced. Comparing the multi-temporal DEMs delivers surface elevation changes in a high spatial resolution of 1 meter and even higher.

Within the alpS project MUSICALS_A, ALS campaigns were conducted in the alpine catchments of the Ötztal Alps in autumn and spring. The surface elevation changes were initially interpreted in terms of snow depth and converted into snow water equivalent (SWE) using a statistical relation between observed snow densities and snow depths. These maps of SWE show characteristically snow accumulation patterns due to glaciation and redistribution processes forced by wind and gravity and thus provide an ideal basis for comparison with model outputs of fully distributed snow hydrological models (e.g. AMUNDSEN). Results can be used for calibration of the model components in terms of total precipitation sums and snow redistribution. Hence runoff generated by spatial differentiated snow melt can be modelled more realistically.

On glacier surfaces dynamical processes of ice flow and compaction of firn additionally induce surface elevation changes at these areas, both with negative and positive signs. A set of in-situ measurements of snow depth by ground penetrating radar, DGPS measurements and snow probing at glacier surface was compared to elevation changes measured by application of ALS for one snow accumulation season. The magnitude of elevation changes caused by snow and ice dynamical processes can be detected by the combination of these methods.

P 11.8

Historical glacier variations in southern South America since the Little Ice Age: examples from Lago Viedma (southern Patagonia) and Mendoza (central Andes)

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There is considerable historical evidence for European glacier dynamics over the past centuries. Evaluation of this information allows reconstructing glacier length variations from the Little Ice Age (LIA) until the present. For several glaciers, reconstructions with decadal or annual resolution can be achieved (e.g. Zumbühl *et al.* 2008, Nussbaumer and Zumbühl, 2012). These revealed that there is a striking asynchrony between Alpine and Scandinavian glacier fluctuations, both during the LIA and in the 20th century. In South America, historical information is much less abundant, but early photographs and maps depict changes for selected glaciers before the onset of modern measurements. Here we provide new evidence to the South American glacier history. Written documents and pictorial historical records (drawings, sketches, engravings, photographs, chronicles, topographic maps) have been critically analysed, with a particular focus on two regions: Lago Viedma (El Chaltén, southern Patagonia, 49.5°S, 73.0°W) and the Río del Plomo basin (Mendoza, central Andes, 33.1°S, 69.9°W).

For the Lago Viedma area, early historical data for the end of the 19th century stem from the expedition of the Chilean-Argentinean border commission (led by the Argentine Francisco P. Moreno). Glaciar Viedma, an outlet glacier of the Southern Patagonian Icefield, is richly documented. In addition, the expedition by the German Scientific Society, conducted between 1910 and 1916, and the photographs by Alberto M. de Agostini, an Italian padre, geographer and ethnographer, give an excellent depiction of the glaciers.

For the Mendoza area, historical sources go back to the arrival of the Spanish conquerors, particularly related to the finding of new routes across the high Andes in the second half of the 18th century. In the beginning of the 20th century, Robert Helbling (1874–1954), a Swiss geologist and pioneer of alpinism, explored the Argentinean-Chilean Andes together with his friend Friedrich Reichert (Reichert, 1946). In the summer of 1909/10, they started a detailed survey of the highly glacierized Juncal-Tupungato mountains, leading in 1914 to the first accurate topographic map of the area. In 1934, the sudden drainage of a glacier-dammed lake in the upper Río del Plomo valley caused fatalities and considerable damage to constructions and the Transandine Railway. A similar event is reported to have occurred in 1786 according to historical records.

Finally we compare the observed glacier fluctuations of the two regions with other glacier reconstructions available (e.g. for northern Patagonia), to give an overview of the glacier evolution in southern South America since the LIA. According to historical evidence and dendro-geomorphological analyses, the LIA maximum occurred between the 16th and 18th century. However, there is a large spatial variability (Masiokas *et al.* 2009). Those observations can be compared with recently developed, high-resolution multi-proxy temperature and precipitation reconstructions. This allows an assessment of the spatial pattern of glacier changes in southern South America, differentiating local effects from regional or larger-scale climate dynamics.



Figure 1. Comparison of Glaciar Piedras Blancas (El Chaltén, southern Patagonia) in 1931 (photo by A. M. de Agostini) and 2012 (photo by S. Nussbaumer).

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Current evolution of some high mountain debris-covered glaciers in western Alps

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The Alps and the cryosphere are some of geographical regions and geosystems the most affected by the current global change. However, local alpine environmental responses are heterogeneous and complex. In this way, numerous glacier system behaviours exist, depending of various regional (*e.g.* annual temperature and precipitation) and local (*e.g.* solar radiation, distribution and thickness of debris cover) factors. Valley ice-bared glaciers are broadly more sensitive to climate variations than high mountain debris-covered glaciers. Indeed, the occurrence of debris mantle (insulation layer) and the localization of this kind of glacier systems within the periglacial belt (roughly above the isogeotherm of -2°C) allow a better preservation of the ice.

Differential GPS measurements and Electrical Resistivity Tomography surveys were carried out on Les Rognes - Pierre Ronde (Mont-Blanc Massif, France), Entre la Reille (Diablerets Massif, Vaud) and Tsarmine (Pennic Alps, Valais) glacier systems. Due to their topographical situation and the numerous Holocene climatic variations, they are characterized by large amounts of debris in the distal part (morainic dam). Periglacial landforms (rock glaciers, push-moraines) occur in these systems located within the periglacial belt. Moreover, the negative mass balance of these glacier systems is reflected by the absence (or limited existence) of an accumulation area (and so the limitation of ice supply) and by the covering of the ablation area on which ice volume is slowly decreasing. In this poster we discuss the kinematics and the internal structure of these three glacier systems.
P 11.10

Ice volumes in the Himalayas and Karakoram: evaluating different assessment methods

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Knowledge about the mass of freshwater stored in Himalayan and Karakoram (HK) glaciers is of particular interest, as this region has the largest glacier coverage outside the polar regions, and hundreds of millions of people live in the lowlands along the rivers draining these mountains. Recent debates, including the so-called 'IPCC glaciergate', revealed considerable gaps of knowledge and understanding of glaciers in this region (e.g. Bolch et al. 2012). Better information about glacier volumes and the ice thickness distribution are required to improve assessments of the future development of these glaciers and their impacts on the hydrological cycle. As direct measurements of glacier volumes on regional scales are not possible, ice thickness and volume assessments have strongly to rely on modeling approaches. Here, we estimate ice volumes of all glaciers in HK using three different approaches, compare the results, and examine related uncertainties and variability.

The approaches used included volume-area scaling using different scaling parameters, a slope-dependent thickness estimation (adapted from Haeberli & Hoelzle 1995), and a new approach to model the ice-thickness distribution based on the approach of Linsbauer et al. (2012). Glacier outlines have been compiled from different state-of-the-art glacier inventories (Bajracharya and Shrestha 2011; Frey et al. 2012) and revealed an overall ice covered area of ~40,800 km² (Bolch et al. 2012). Topographic information has been obtained from the void-filled version of the Shuttle Radar Topography Mission digital elevation model (SRTM DEM).

The volume-area scaling approach resulted in glacier volumes ranging from 3632 to 6455 km³, depending on the scaling parameters used. The approach for slope-dependent thickness estimations had to be adjusted to the modern glacier inventory data, and generated a total ice volume of 2330 km³. A total volume of 2955 km³ resulted from the modified ice-thickness distribution model. With the exception of the volume-area scaling, results are clearly at the lower bound of previous estimates or even smaller, and possibly hint at an overestimation of the potential contribution of HK glaciers to sea-level rise.

The range of results also indicates that large uncertainties still persist in ice volume estimations. Comparisons with *in situ* measurements like ground penetrating radar (GPR) are hampered by the fact that (a) almost no suitable results of GPR measurements on glaciers are available for the study region; and (b) that only the results of the ice-thickness distribution model would allow such comparisons. By applying different combinations of model parameters and by altering glacier areas by ±5%, uncertainties related to the different methods are evaluated.

The distributed ice-thickness modeling approach leads to the most reliable results, as it is based on simple but robust icemechanical considerations rather than extrapolated statistical relations. It allows comparisons with *in situ* measurements and it has numerous potential further applications (Linsbauer et al. 2012). Therefore, the use of such models can be recommended, although they are more labor intensive than statistical scaling approaches. In combination with digital glacier outlines and DEMs with (near-) global coverage, they offer the possibility to improve ice-volume estimations of the HK region, but also of other glacierized mountain ranges.

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Information on glacier dynamics from probabilistic icequakes location (Triftgletscher, Switzerland)

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The precise characterization of icequake sources offers valuable insights into local stress, the presence of water and basal sliding. The reliability of the conclusions however strongly depends on the accuracy of hypocentral locations, which is therefore a key point for the interpretation of icequakes record in terms of glaciological processes. The present study focuses on seismic data from Triftglescher, Switzerland, which has been monitored since 2007 due to its steep tongue prone to break-off. Using continuous seismic records from an on ice campaign network we determine icequake hypocenters with the probabilistic source location method implemented in the software NonLinLoc. The calculations offer a perspective on what degree of accuracy can be achieved for icequake locations. Investigated area was described by means of a 3D velocity model including both ice and bedrock media. Our locations reveal icequake sources near the glacier surface as well as near the bed.

We interpret both types of events in terms of glacier dynamics: shallow seismic emission is discussed with the help of surface strain rate analysis, and the capability of near bedrock icequakes to be explained with double couple source mechanisms or tensile fracturing is assessed. Finally, we propose some clues for the detection of periods characterized by enhanced break-off risk.

P 11.12

Using glacio-speleological methods to test GPR interpretations about changes in dynamics, thermal state and drainage system of Tellbreen, a high arctic glacier on Svalbard

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Glacier response to climate change has attracted a large amount of research effort in recent years (WGMS, 2008). Most of this has focused on glacier changes in length, area, volume and mass. However, glaciers can also respond to climate change by altering their thermal condition and drainage system configuration. In turn, these internal changes can influence glacier dynamics and mass balance, and either damp or amplify glacier response to climatic forcings. Relatively little research has been conducted on long-term internal changes to glacier systems, largely due to the difficulty of obtaining data on past glacier states.

Recent developments in glacio-speleology have opened up new opportunities to make direct observations of glacier drainage systems, and gain access to glacier beds and basal ice sequences (Gulley et al., 2009a, b). Exploration of englacial and subglacial conduits, therefore, allows the simultaneous investigation of: (1) the present state of the glacier drainage system and basal thermal regime; and (2) past states of the glacier through study of basal ice characteristics.

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In 2011 and 2012 speleological mapping of 3 different caves has been conducted in Tellbreen, a cold-based glacier in central Spitsbergen, Norway. These explorations have shown that the conduits have both englacial and subglacial components, and some sections are even incised into the glacial till. Furthermore, these findings indicate that Tellbreen had formerly at least partly a temperate bed and was much more dynamically and geomorphologically active during its Little Ice Age maxima than it is today.

This study demonstrates the capability and applicability of glacio-speleology to test findings based on indirect methods such as Ground Penetrating Radar (GPR) made by Baelum & Benn (2011). Additionally it reveals the present and especially the past behaviour of Tellbreen in a new light.



Figure 1. Exploring and mapping of one side channel of Smokey Cave in Tellbreen. Channel dimensions at this position: width 9m and height 3m. © Philipp Schuppli

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Understanding the response of very small glaciers in the Swiss Alps to climate change: An integrated study approach applying different monito-ring techniques

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To date, glaciological research in the European Alps (especially in the Swiss Alps) has been focussing on medium and large valley glaciers (> 3 km²), which account for the major part of the glazierized area and ice volume or fresh water storage. However, present knowledge about Alpine glaciers is somehow not representative in terms of glacier size distribution, as more than 80% of all Swiss glaciers are smaller than 0.5 km² (Huss 2010). They belong to the class of very small glaciers, occurring mostly in circues, niches and below headwalls where topoclimatical factors and snow accumulation patterns are favourable for the persistence of snow and ice. It is not clear whether the findings and theoretical concepts elaborated for medium and large valley glaciers can be transferred one to one to very small glaciers (Kuhn 1995). Thus, this study takes a first step in filling the relevant knowledge gap about the behaviour and response of very small glaciers in the Swiss Alps to climate change.

So far, the only very small glacier investigated in Switzerland is Pizol glacier (SG), where direct mass balance measurements since 2006 provide a first example for their response to climate change (Huss 2010). This mass balance monitoring program will be continued as part of this study. Furthermore, a number of additional very small glaciers covering the entire Swiss Alps was chosen as appropriate study glaciers. This year, direct mass balance measurement campaigns have been started on Glacier du Sex Rouge (VD), St. Annafirn and Schwarzbachfirn (UR), Blauschnee (AI) and Vadret da Corvatsch (GR). Planned annual terrestrial LiDAR surveys of the surface of these glaciers will allow derivation of geodetic mass balances as well.

Measured ice thickness data is available for some few very small glaciers. This database is being extended within this study. Ice thickness was already directly measured on St. Annafirn (UR) and Glacier du Sex Rouge (VD) using Ground Penetrating Radar (GPR). Further GPR surveys on other glaciers will follow.

The first results gained so far show that topoclimatical factors, snow redistribution (wind drift) and avalanching seem indeed to play an important role in the mass balance of very small glaciers. Accumulation and ablation patterns show a high small-scale variability. Over the past few decades, very small glaciers in the Swiss Alps vanished dramatically and even more than large or medium sized valley glaciers. Thus, they probably react more sensitive and faster to current climate change. From 2006 to 2011, Pizol glacier showed large mean annual mass losses of about 1.5 m w.e. Surface area and ice volume losses are significant as well. Since 1850, St. Annafirn (UR) lost more than 80% of its surface area, with an accelerating trend over the past four decades. On average, St. Annafirn is still about 13 m thick, with maximum thicknesses up to 40 m (Fig. 1). The estimated ice volume is 2'197'000 m³ (0.0022 km³). This corresponds to one third of its modeled ice volume in 1973 (Linsbauer et al. 2012). The freshwater still stored in St. Annafirn roughly amounts to 2/3 of the volume of Lake St. Moritz.

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Figure 1. St. Annafirn near Gemsstock (Andermatt, UR): Area loss since 1850 and current (2012) ice thickness modeled from linear GPR measurements. Underlain to the digitized glacier outlines is a high-resolution (25 cm) swissimage orthophoto taken in autumn 2010 (swisstopo).

P 11.14 A straightforward method for the automated calculation of glacier flow lines.

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Glacier flow lines are an important concept in glaciology. Basically they describe the direction of the ice flow from accumulation zone to the ablation area. Flow lines are used in various flow modelling concepts (e.g. Greuell, 1992) and they are essential to assess the length of a glacier.

Nevertheless, defining glacier flow lines on complex glacier geometries is not a trivial task and certain properties of the glacier surface (e.g. convex cross-sectional surfaces in the ablation areas) prevent the calculation of flow lines from using hydrological flow models. Flow lines are generally drawn manually, an approach that becomes unfeasible when flow lines for large glacier samples would be required. Only recently a first semi-automatic method has been developed that allows calculating central flow lines using GIS software (Le Bris, subm).

Here a straightforward approach for the calculation of surface glacier flow direction is presented. For input the flow line computation requires glacier polygons and a Digital Elevation Model (DEM). The method relies on two basic criteria and a series of trade-off functions between them. The output is a set of flow lines comprising every individual branch of a glacier. The approach is fully automated and no glacier, glacier-type or region specific adjustments are made.

The method was tested for regions with numerous local glaciers on Greenland (i.e. outside of the ice sheet). Thereby the flow line computation was found to work well on all types of glaciers including the ice caps. The DEM used is of intermediate quality (GIMP-DEM, Howat et al., in preparation) and it remains to be tested to what degree a lower quality DEM (e.g. GDEM v2, Tachikawa et al., 2011) will influence model performance.

The automated computation of flow lines for extensive glacier samples is believed to open up new possibilities in glacier flow modelling and calculation of past as well as future glacier extent. At the same time a more automated determination of geometrical properties such as the glacier length might become possible.

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Symposium 11: Cryospheric Sciences

Caterpillar-like flow of the Greenland Ice Sheet: observations of basal control on ice motion.

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Caterpillar-like flow of the Greenland Ice Sheet: observations of basal control on ice motion. Varying basal motion due to episodic basal water supply is a long-established component of ice flow. However, the physical processes that govern the role of water in basal motion still remain only weakly understood. We instrumented four boreholes at two sites with sensor systems to better understand the processes controlling seasonal flow velocity variations in the marginal zone of the Greenland Ice Sheet. We present measurements of borehole deformation, subglacial water pressure and surface motion during one year (July 2011 to September 2012). Subglacial water pressure and ice deformation show periodic variations on several time scales which are delayed by up to half a period, depending on sensor depth. These observations are interpreted as ice motion in a caterpillar-like fashion, as opposed to the conventionally assumed shear flow. Using a time-dependent, Full-Stokes ice flow model we find that spatially and temporally varying basal motion can explain the observed variations in deformation, and the delayed reaction at different depths. These new data show that the reaction to basal motion is not uniform throughout the ice column, but varies with depth.

Complex age-depth relation in a mid-latitude glacier

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Glacier highstands since the Last Glacial Maximum are well documented for many regions, but little is known about glacier fluctuations and lowstands during the Holocene. This is due to the fact that the minimum extent is not imprinted in specific features like terminal moraines and that those areas are currently ice covered, limiting the access to sample material. In this study we report a different approach, using a 72 meter long surface-to-bedrock ice core drilled on Tsambagarav glacier in the Mongolian Altai (4140 m asl, 48°39.338'N, 90°50.826'E). This for the region typical flat-top glacier has low ice temperatures and a flat bedrock topography at the drill site which are ideal properties for a climate archive.

The ice core from Tsambagarav glacier was dated with a variety of methods, including identification of reference horizons, annual layer counting, nuclear dating with ²¹⁰Pb, and a novel ¹⁴C technique.

The upper two third of the ice core correspond to the period 1815 to 2009 AD with annual resolution and strictly follows simple glacier flow models proposed by Nye (1963) or Thompson et al., (1990). For the lower third of the ice core faster layer thinning than predicted by flow models was identified. Such characteristic has already been noticed before for other midlatitude glaciers frozen to bedrock (Thompson et al., 1998). The section 43 to 52 m weq experiences stronger thinning than the section below and above, a characteristic we explain through varying accumulation rates. To deduce a continuous timescale an empirical equation was derived by using the ¹⁴C results.

Radiocarbon measurements of the basal ice revealed an age of approximately 6000 years before present (BP). We interpret the basal ice age as indicative of ice-free conditions at 4100 m asl prior to 6000 years BP. This age marks the onset of the Neoglaciation at the end of the Holocene Climate Optimum. Since most glaciers in the Mongolian Altai have comparable or lower elevation we conclude that they are not remnants of the Last Glacial Maximum but were formed during the second part of the Holocene. The ice core derived accumulation suggests significant changes in the precipitation pattern over the last 6000 years. During formation of the glacier wetter conditions than presently prevailed, followed by a long dry period from 5000 years BP until 250 years ago. This is consistent with the precipitation evolution from lake sediment studies in the Altai.

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Ice level changes from seasonal to decadal time-scale at Lava Beds National Monument, NE California, USA

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Numerous lava tube caves host seasonal or perennial ice accumulation in the Lava Beds region (Halliday 1954, Knox & Gale 1959). Regular ice level monitoring has been conducted for eight ice caves since 1990, and additional five caves were also included into the monitoring network during recent years.

Monitoring data reveal that the seasonal cave ice phenology can be characterized by autumnal ice level low-stands. Regarding the multiannual evolution, both positive and negative ice mass balance periods were detected during the past 23 years.

Positive mass balances were reported for many caves from the late 1990s. Ice level is still stable in Skull Ice Cave, B-020 and U-200. However severe ice loss has characterized the evolution of the other caves. Major ice loss started in 1998-99 in the Merrill, C-270 and M-470 ice caves, while not until 2003 in L-800.

The recent rapid ice melt was fatal for some caves. Perennial ice disappeared from M-470 and M-475 by 2005 and from Merrill Ice Cave by 2006, for instance.



Figure 1. Secular decline of ice volume in six major Lava Beds NM perennial cave ice deposits. Historical ice level changes can be extended back to 1956 at Merrill Ice Cave by ice level estimations based on stratigraphic (Sowers & Devereaux 2000) and archival photographic (Fuhrmann 2007) records.

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Towards an integrative analysis of mountain permafrost monitoring elements

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Surface and subsurface characteristics have to be considered in addition to climatic variables to evaluate the sensitivity of mountain permafrost to changing atmospheric conditions. To this end, the sub-project TEMPS-B of the newly funded SNF Sinergia project «The Evolution of Mountain Permafrost in Switzerland» (TEMPS, 2011–2014) follows a landform-specific approach. It utilizes a vast data set available from two decades of permafrost monitoring in Switzerland, which comprises meteorological, geophysical, kinematic, and ground thermal parameters from more than 20 established sites in the Swiss Alps.

It was shown in a few case studies that the different monitoring parameters complement each. Their joint analysis is essential in order to comprehensively understand the response of mountain permafrost to climatic changes. In the TEMPS-B project, the unique data set from the PERMOS network is used together with the data from a new automatic geoelectric monitoring system and a model to calculate ice and water contents for a time-dependent quantification of the subsurface composition of various sites featuring different typical permafrost landforms. By this, the interdependencies between atmospheric forcing and changes in subsurface ice and water contents as well as ground temperatures are analyzed on a broader scale. This will enable sound statements beyond singular case studies.

To perform joint statistical analyses of the different monitoring parameters, the data will be integrated and homogenized in the first place. In a next step, e.g. landform-specific dominant factors responsible for changes in subsurface ice and water contents or regional climatic impacts on different permafrost sites can be identified. Further, the 4-phase fractional composition (rock/air/ice/water) of the subsurface and its temporal changes shall systematically be determined for different landforms based on individual geophysical surveys and high-resolution geophysical monitoring.

The evolution of ground surface temperatures and rock glacier dynamics in the Furggentälti Valley (Gemmi, VS)

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In the western part of the Swiss Alps near the Gemmipass, a long-term permafrost monitoring site has been installed by the University of Berne in 1987 to observe the further development of three rock glaciers and different periglacial processes and landforms (Mihajlovic et al. 2003). Situated in a relatively warm and wet climate at elevation levels between 2450 and 2850 m asl., this test area became one of the longest permafrost-related temperature and kinematics time series in the Swiss Alps and owns the "reference site" status within the national permafrost monitoring network PERMOS. The main goal of the current research in this area is to improve the understanding of the rock glacier dynamics regarding the evolution of ground surface temperatures and terrain movements observed during the past two decades.

Over the monitoring period several climatic events occurred and the air and ground temperatures and the kinematics as well show significant changes in long-term and a high seasonal and interannual variability. Furthermore the activity pattern and the morphology of the largest and lowermost rock glacier in the valley were completely changing during the last decade. Some parts at the rock glacier sides seem to become inactive while creep velocities in the center were increasing up to 400% compared to the average velocity before 1990 and thus forming distinctive shear zones (Krummenacher et al. 2008).

A signal-response analysis using meteorological data, ground surface temperatures, terrestrial photographs and kinematic data show that the overall rock glacier movements react very sensitive to climatic events (e.g. Delaloye et al. 2008 and Kääb et al. 2007). As the snow cover is modulating the atmospheric forcing at the ground surface and thus represents a key parameter for the ground thermal regime, its dynamics might also have a big influence on the kinematics. Probably a mostly temperature-driven creep mechanism is superimposed by landslide-like movement components which are sensitive to melt water infiltration and therefore causing acceleration connected to the snow melt period (like discussed in Ikeda et al. 2008). Compared with findings from other permafrost research sites in the Swiss Alps, the interannual variability of rock glacier creep follows a similar pattern (Delaloye et al. 2008).

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12. Advances in applied hydrology and limnology

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Commission for Hydrology CHy Swiss Society for Hydrology and Limnology SGHL Operational Hydrology Working Group GHO

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	alpine catchment	

- 12.2 Halder J., Vennemann T.: Application of stable water isotopes to evaluate tributary mixing and micropollutant fate in Swiss lakes
- 12.3 Jörg-Hess S., Fundel F., Jonas T., Zappa M.: A statistical approach to refining snow water equivalent climatologies in the Swiss Alps
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- 12.9 Wever N., Fierz C., Jonas T., Lehning M.: The dual nature role of the snow cover in rain on snow events and a note on latent heat

POSTERS:

- P 12.1 Darvishi Khatouni J., Lak R., Mohammadi Ali: Hydrogeochemistry and Brine Evolution of Urmia Lake (NW of Iran)
- P 12.2 Rinderer M., Kollegger A., Fischer B.M.C., Stähli M., Seibert J.: Sensing with boots and trousers A new qualitative field method to capture shallow soil moisture patterns in wet environments
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12.1

Investigating spatial and temporal runoff generation mechanisms in a Swiss pre-alpine catchment

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Spatial and temporal rainfall and runoff data of mountainous catchments are generally sparse and even when they exist, more detailed information such as groundwater levels or isotopic data are usually lacking. This makes difficult to identify runoff generation processes and system conditions.

Here we present first results from a new data set collected during three years of measurements in the Zwäckentobel, a 4.3 km² Swiss pre-alpine catchment in the Alptal. The high annual precipitation input, flashy character of stream flow dominant wet conditions and the existence of long-term data for one sub-catchment make this catchment an exciting study area for investigating rainfall-runoff processes. An open challenge is the runoff contribution of sub-catchments and the response of individual streams to storm flow in space and time.

The presented research projects try to address these issues at different temporal and spatial scales and with different approaches but one final goal: Advancing the understanding of runoff generation processes of steep pre alpine catchments in space and time. At a larger scale the focus was on comparing several sub-catchments, which differ in size, topography and land-cover. The aim was to learn from differences, similarities and to put each catchment into perspective at different scales. Three snapshot campaigns were made during steady flow conditions with about 100 water sampling locations. From this information spatial patterns and their underlying ordering mechanisms were extracted. During storm flow the basic question was whether different sub-catchments respond differently to rainfall and if so whether the runoff contribution processes could be used to explain the differences? For the Zwäckentobel, six sub-catchment were instrumented in addition to the one long term reference catchment and rainfall, runoff and isotope concentrations were measured and compared among the sub-catchments.

To capture surface- and subsurface flow processes in detail one of the sub-catchments (20 ha) was selected and instrumented with a spatially distributed groundwater measuring network. Sites were distributed to cover a representative range of wetness conditions and morphology. Within the sub-catchment stream flow discharge of seven nested sub-watersheds was constantly measured. The aim of this detailed study was to identify governing controls of groundwater dynamics, which can then potentially be transferred to ungauged site within the sub-catchment or neighbouring catchment to predict groundwater dynamics under consideration of system conditions and precipitation input.

Here we present first results of this combined study applying hydrometric, hydrochemical and isotope data in a complementary manner to learn more about the key controls of runoff generation in wet pre-alpine catchments. 12.2

Application of stable isotopes of water to evaluate tributary mixing and micropollutant fate in Swiss lakes

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The isotope network of Switzerland (ISOT) is regularly measuring the isotope compositions of surface water, precipitation and groundwater at 23 sampling locations (BAFU 2009). This provides a large data base and wide range of applications. In the framework of this study ISOT data were used in combination with stable isotope compositions of water, obtained from depth profiles taken throughout Lake Geneva. The overall research goal was to study the hydrodynamics of the lake and evaluate micropollutant transport. In principal the research idea is based upon the fact that rivers, which originate from high altitude, do have a distinct oxygen and hydrogen isotopic compositions compared to a lake, which is also fed by other water sources with a watershed at lower altitude. The presented method may therefore be applicable for several peri-alpine lakes in Switzerland and elsewhere.

Results of stable isotope compositions show that the Rhône River is interflowing in the metalimnion during stratification and Rhône River water could be traced for the first time for about 55 km throughout the lake. In summary, these findings suggest an alternative method compared to more conventional methods such as, for example, conductivity to trace river water dispersion and to monitor future changes in the hydrodynamics of Lake Geneva. This issue may become more important considering the extension of reservoirs as well as renaturalisation projects in the watershed, which may potentially change Rhône River water density. In combination with the induced warming of the lake epilimnion due to global warming (CIPEL 2011), changes in the interflow depth of the Rhône may have an impact on the oxygenation and nutrient cycling in Lake Geneva.

In addition to river mixing the method also allows to trace wastewater dispersion, which is discharged into the Bay of Vidy, Lausanne. Micropollutants, which have been detected in the Bay of Vidy (Bonvin et al. 2011) seem to be derived mainly from the wastewater treatment plant, however may also originate from diffusive sources. The stable isotope compositions of water allows to quantify the Rhône River water interflow into the Bay of Vidy, as well as to estimate of the fractions of wastewater, dilution factors and sources of micropollutants.

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12.3

A statistical approach to refining snow water equivalent climatologies in the Swiss Alps

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Reliable information about snow water equivalent (SWE) is important for estimating water resources in specific areas. SWE also is a relevant state variable in hydrological models set up for alpine areas. In Switzerland the density of available monitoring networks allow to directly generate highly resolved SWE maps using data interpolation and assimilation techniques. However, varying station densities over the past decades pose difficulties when trying to calculate spatially-explicit SWE anomalies or compare current with past snow situations. At the same time, accurate evaluations of this sort are becoming increasingly important in lake and reservoir management during the spring melt. This contribution elaborates on the effect of station density on assimilated SWE maps. We come up with a procedure to enhance maps from years with limited availability of monitoring data based on spatial patterns recorded in years for which more data is available.

Two distributed SWE climatologies have been produced: A short climatology of daily SWE maps over 9 years (2001-2009) based on 203 measuring stations and a longer climatology (39 years) based on data from 110 stations. In a first step the quality of the shorter climatology is evaluated by cross validation against station data. This short climatology is considered as reference data set and represents the most accurate distributed snow information available. By utilizing a quantile mapping approach (Panofsky and Brier, 1968; Fig 1), the 39-year climatology is improved based on calibration to the reference climatology. The approach accounts for elevation, region, season and amount of snow, and is done separately for each grid cell and day.

First, the results of the quantile mapping are tested for the nine overlapping years 2001-2009. As a result of the calibration, the difference between the two SWE climatologies could nearly be removed in most regions. Additionally an independent evaluation is performed, using four additional stations that were not used for the reference data set. The quantile mapping is further evaluated for the non-overlapping period 1971-2000 with an independent dataset. Finally, the value of the enhanced long climatology will be illustrated by way of three sample applications. The first application uses the hydrological model PREVAH. In the second application the SWE distributions of the three climatologies are compared. The predictability of discharge using SWE is shown in the third application.



Figure 1: Illustration of quantile mapping. The quantile of the long climatology value is replaced by the value of the same quantile of the reference climatology.

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NRP61/SWISSKARST Project. Mapping karst water resources using KARSYS approach. Application to the Bernese Jura (BE, Switzerland)

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Karst hydrogeological systems and aquifers have been represented by a large type of hydrogeological maps in the past. The use of the full 3D approach KARSYS (Jeannin et al. in press) reveals that none of these representations are really adequate to depict specificities of recharge and flow organization in karst. In the frame of the Swisskarst project – part of the NRP61 - and thank to additional funding provided by the Amt für Wasser und Abfall des Kantons Bern, a new concept of karst hydrogeological map has been developed along with a study of groundwater resources in the Bernese Jura. Result seems satisfying, reproducible and usable. The map includes the following indications: catchment boundaries, specific recharge modalities (autochthonous, allochtonous or mixed), specific flow mechanisms (diffluence/convergence), specific 3D geometry of main flow paths and the location of confined/unconfined saturated part(s) of the aquifer. It also introduces the concept of sub-catchment units which refers to an area with a uniform type of recharge and uniform flow properties at the considered scale (see on Figure 1).

Advantages of this map are: (i) the possibility of representing subcatchments (parts of catchments) belonging simultaneously to two or more adjacent karst systems - this is relevant for the respective water balance assessments - (ii) a clear superimposition of the mechanisms concerning on the one hand surface characteristics (catchment location, distinction in the recharge types) and, on the other hand the flows at depth; (iii) the possibility of indicating the water path from various parts of the catchment to the spring(s) or to the temporary outlets according to various water stages.

One disadvantage of this map is the representation of karst features depending on the selected scale: Some small scale features often induce huge effects on the system hydrology (local fault, old conduits, etc.) and are not drawn - or even not detected. As the readability of the map could be strongly disturbed by the presence of superimposed aquifers (e.g. Malm & Dogger) we suggest a separate map for each aquifer. The main weakness of the map is to represent vertical exchanges between aquifers evidenced by the 3D-analysis, especially in folded/overlapped contexts. Questions remain concerning the depth considered in the hydrogeological interpretation (e.g. interactions between Malm and Dogger aquifers or even deeper ones).

Application on the field of the Bernese Jura (500 km², >50'000 citizens) leads to the characterisation of 17 significant karst systems, describing their properties as well as the connections they have with adjacent ones. Mapping the karst hydrogeological organization at the scale of these aquifers (close to 1/25 000) shows the presence of seven main groundwater bodies (i.e. saturated part), and reveals exchange processes previously suspected or even proven by dye tracer tests. It also depicts areas where geological data or structural interpretations do not match together with the karst hydrogeological interpretation (Malard et al. 2012). Recent applications in other cantons prove the efficiency und usefulness of this approach. Improvements, especially on the way of mapping are still on-going and any input in order to make the map accessible also to non-hydrogeologists is welcome.

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- Malard A, Vouillamoz J, Weber E, Jeannin PY (2012) Swisskarst Project toward a sustainable management of karst water in Switzerland. Application to the Bernese Jura. Actes du 13e Congrès National de Spéléologie, Muotathal, Suisse. 29 sept au 01 oct 2012.





 \uparrow Figure 1. Principles of the KARSYS approach and the resulting karst hydrogeological map. This example focuses of the karst system with springs in red.

← Figure 2. Hydrogeological map of the Brunnmühle karst system (also available on http://www.swisskarst.ch /images/Resultats/Bern/Brunnmuehle-carte.pdf) Symposium 12: Advances in applied hydrology and limnology

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12.5

Assessing controls on cold-season recharge: The Vers Chez Les Brandt study site in the Swiss Jura Mountains

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The scientific community has ubiquitously acknowledged that climate change could shift the volume and temporal distribution of groundwater recharge, particular in cold-regions, drastically altering available groundwater resources. As seasonal snow pack plays a significant role in storage and redistribution of water, many studies have addressed recharge and runoff processes attributed to spring onset snowmelt. However, previous work has failed to identify inter-cold-season recharge processes and their relationships to climatic conditions prior to spring snowmelt, particularly in low alpine, karstic environments. If cold-region aquifers are to be sustainable and effectively managed, the dependency of winter recharge on climatic conditions should be identified and their relationships quantified. The Vers Chez les Brandt test site, where water infiltrating from a zone of approximately 2500m2 drains towards a single water arrival point in a cave 53m below its recharge zone, is an ideal location to study unsaturated recharge processes. A weather station and snow depth sensor were installed within the site's recharge area while the upper meter of soil-water was vertically profiled for physical parameters including water content, electrical conductivity, and temperature. Vadose water draining into the karst cavity was assessed for discharge, electrical conductivity, and temperature. Through time-series analysis and bivariate statistical regression of climatic data with that of soil and unsaturated zone waters, we derive the relative impacts of climatic variables on infiltration throughout winter months, thereby shedding light on the information gap concerning inter-cold-season recharge. This detailed approach revealed that, even with a shallow soil frost and an established meter thick snowpack, air temperature strictly governs infiltration; with positive air temperatures of even just 1oC resulting in observable increases in soil water content and vadose zone outflow. Results imply that equal consideration should be given to winter recharge as is afforded to that historically given to spring on-set snowmelt within groundwater modeling applications and management practices. Additionally, temporally detailed site temperature data is crucial for accurate assessments of recharge within the winter months.

12.6

Environmental factors affecting methane concentrations in Central and Northern European lakes

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Lakes are a significant source of methane (CH₄) to the atmosphere, contributing 6-16 % of total natural methane emissions (Bastviken et al. 2004). However, observations of CH₄ concentrations and emissions in lakes in different geographical areas are still sparse and factors controlling the CH₄ dynamics in different lake types are not well described.

We sampled CH, concentrations and physiochemical parameters of water in different depths of the water column in 32 small, central and northern European lakes were sampled (Figure 1). This unique and methodological consistent dataset, including also information on δ^{13} C of CH₄ and dissolved inorganic carbon (DIC), is well suitable for analyzing which factors controls the CH₄ dynamics in temperate and boreal lakes. Here we present the first findings of the relationship between CH_4 and environmental variables.

The studied lakes differed strongly in their morphology and size (surface area from 0.3 to 343 ha, maximum depth from 2 to 30 m) as well as in their nutrient status which ranged from oligotrophic to hypertrophic. In 24 out of 32 lakes the hypolimnion was anoxic in late summer when the lakes were sampled. Concentrations of dissolved CH_4 in different depths of the water column varied highly between lakes. In general, highest CH_4 concentrations were observed above the sediment surface in the deepest sections of the lakes where concentrations reached up to 2900 μ M. In most of the lakes, concentrations decreased dramatically in the upper hypolimnion and further in the mixed surface layer, where the highest registered concentrations were only 20 μ M. However, no statistically significant correlation between bottom and surface water concentrations was found.

First results suggest that hypolimnetic CH_4 concentrations are strongly related to environmental variables describing hypolimnetic conditions, such as oxygen ($r^2 = 0.60$, p = 0.001) and nutrient concentrations in the lake bottom water (total nitrogen $r^2 = 0.60$, p = 0.001 and total phosphorus $r^2 = 0.40$ p = 0.01). Also, CH_4 concentrations in the bottom water seem to be related to water temperature and lake surface area. On the contrary, the results of this study indicate that CH_4 concentrations in surface water are more difficult to predict based on other environmental variables. Weak links exists between CH_4 concentrations in surface water and factors associated to water column mixing and gas transport. These can be represented for example, as difference between surface and bottom temperatures, lake area or relationship of area and maximum depth.

The study will be continued with more detailed statistical analyses on δ^{13} C of CH₄ and DIC and variables representing catchment land cover and climate. Furthermore, an additional 16 lakes will be sampled to enlarge the dataset and ensure that it covers wide gradients in limnological conditions.



Figure 1. Geographical distribution of the studied lakes.

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12.7

Temperature and salinity staircases in Lake Kivu

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Temperature and salinity in Lake Kivu (Central-Africa) are both increasing toward the sediment. Curiously, this increase happens step wise over large sections of the profiles: Several hundred mixed layers, with nearly constant temperature and salinity, are separated by thin and stable interfaces (Fig.1). This phenomenon is known as double diffusion. Our goal is to understand how such staircase structures are maintained, how they transform over time and how the vertical and horizontal fluxes of heat and salt are affected. Direct numerical simulations, supported by laboratory experiments and microstructure observations, suggest that vertical fluxes through the central part of the interfaces are molecular and can thus be determined by accurately measuring interfacial gradients of temperature and salinity. We present the most detailed microstructure observations of temperature and salinity staircases up to date, including the full resolution of interfaces down to vertical scales of about 1 mm. On average temperature interfaces were found thicker than salinity interfaces by a factor of 2.6. This difference in interface thickness causes density inversions (and thus local instabilities) above and below interfaces which can detach as blobs or thermals and drive the mixing in the adjacent layers. We compare our observations to theory and test whether measured molecular fluxes through interfaces support existing flux laws.



Figure 1. (a) Typical Lake Kivu profiles of temperature and salinity. (b) Double-diffusive staircases within the 10 m long section marked by the rectangle in (a)

12.8

Trend analysis of snow water equivalent

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The temporary storage of water in form of snow plays an important role in the water cycle. It impacts the seasonal discharge and the water supply in lots of areas of the world. Especially in spring the snow water equivalent (SWE) is of particular significance to forecast the magnitude of snowmelt runoff to issue possible flood warnings. The regional and annual variability of SWE is important for the maximum snow load codes or the hydropower industry, which is interested in detailed forecasts of the discharge for efficient energy production.

Moreover, it is also important to analyse the long-term variability and trends of SWE measurements to determine how climate change impacts the snow water resources. The last similar analysis is 20 years old (Rohrer et al., 1994) and found no trends for the annual maximum SWE.

We will reveal first results of long-term biweekly measured SWE data from different regions in Switzerland. The measurement sites are located between 1200 and 2500 m asl. More than a dozen of these sites are operational since 50+ years. Mid-winter and spring snow pack trends will be investigated separately. We will also show the performance of different SWE parameterizations, which can be used to fill gaps in the existing data series.

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12.9

The dual nature role of the snow cover in rain on snow events and a note on latent heat

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Rain on snow events often cause flooding and are severe threats in many areas of the world. Analysing a case study in the Swiss Alps of 10 October 2011, we show that the status of the snow cover before the event can modify the runoff response significantly. In a region located in the Bernese Alps of Switzerland, a rather shallow snow cover was quickly turned into a melting snow cover and aggravated the runoff from warm precipitation causing local flooding and severe damage. Other regions in Switzerland, where the precipitation event had similar characteristics, were affected less, mainly because a much thicker snow cover was able to store some of the precipitation and therefore caused a more moderate runoff reaction. It is further shown that latent heat exchange has a significant role in the warming of the snow cover, amounting to approximately 50% of the total energy for melt. The snow melt due to latent heat exchange thereby strongly exceeds the melt energy from the rain itself. With climate change, rain on shallow alpine snow covers is expected to become more frequent and the process should be properly represented in warning scenarios.

P 12.1

Hydrogeochemistry and Brine Evolution of Urmia Lake (NW of Iran)

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Abstract

Urmia Lake in the northwestern corner of Iran is one of the largest permanent hypersaline lakes in the world and the largest lake in the Middle East. It extends as much as 140 km from north to south and is as wide as 50 km east to west and water body area is about 6000km² during high water periods. The lake was declared a Wetland of International Importance by the Ramsar Convention in 1971 and designated a UNESCO Biosphere Reserve in 1976. Due to building one huge dike (Highway) at 1980 in the middle part of Urmia lake, lake actually divided in 2 part (connection pass between two parts is just one channel with 1400m wide).

Hydrochemistry of the water resources basin show mainly chloric and sulfidic brine due to the variable lithology and geology of the surrounding area. Hydrochemical investigations were carried out over a time period from 2007 to 2012 using previous published data with recently(2010, 2012) collected water samples from lake. 120 water samples were used for this research. Results show distinct changes in the brine type over time; from Na-Mg-Cl type in 2007 to 2010 which is comparable with Great Salt Lake in the USA. Chemical composition of lake in 2007, the percentage of Na is higher than Magnesium. In 2011 and 2012 water composition is HCO3<<Ca+Mg. That is, the path of brine composition on the Eugster and Hardie flow diagram has changed from (Na-Mg-Cl) to (Mg-Na-Cl) in 2011 and 2012 due to precipitation and crystallization of Halite. Then estimated Mg-Cl-SO₄ brine type for future of Urmia Lake. Na to Mg ratio is 5.12 in 2007. But this amount in 2011 is 0.68 and 0.56 in 2012. In future with Increasing of Evaporation, Mg to Na ratio will be increases and are becoming more Differences in the composition of brine in the North and South parts of Lake. This rapid changing in hydrochemistry of brine is not normal in this hyper saline lake. Because from 2000 till now more than 10 dam made on the Urmia Catchment Rivers and the water input to the Lake Decreases to near zero and due to huge amount of evaporation (100cm/year), we have catastrophic condition in Urmia Lake.



Fig: A) sample point on Urmia Lake. B) Stiff Diagram of the Main Ion in Urmia Lake from 2007-2012.

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P 12.2

Sensing with boots and trousers - A new qualitative field method to capture shallow soil moisture patterns in wet environments

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Soil moisture patterns and their spatio- temporal dynamics are of central interest in catchment hydrology. It has been demonstrated, that information about these can give insightful information on dominant runoff processes. Common measuring techniques are time consuming and/or destructive (e.g., gravimetric method) or need sometimes expensive instruments (Time Domain Reflectometry, TDR). Furthermore in very wet soils with a high organic content TDR often does not provide reliable results.

Here we present a qualitative field method which has been developed to offer a supplement to common quantitative measuring techniques as it allows a quick and inexpensive mapping of soil moisture conditions. This soil wetness classification scheme is based on qualitative but well-defined topsoil indicators which can easily be mapped in the field. The scheme consists of seven wetness classes from 'very wet', when water is visible at the soil surface to 'very dry', when a person could sit at that spot for some minutes without getting wet trousers. As quantitative methods like this new field method, are often criticized to be affected by subjectivity, we systematically tested the new approach: Two groups of 10 non-expert raters each were asked to classify 52 marked sites of different wetness within a catchment in the Swiss pre-alps (Erlenbach / Alptal).

The dataset comprising of roughly 1000 classification cases was analyzed in terms of degree of agreement: In 70 % of all classification cases raters agreed and in 95 % they were off by maximum one wetness class when assessing the sampling sites (Rinderer et al. in press). Driest and wettest class assignments showed little spread in classification and therefore seem to be well defined and easily recognizable.

Intermediate wetness classes turned out to be more difficult to assign, resulting in a larger spread of class assignments (Fig.1). A few raters showed a tendency to classify sites either too dry or too wet but the mean classification difference was still within the range of one wetness class. In a second step the agreement between qualitative wetness classes and quantitative wetness measurements was assessed: At 45 sites first the quantitative wetness class was determined, then soil water content was measured with a portable TDR device and finally soil samples were taken to the laboratory for gravimetric water content analysis. Results of this test proved an overall agreement between qualitative wetness classes and quantitative measurements. For intermediate wetness classes the median and interquartile range (IQR) however were not clearly distinct from those of neighboring wetness classes.

These findings were similar to the analysis of a third dataset comprising of 454 averaged TDR values and associated qualitative wetness classifications. The data was gathered during 8 days of field champagne between August and October 2010 repeatedly assessing 100 spatially distributed sampling locations in the Erlenbach each time (Kollegger 2010).

Systematic testing of the interrater-agreement and the correspondence of qualitative and quantitative measurements showed the potential of the new qualitative method. It does not intent to replace common quantitative methods but offers a potential to supplement them with the capability of covering a large number of spatially distributed sampling points. Such spatially distributed soil moisture datasets can be of importance for constraining model parameters and for studying hydrological processes, their key-controls and spatial organization.

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Fig. 1: Wetness class assignments for each of the 52 sampling points numbered and sorted by the mode of class assignments of group 1 for each sampling point. Gray shades indicating relative frequency of wetness class assignments. White circles show the mode as reference (adapted from: Rinderer et al. in press).

P 12.3

Accounting for precipitation and temperature co-variation for design flood estimation in Alpine environments

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Simulation of long discharge time series has become a standard tool for design flood estimation. A key hereby is the generation of appropriate meteorological scenarios to drive the hydrological model with so-called weather generators. These stochastic models generate all required meteorological variables, in particular precipitation and temperature, at one or several locations.

Precipitation (P) is known to depend on temperature (T), yet most weather generators do not explicitly model their co-variation. Accordingly, they do generally not reproduce the observed P-T scaling at time steps relevant for the study of hydrological extremes (hours to days). The use of such weather generators to produce long hydrological time series and for design flood estimation might, thus, lead to unreliable results in snow-influenced environments. Based on a real-world case study – design flood estimation for the Upper Rhone catchment (5000 km²) in the Swiss Alps - we illustrate potential shortcomings of a classical weather generator (not accounting for P-T co-variation). Proposing a new copula-based approach to relate precipitation to temperature, we discuss the importance of explicitly including P-T co-variation in hydrological simulation for the study of extremes in Alpine or other snow-influenced environments.

P 12.4

Operational implementation design of radar and raingauge combination in Switzerland

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Radar monitoring provides a widespread, detail-rich picture of the precipitation over a region of interest. This is typically quite informative regarding where and when it rains, i.e. it provides a vivid picture of trends and outlines of precipitation in a very high temporal resolution. However the involved complexity between transmitting a radio-signal at some overground air-mass volume and producing, based on the backscattered radiation, a final precipitation estimate on-ground, often causes errors, occasionally of significant size. One naturally seeks a remedy in the form of an adjustment of the radar estimates map. Raingauge measurements provide a strong basis for such an adjustment. Undoubtedly, raingauge measurements are by no means error-free, and raingauge networks are typically too sparse to guarantee sufficient representativity, especially when meteorological microvariability is on stage. Still, the fact that raingauges are far less complex than radars and (most importantly) provide direct monitoring of rainfall, renders their measurements almost ipso facto more reliable than radar estimates; commonly they are taken as our "best bet" regarding the ground truth of precipitation depth.

Combining the two monitoring devices in a real-time operational environment involves a gamut of problems, variable in size and complexity. First a suitable method has to be identified and coded. A series of tests over significantly long timeperiods has to take place. Appropriate skill scores have to be collected and studied in a systematic fashion. Behaviour in typical and rare occasions has to be followed and understood. Results of any such suitable method will depend on a number of commonly complex and interacting factors, such as the meteorological condition, the involved topography, and the error structure of the monitoring devices. A real-time operational application depends to a major degree on the sophistication of the code it has been built upon, and the careful configuration of the involved parameters; human intervention has little share after deployment and the focus of such an application is to make correct decisions on how to treat myriads of situations, each of them ultimately unique.

Apart from the scientific part, synchronization of data sources, timely retrieval, production of error-free, correctly-formatted input for the combination process to follow up flawlessly, but also a broad exception-handling on a plethora of points that may not work as expected, should be taken care. Moreover, the output has to be consistent and useful in terms of format and metadata and clients needs, and be transmitted in a continuous and uninterrupted fashion to databases, repositories, or appear as online material.

We will discuss our experience on working on a radar-raingauge combination tool over more than two years. We have employed geostatistical techniques which involve spatiotemporal information to model the correlations between precipitation on raingauge locations, while using the radar field as external drift. The spatiotemporal aspect of our application improves the stability of our algorithm and the dependability of its outcome, while the involvement of the radar field assures that the trend and outline details provided by its monitoring are preserved in the output.

The aim of our application (planned to start operating in the beginning of 2013) is to produce hourly-aggregated raingauge-adjusted radar maps (resolution 1km²) of precipitation every 10 minutes. For this reason it has been built in a computationally-effective basis, employing numerous vectorized functions which operate simultaneously on all members of sizeable sets such as rasters. It is due to the speed of this approach that our algorithm is able to operate as a real-time tool with a high-resolution update rate.

Although the main requirement is to produce precipitation maps within Switzerland where both radar and raingauge data are available, we employ sophisticated schemes to cope with the (extrapolation) regime outside the swiss border. We will present the concept of the "virtual raingauges" which is promising in producing a foundation for resolving such concerns. Moreover we will show how hourly- aggregations rainfall maps can be disaggregated effectively into shorter temporal scales, such as five-minute maps; this approach could be valuable for situations where very high temporal resolution precipitation maps are of essence.

We expect this new product to be useful for a number of practical applications coming from fields where accurate precipitation estimates are of importance, e.g. civil protection, flash flood warnings, intervention during flooding, flood prevention, hydro power management, agriculture, and tourism. Contact with representatives of these fields is continuously helping us to focus our efforts on targeted goals, but also expand our aim to meet broader needs of various areas.

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P 12.5 Snowfall limit forecasts for hydrological modeling

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Hydrological flood forecasting in mountainous areas requires accurate partitioning between rain and snowfall to properly estimate the extent of runoff contributing areas. Many existing forecasting systems rely for this partitioning on the standard hydrological method, which consists of computing the amount of snowfall based on ground air temperature. The most common method consists hereby of computing a linear transition from rain- to snowfall in a given air temperature interval (e.g. between 0 and 2°C). Within a forecasting context, however, such an air temperature-based approach omits the additional forecast information which is contained in the snowfall-limit forecast - a standard product of meteorological forecasts based on limited area models (LAM).

To overcome this shortcoming and to test the value of snowfall limit forecasts for hydrological modeling, we propose a method to make use of snowfall limit information from LAMs for a catchment-scale hydrological model (Tobin et al., 2012). LAMs consider the vertical, humid, atmospheric structure in their snowfall limit calculations. The proposed approach is thus more physically-based than inferring snowfall limit estimates based on (dry) ground temperature.

The presented case study uses forecast re-analyses from the COSMO Limited Area Model as input for discharge simulation in the Viège catchment located in the Valais and part of the forecasting system Minerve (García et al., 2010). Results demonstrate that the use of COSMO snowfall limits during spring snow melt periods can provide more accurate runoff simulations than routine procedures, with practical implications for operational hydrology in Alpine regions.

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symposium 13: Limnogeology: Crystalizing F.-A. Forel vision

13. Limnogeology and the interdisciplinary study of lacustrine sediments: Crystalizing F.-A. Forel vision.

Stéphanie Girardclos, Mario Morellon-Marteles, Adrian Gilli

Swiss Commission of Oceanography and Limnology (COL)

TALKS:

- 13.1 Amann B., Mauchle F., Grosjean M.: Varved Lake Oeschinen: quantitative assessment of climate signal in the sediments
- 13.2 Bellwald B., Anselmetti F.S., Gilli A.: Paleoseismologic implications of the sediment stratigraphy in Lake Silvaplana (Engadine, Eastern Switzerland)
- 13.3 Decrouy L.: Evolution of the ostracod fauna in Lake Geneva since the pioneer work of F.-A. Forel
- 13.4 Filella M., Rodríguez-Murillo J.C.: Carbon fluxes from sediments of a Mediterranean semiarid freshwater wetland and comparison with other continental sediments
- 13.5 Glur L., Wirth S.B., Anselmetti F.S., Gilli A.: Enhanced occurrence of extreme precipitation events during periods with cool summers: A 2500-year long Northern Alpine flood reconstruction
- 13.6 Graham N., Loizeau J.-L.: Advection of particle-bound contaminants in Vidy Bay, Lake Geneva, Switzerland
- 13.7 Lak R., Darvishi khatooni J., Mohammadi A., Salehipuor Milani A.: Paleolimnology study and causes of Sudden decr
- 13.8 Le A.D., De Pascalis F., Umgiesser G., Wildi W.: Thermal structure and circulation patterns of Lake Geneva (Lac Léman)

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13.1

Varved Lake Oeschinen: quantitative assessment of climate signal in the sediments

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In the context of lake deposits as paleoclimatic archives, varved (annually laminated) lake sediments may provide quantitative insights into millennial- to Holocene long seasonally-resolved climate state variables (temperature and precipitation). Specific varve properties can be calibrated and verified against a time series of meteorological data (Blass et al. 2007). This remains a methodological challenge.

Here we present a calibration and verification study from clastic-varved Lake Oeschinen, Bernese Swiss Alps, for the period AD 1920-2008. We show that varve thickness can be used as quantitative predictors for summer (May – August) precipitation. This provides the foundation for a Holocene-long quantitative precipitation reconstruction.

Lake Oeschinen (46°30'N, 7°44'E, 1578 m a.s.l.) is a proglacial 56 m deep dimictic oligotrophic high-elevation lake with a surface of 1.2 km² located in the north-western Swiss Alps. It was formed by an Early Holocene rock slide. Knowledge of the catchment configuration (geology, topography and hydrology) is crucial for the understanding of the mineralogical composition, the sediment transport and the formulation of a process model for the varve formation. 30% of the catchment area is glaciated and all glaciers are located in the Jurassic limestone (up to 84% calcite) area to the southeast of the catchment with the high mountains. Tertiary Flysch and sediments with up to 60-80% siliciclastic minerals are found in the north-western part of the catchment. it is hypothesized that the amount of summer rainfall controls the amount, and mineralogical and elemental composition of the sediments transported into the lake.

We analyzed a 50-cm long sediment core that goes back to AD 1920. Mm-laminated lithoclastic sediments consist of two Facies: A (Varves) and B (Turbidites). The varve characteristics have been previously verified (from a core retrieved in 2007) by ²¹⁰Pb, ¹³⁷Cs and SCP (Spheroidal Carbonaceous Particles) counts profiles. The varves consist of laminae couplets with a coarse dark summer layer enriched in siliciclastic minerals and a lighter fine-grained calcite-rich winter layer on top deposited when the lake is frozen.

According to the varve formation hypothesis, we used the estimated process model to objectively and reliably construct an initial chronology (Fig.1A). This shows a high degree of reproducibility. We then calibrated annual varve thickness, which was identified as the best proxy, with local hydrometeorological data, following von Gunten et al. (2012). Due to varve counting uncertainties we applied a 3-year triangular filter to the time series. The results revealed that varve thickness in Lake Oeschinen was primarily controlled by cumulative summer precipitation (MJJA) (r=0.64 at p<0.05, means for AD 1920-2008), thus validating the hypothesis (Fig.2). This calibration model is now being used for a millennial-long annually resolved quantitative precipitation reconstruction for the north-western Swiss Alps.



Figure 1. Varve chronology and its associated standard deviation through the sediment core. This is based on three independent varve counts.



Figure 2. Graphic comparison between instrumental summer precipitation (red line) and its reconstruction (black line). The corresponding RMSE (Root Mean Square Error) is represented in grey shading through the calibration period 1921-2007. Note that a 3-year running mean was used.

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Paleoseismologic implications of the sediment stratigraphy in Lake Silvaplana (Engadine, Eastern Switzerland)

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Lakes in the perialpine realm are sinks for erosional products. Their deposits generally form a quiet, highly sensitive and complete continuous sedimentary archive so that climatic, environmental, tectonic and anthropogenic changes and events of the past are recorded. The goal of this study is to improve the knowledge of tectonic and sedimentologic processes affecting Lake Silvaplana in the Upper Engadine, which is influenced by a large fault system, the Engadine Line. Previous studies documented that severe prehistoric and historic earthquakes occurred in the area, so that investigating the sediments of Lake Silvaplana should extend this paleoseismic event catalogue.

For this purpose, high-resolution seismic profiling with a 3.5 kHz single-channel pinger was conducted, combined subsequently with recovery of a long sediment core. Seismic lines show generally a good penetration of the acoustic signal down to a maximum sub-lake floor depth of ~90 m, so that the acoustic basement (bedrock or moraines) can be identified throughout the lake. A quasi-3D analysis of the sedimentary fill of the basin was obtained from the seismic stratigraphic interpretation. Sedimentary mass-wasting processes and related deformation structures, such as mass flows and megaturbidites, are identified and mapped throughout the lake basin. Coeval mass-flow deposits and associated overlying megaturbidites are a key criterion to identify a seismic trigger mechanism. In fact, ten horizons with synchronously initiated mass-movement deposits were recognized, which thus are interpreted to have likely been triggered by earthquakes.

A 10.5 m-long sediment core was recovered from the deepest lake basin using an Uwitec percussion piston-coring system. Density, magnetic susceptibility, and grain-size, as well as the lithologic succession were determined. Sediment chronology was achieved using radiocarbon measurements and gammaspectroscopic measurements of ²¹⁰Pb and ¹³⁷Cs radionuclides. A precise core-to-seismic correlation allowed finally dating the event horizons defined in the seismic profiles.

Four seismically-detected events were recorded in the long core and dated to 1801, 1723, 821 and 596 AD. The ages of the other six events were estimated using a constant sedimentation rate to 1200, 1400, 2900, 4800, 7400, 8000 BC. These prehistoric earthquakes are compared with the existing historic and prehistoric earthquake catalogues, the latter derived from mass-movement deposits in surrounding lakes (Lake Como, Lake Sils). Eventually, this study allows expanding the earthquake catalogue of the Eastern Swiss Alps and the neighboring northern Italian area, providing novel insights for the regional seismic hazard assessment.

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Figure 1. Core photograph, lithological column and petrophysical properties of the long sediment core. Colored bars show correlations of petrophysical properties with event layers (yellow: floods, blue: earthquakes). Flood layers with a thickness of up to 2 cm are displayed on the right. Between 4 and 6 m core depth, the most striking multiple-slide event layer was described. This mass movement, consisting of two phases, i) an underlying mass flow covered by ii) a megaturbidite, can be perfectly correlated with the seismic data. The volume of the megaturbidite was calculated to 292·10³ m³, with a maximal thickness of 2 m in the basin center.

13.3 Evolution of the ostracod fauna in Lake Geneva since the pioneer work of F.-A. Forel

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François-Alphonse Forel, while not being an expert on ostracod systematics, mentioned these tiny arthropods when he described the living fauna of Lake Geneva in 1904. After a taxonomic revision of Forel's inventory, it can be deduced that Lake Geneva was oligotrophic and that deep water was cold and well oxygenated at that time. The study of the living population of ostracods in western Lake Geneva ('Petit Lac') more than 100 years after the pioneer work of F.-A. Forel indicates that several species disappeared or became restricted to small ecological niches at intermediate water depth. This change in ostracod population could be related to the anthropogenic degradation of water quality during the 20th century.

The study of ostracod fossil assemblages in Lake Geneva enables an estimation of the impact of water eutrophication on benthic community as well as a better understanding of sedimentary conditions during such environmental changes. The division of Lake Geneva in two sub-basins with distinctive morphological characteristics with similar nutriment overload during the 20th century makes it particularly suitable for such a case study. Lake Geneva provides the opportunity to study the induced environmental changes in a basin where deep water has always remained well oxygenated (Petit Lac) as well as in a basin where oxygen depletions occurred periodically (Grand Lac). In addition, physico-chemical parameters have been measured by the CIPEL on a monthly basis in both basins since 1957. The evolution of ostracod fauna can, therefore, be compared to a large and detailed set of environmental data.

Two short cores were collected in the deepest zones of Grand Lac at 300 m water depth and Petit Lac at 58 m water depth. Lithology and ostracod fossil assemblages have been determined for the two cores. The results indicate that before the 20th century, the profundal ostracod population of both basins was dominated by *Candona neglecta* and *Cypria ophtalmica* forma *lacustris* while *Limnocytherina sanctipatricii* and *Leucocythere mirabilis*, although less abundant, were continuously present. This fossil assemblage, and especially the presence of the latter two species, indicates that oligotrophic condition, namely cold deep water, good oxygen supply and low sediment organic content prevailed before the 20th century. During the first half of the 20th century, the populations of *L. mirabilis* and *L. sanctipatricii* started to decline in both basins while the sediment organic content increased gradually. During the second half of the 20th century, *C. lacustris* colonized the profundal zone of Petit Lac and dominated rapidly the population. During the same time period, the total individual abundance (especially for *C. neglecta* and *C. lacustris*) raised strongly while the sediment organic content remained high all along. In contrast, the population in Grand Lac experienced pronounced modifications during the second half of the 20th century, with high abundances during periods of moderate to high oxygen levels and almost complete lack of ostracods at time of low oxygen levels.

The changes in ostracod population can be attributed to several causes. Higher supply of organic matter sinking from epilimnion led to a change of sediment texture at the bottom of the lake. This resulted in the disappearance of species sensitive to habitat degradation such as *L. mirabilis* and *L. sanctipatricii* even if oxygen levels remained high. In contrast, more tolerant species, such as *C. neglecta* or *C. lacustris* benefited from higher food supply and were favoured. Yet, as oxygen level dropped in Grand Lac, the whole ostracod fauna declined progressively and vanished almost completely. During cold winters, complete overturn of water column could occur, restoring high oxygen level at depth. Return of adequate levels of oxygen led to a rapid proliferation of the ostracod population until oxygen began to drop again.

Pb-210, Cs-147, and C-14 dating are still in progress. They will allow us to better compare our data with historical measurements to constrain the sedimentary changes more accurately and to reconstruct oxygen and primary productivity levels through the last centuries. Last but not least, the analyses of isotope composition of ostracod valves will provide helpful information on water temperature and carbon cycling at time and place of valve calcification.

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Carbon fluxes from sediments of a Mediterranean semiarid freshwater wetland and comparison with other continental sediments

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Sediments are an active biogeochemical compartment in continental waters. Sediments in freshwaters, particularly in lakes and wetlands, sequester carbon by burying inorganic and organic carbon. However, not all organic carbon deposited in wetland sediments can be considered as being permanently trapped because it undergoes oxidation processes with production of CO_2 but also of a large variety of organic compounds, ranging from refractory organic matter (ROM) to labile low-molecular-weight molecules. These organic compounds may diffuse from the interstitial waters to the water column depending on existing concentration gradients.

Although dissolved organic carbon (DOC) fluxes from wetlands may be high (Moore et al., 1997), not much is known about DOC cycling in these systems. Moreover, most of what has been published deals with boreal and forested peatland areas. We have measured fluxes of DOC in wetland sediments from a semiarid freshwater wetland, the Tablas de Daimiel, Spain by using passive diffusion samplers (peepers) (Filella et al., 2012). The system –characterised by highly variable hydroperiodicity conditions– was completely flooded at the time of sampling (February 2011). Not only dissolved organic carbon (DOC) concentration profiles were measured in sediment porewaters but refractory organic matter (ROM, usually known as humic substances) was also quantified by using a novel voltammetric method. Although the Tablas de Daimiel wetland is known to act as a long-term carbon sink (Domínguez-Castro et al., 2006), at the time of the observations waters experimented a 7-fold increase in measured ROM concentrations from the inlet to the outlet, which points to a net exportation of ROM from the wetland and to the existence of an internal source, most probably diffusion from the sediments. These observations suggest that intermittently-flooded freshwater systems may act in some periods as net exporters of organic carbon.

To put these results in a wider context and to get a better understanding of the possible role of sediments as a source of DOC in freshwater systems, we have thoroughly revised the limited number of published studies reporting organic matter profiles in sediment interstitial waters and estimated the corresponding fluxes when possible.

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13.5

Enhanced occurrence of extreme precipitation events during periods with cool summers: A 2500-year long Northern Alpine flood reconstruction

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Severe floods caused by heavy precipitation represent a major natural hazard in the alpine realm. With current climate change, the frequency of flood events caused by heavy precipitation events is expected to be subject of considerable modifications that could substantially increase social and economical damage due to flood events. To assess the natural variability of this natural hazard and hence to better predict future flood risk, we reconstruct the frequency of flood events during the past 2500 years in Northern Switzerland by using lake sediments. Lakes record flood events by specific sedimentary deposits, i.e. 'turbidites' or flood deposits. They are composed of terrigenous material that is mobilized during heavy precipitation in the catchment area and is deposited at the bottom of the next downstream lake with the intense riverine in-wash (Gilli et al. 2013). This allows the reconstruction of flood-recurrence rates in the past, offering time series reaching far beyond the relatively short time interval covered by instrumental and historical data.

To provide a spatially and temporally highly resolved 2500-year long flood chronology of large-scale heavy precipitation events in the Central Northern alpine region, we apply a multiple-lake approach, investigating 10 individual lakes along a transect from the Swiss Plateau to high-alpine environments (from 447 m a.s.l. to 2065 m a.s.l.). In total, 825 flood events, recorded as in individual and dated flood layers, are combined to obtain a regional dataset.

The observed flood occurrence is characterized by high-amplitude decadal to centennial fluctuations, with site-specific average flood-recurrence rates between 16.7 and 80.7 years. This indicates a high variability in the absolute number of recorded events, reflecting varying susceptibility of the lakes to record floods. In order to establish a flood chronology representative of the entire Northern alpine region, we compiled the 10 individual records into one, by weighting each lake equally and normalizing the records to a 'flood activity' reaching from 0% (corresponding to no flood layers) to 100% (maximum number of flood deposits) within a time window of 50 years. Furthermore, we verified the established flood reconstruction of the Northern Alps by comparison with an independent historical flood reconstruction for the same study area covering the past 500 years (Schmocker-Fackel and Naef 2010). The two independent datasets are in good agreement, characterized by three coinciding peaks. This confirms our approach and validates its applicability even during times with intense human impact.

The complete flood chronology is characterized by eleven well-distinct periods of high flood frequency that are developed around 1860, 1730, 1630, 1310, 1150, 850, 590, 350, 120 C.E. and 150, 340 B.C.E.

Regarding the best-characterized climatic periods during the past 2500 years, i.e. the Little Ice Age (1430 -1850 C.E.; LIA) and the Medieval Warm Period (950-1350 C.E.; MWP), we find a generally enhanced flood activity during the LIA compared to the MWP. These findings are in good agreement with other studies reconstructing flood events, which have also observed increased flood activity during LIA in central Europe (e.g. Schmocker-Fackel and Naef 2010).

In addition, all major peaks in flood activity of the Northern alpine flood chronology coincide with periods of low mean summer temperatures reconstructed based on tree-ring records for Europe of the last 2500 years (Büntgen et al. 2011) and correlate to major advances of the Lower Grindelwald Glacier (Holzhauser et al. 2005). Therefore, we propose a temperature-dependent change in circulation patterns, which favour the occurrence of floods during cooler periods in the last 2500 years. The apparent discrepancy of cooler temperatures and more frequent extreme precipitation, contradicting the basic Clausius-Clapeyron equation of higher atmospheric moisture-transport capacity with increasing temperature, can be explained by a regional circulation pattern overruling the temperature effect. This pattern of more floods with cooler temperatures is thus representative for the Northern alpine region only and must not represent a global signature.

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13.6

Advection of particle-bound contaminants in Vidy Bay, Lake Geneva, Switzerland

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Understanding sediment and particle dynamics is paramount in determining the fate of hydrophobic pollutants within an aquatic ecosystem. Knowledge of pollutant dispersal to sediments provides insight into accumulation zones, or "hot-spots", which aids in mitigating future economic, health, social, and environmental impacts from acute or chronic contamination. Vidy Bay is of great concern due to the presence of a wastewater treatment plant (WWTP) outlet pipe and combined-sewer overflows dumping directly into the bay.

Natural radionuclides, such as ⁷Be, ²¹⁰Pb, and ²³⁴Th are used as surrogates for hydrophobic pollutants since they behave similarly within a lacustrine environment (with respect to adsorption and transport). In addition, the varied half-lives of these radionuclides, aid in the differentiation between short and long-term dynamics. These analytes, combined with more traditional parameters, such as carbonate and organic matter content, and particle size diameter were investigated.

Samples in Vidy Bay area were collected via sediment traps and sediment cores. Atmospheric inputs were monitored using an atmospheric trap situated in Versoix. Local water conditions, 5m above the lakebed, were monitored using a RCM-9 MKII Current Meter. Parameters measured include current velocity and direction, temperature, and turbidity, during the twenty-two month study.

Sites within the bay, exhibit an overall winnowing effect, while a site just outside the bay, showed an overall focussing effect (as exemplified in Fig 1.). The hydrodynamic parameters measured at the sediment surface show daily mean currents as high as 15cm/s. They also show evidence of a gyre know to prevail within the bay, along with down welling and Ekman spiral formation during seasonal wind events. Results show evidence of an overall sediment advection from the bay, towards the main basin of the lake.



Figure 1. Radionuclide flux differences monitored at site NG3

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13.7

Paleolimnology study and causes of Sudden decrease in water level of Urmai Lake

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Urmia Lake is one of the biggest and hyper saline Lakes in the world. It is located at the northwestern part of Iran. Today, it has been endangered by drying up processes. This environmental hazard is one of the most significant geological problems of Iran. Verification of evolutionary history of Holocene and understanding the reasons for sudden downfall of Urmia Lake water level is the main subject for current study. In this research, remote sensing examinations for a period of 35 years, 55-year climatic data processing and their relationship with Lake Water fluctuations were implemented, and undisturbed sedimentary cores of western coast of Lake sediments were prepared by Auger coring method. 16 cores having a maximum depth of 9 meters, and totally 98m of the Lake sub-floor sediments were verified. Sedimentary facies were separated by color, grain size, mineralogy specifications, sedimentary fabrics and evaporative minerals. With regard to vertical sedimentary facies (from surface to sub-surface areas) changes, geography, climatic conditions and Lake water level fluctuation were re-constructed. Results indicated 17 separable types of sedimentary facies in cores. Facies are from Lacustrine, Swamp, fluvial and terrestrial environments. Coring and verification of Lake Sub-environment sedimentary facies indicate that sequential drying up tracks are visible in the coastal areas of Urmia Lake. However, the main part of the Lake has had Lacustrine environment (6.5m of the Lake floor sediments) for 13000 years. Sedimentation was continuous during the mentioned period and seismic data confirm this issue. Climate change and particularly evaporation increment are significant agents in downfall of Lake Water. But these are not the main causes for drought in Urmia Lake region. Iran has experienced a long-term drought since 13000 years ago up to now. Hence, shallow Lakes, such as Maharloo, Mirabad and Zarivar were frequently dried. It is important to note that Urmia Lake has never experienced dryness except in coastal areas. The main stage of Urmia Lake region drought commenced about 13000 years ago. This event indicated coincidence with the last Ice Age. Regarding the Ice Age, downfall of moisture and Lakes' water levels of North Africa and southern Asia was pointed out. Therefore, today, the important agent in downfall of the Urmia Lake water is anthropogenic factor (building more than 20 dams on the Urmia Lake Rivers).

Key Words: Urmia Lake, Paleolimnology, Lake water level, Sedimenty core

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Fig1: Stratigraphical column of Urmia Lake cores

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13.8

Thermal structure and circulation patterns of Lake Geneva (Lac Léman)

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Abstract: Hydrodynamic processes in Lake Geneva (Switzerland and France) have been studied since the pioneering work of F.A. Forel (1892, 1895, 1904) who initiated the science of limnology as a branch of oceanography. Lake Geneva is characterized by a thermal stratification of the water column from spring to autumn and a homogenization from late winter to the beginning of spring. Lake Geneva is a "monomictic" lake according to the classification of Hutchinson (1957).

A three-dimensional finite element model, SHYFEM, with the ability to simulate the temperature structure and water movement was applied for Lake Geneva. The finite element grid, superimposed on the bathymetric data, has a resolution of 8149 triangular elements and 4553 nodes, covering the two lake basins: Petit-Lac and Grand-Lac. The model was run for a period of one year (2005) with continuously updated weather data. The model solves the equations for the conservation of mass transport, dynamics and temperature, which can simulate the water temperature, current velocity and direction. The annual thermal cycle begins with isothermal conditions in winter, followed by thorough mixing in late winter, and by stratification from May to October. The annual cycle of temperature distribution in the Grand-Lac shows strong seasonal trends. Depending on the difference in volume and morphology of the basin, cooling and warming during the transition periods (spring and fall) are slower in the Grand-Lac than in the Petit-Lac. Minor differences within the basins could be linked to local circulations between coastal areas and deep areas, as well as the influence of fluvial input, including the Rhone.

Over much of the year, the waters of Grand-Lac circulate in a gyre turning counterclockwise. The size and lifetime of the vortex varies depending on weather conditions. Appendices of the main gyre are found in major bays of the northern shore, in Morges and Vidy (Lausanne). These are less stable than the main gyre and their direction may switch depending on wind direction. In the transitional area between the Grand-Lac and the Petit-Lac a gyre oriented clockwise is established. The western end of the Petit-Lac is characterized by a counterclockwise circulation system. In the Petit-Lac, flow towards the Rhone outlet mainly occurs in surface waters and along the borders of the basin, while the return currents to the Grand-Lac are deeper-water currents and found in the central part of the basin. In the Grand-Lac, the downstream flow from East to West follows the northern edge of the basin, while the return current, from the western to the eastern part of the basin, predominantly follows the southern border.

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P 13.1

Sedimentological processes in the Rhone Delta subaquatic canyons (France-Switzerland)

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Deltas are very sensitive environments and highly vulnerable to variations in water discharge and the amount of suspended sediment load provided by the delta-forming currents. Human activities in the watershed, such as building of dams and irrigation ditches, or river bed deviations, may affect the discharge regime and sediment input, thus affecting delta growth. Underwater currents create deeply incised canyons cutting into the delta lobes. Understanding the sedimentary processes in these subaquatic canyons is crucial to reconstruct the fluvial evolution and human impact on deltaic environments, and to carry out a geological risk assessment related to mass movements, which may affect underwater structures and civil infractructure.

Recently acquired high-resolution multibeam bathymetry on the Rhone Delta in Lake Geneva (Sastre et al. 2010) revealed the complexity of the underwater morphology formed by active and inactive canyons first described by Forel (1892). In order to unravel the sedimentary processes and sedimentary evolution in these canyons, 27 sediment cores were retrieved in the distal part of each canyon and in the canyon floor/levee complex of the active canyon. Geophysical, sedimentological, geochemical and radiometric dating techniques were applied to analyse these cores. Preliminary data show that only the canyon originating at the current river mouth is active nowadays, while the others remain inactive since engineering works in the watershed occurred. However, alternating hemipelagic and turbiditic deposits in the easternmost canyons, evidence underflow processes during the last decades. Two canyons, which are located close to the Rhone river mouth, correspond to particularly interesting deeply incised crevasse channels formed when the underwater current broke through the outer bend of a meander in the proximal northern levee. In these canyons, turbidites were observed in the sediment record indicating ongoing sediment dynamics during whether extreme flood events or mass-movements due to deltaic scarp failures. The active canyon shows a classic turbiditic system with frequent spillover processes in the canyon floor/levee complex. Geotechnical measurements, a decrease in the frequency of turbidites and a fining upward sequence along the levee suggest that erosion dominates sedimentation in the canyon floor, while sedimentation dominates in the rapid levee building-up process, with sedimentation rates that exceed 2.5 cm/yr in the proximal areas. Therefore, mechanisms controlling the sedimentary evolution on the active canyon represent a complex interplay between erosion and sedimentation.

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Triggering mechanisms and geomorphological implications of debris flows in subaquatic canyons: The Rhone delta (Lake Geneva, Switzerland, France)

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Subaquatic canyons in deltas are major pathways for the transport of particles from rivers / the upper delta slops to the deep basins. They represent active environments with frequent deltaic failures and massmovements potentially bearing hazard-related (tsunami waves) and economic (infrastructure damages) implications. Understanding sedimentary processes and mass-movement triggering mechanisms is crucial to assess related consequences and to carry out geological risk assessments.

The Rhone River delta in Lake Geneva (Switzerland, France) is a complex underwater structure with several active and inactive subaquatic canyons, similar to marine deltas but at a smaller scale. The difference between two bathymetric surveys in 1986 and 2002 revealed an inversion in the topography of the distal active canyon, as a former distal canyon was transformed into a mound-like structure. A 12 m-thick layer was deposited in the canyon and modified the sediment transfer conduit. Sediment cores from this deposit were retrieved in-situ in 2002 and 2011 via the "F.-A. Forel" and Russian MIR submersibles, respectively. These cores contained a homogeneous, sandy material. Its sediment texture, grain-size, high density and shear strength, and low water content suggests that it corresponds to a debris-flow deposit that possibly took place after the initiation of a mass movement due to a scarp failure in proximal areas of the canyon. In addition, insitu geotechnical tests on the modern canyon floor have shown a soft top layer above a stiffer substratum. This soft layer, which increases in thickness towards distal areas, may act as a basal surface for hydroplaning, and might have allowed the debrite to be transported 9 km away from the source of the scarp failure. Similarities in textures and grain-size of the debris flow and levee deposits hint at the proximal northern levee as the source of this material. Rapid sediment loading in this area, at the rate of >2.5cm/yr, steep slopes in the canyon walls and increased pore pressure due to high methane concentrations may have reduced the stability of the canyon wall in this area. Discrete sandy intervals show very high methane concentrations and thus could correspond to potentially weak layers prone to scarp failures. Nevertheless, the probable cause for the 2000 AD Rhone delta event was an exceptional flood in October 2000 which undercut the slope, and subsequently decreased the stability by increasing the shear stress and triggered the mass failure in the already unstable canyon walls. Besides economic and hazard-related implications, such mass failures represent significant and underestimated causes in morphological evolution of underwater canyons by damming the channel and, eventually, forming short-term meanders susceptible to further erosion, as seen in a recent multibeam bathymetric map obtained in 2012.

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P 13.3

Lake Geneva sediments as archive for past environmental changes and human activity during the last 3000 years

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Lake sediments are excellent archives of environmental changes in the watershed and provide high-resolution records of regional paleohydrological variability. Lake Geneva is the largest peri-alpine lake in western Europe, with a maximal water depth of 309 m. It is part of the Rhone river system and was formed during the Pleistocene by glacial erosion. Our study focuses on the deepest part of the lake basin, where sedimentation is mainly controlled by fluvial input from the Rhone and Dranse rivers. These two river systems are sensitive to regional climate variations in the alpine realm and to human activity that affect the discharge regime and sediment delivery to the lake.

In Lake Geneva, high resolution seismic reflection profiles reveal two distinct units in the late Holocene sedimentation history. One unit (Unit 1) consists of a succession of five large lens-shaped seismic sub-units, characterized by transparent/ chaotic seismic facies with irregular lower boundaries, interpreted as mass-movement deposits. These sub-units are interbedded within parallel, continuous, high-amplitude reflections, interpreted as the 'background' lake sediment. The second unit (Unit 2) consists of 5 m-thick 'background' seismic facies with parallel geometry. It displays alternating dm-thick chaotic/transparent and continuous, high amplitude reflections, which are interpreted as hemipelagic layers punctuated by turbidites. This turbidite layers, are interpreted as floods- and mass movement-related deposits.

Four 7- to 12-m long sediment cores were retrieved with a modified Kullenberg system from the deepest part of Lake Geneva. The sedimentary sequence spans the last 3000 years. Magnetic susceptibility and density were measured by Geotek Multisensor Core Logger at 0.5 cm resolution. X-ray fluorescence was carried out using an Avaatech core scanner from the University of Barcelona at 1-cm resolution. This technique provides semi-quantitative information of the sediment elemental composition. Clastic-related elements such as Ti, K or Si records extreme precipitation events in the lake watershed while the Fe/Mn ratio and Calcium in the sediment provides information about the redox conditions in the lake bottom and the calcite endogenic precipitation in the epilimnion respectively. The sedimentary record suggests a complex hydrological variability during the last two millennia during different climatic facies such as the Medieval Warm Period (MWP) and the Little Ice Age (LIA). However, the climate signals are certainly also overprinted by human activity during the last 3000 years, and particularly during last centuries with river regulation and dam building on the Rhone river and disentangle both forcing mechanisms is needed in order to achieve an adequate paleoclimatic reconstruction.

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Subaquatic landslides and sediment deformation structures within the geologic archive of Lake Neuchâtel

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Lake sediments are highly sensitive archives of past environmental changes and geological events, such as earthquakes. Sublacustrine landslides deposits are important components in the sedimentary infill of lakes. Previous studies linked sublacustrine mass-transport deposits to historical earthquakes. They thus calibrated the use of sediment instabilities recorded within lacustrine sedimentary archives as indicators of past seismic events (Schnellmann et al., 2006; Strasser et al., 2006). Synchrony of multiple mass-transport features at different locations within a basin is the main criterion to postulate seismic triggering. We aim to study the sublacustrine mass-movement deposit inventory of Lake Neuchâtel, as it provides great insight into past seismotectonic activity and natural hazards since Late Glacial times, when lakes in their existing form within the study area were formed and continuous lake sedimentation set in.

In this study, we present preliminary results from newly acquired high-resolution reflection seismic and swath bathymetry data, which we integrate with seismic airgun data acquired by Gorin et al. (2003), as well as with piston-core data by Schwalb (1992). Extensive reflection seismic and swath-bathymetry measuring campaigns on Lake Neuchâtel took place in winter 2011 and spring/summer 2012. Swath-bathymetry data (Kongsberg EM 2040 multibeam) provide precise highresolution lake floor morphological data. Dense grids of high-resolution reflection seismic data (3.5 kHz pinger source) are used to image the sedimentary infill of the Lake Neuchâtel basin with decimeter-scale vertical resolution. This allows systematical mapping of mass-movement deposits, landslide scars and lake-floor deformation structures. Seismicstratigraphic correlation is used to determine the chronostratigraphic relations between deformation events.

Correlation of initial seismic-stratigraphic interpretation with piston cores by Schwalb (1992) indicates sequences of lacustrine background sedimentation, interbedded with turbiditic deposits, which are intercalated with mass-transport units. First results show strong evidence for at least one distinct seismic horizon with multiple, basin-wide subaquatic landslides and sediment deformation features.

Lake Neuchâtel is a perialpine lake located on the border between the Swiss Molasse basin and the Jura mountains, an area of low overall seismicity. In the study area, however, a zone of increased seismicity gives evidence for neotectonic activity along distinct fault zones (Gorin et al., 2003; Kastrup et al., 2007). It remains to be further investigated if the observed multiple landslide horizon may relate to past seismic activity along such faults. Additionally, next to sediment deformation-structures, some of these potentially active fault zones may be marked by fluid expulsion structures on the lake floor. In fact, several of those have been mapped, and future analysis will reveal whether these truly indicate active fluid migration along such faults, or, alternatively, may relate to a karstic groundwater system. Eventually, the present study investigating and discussing depositional and post-depositional sedimentary processes in Lake Neuchâtel, aims to link sedimentological data to neotectonic activity.

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Lake Biel sediment record during the last 7500 years and impact of the Aare river deviation in 1878 AD.

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Lake sediments are excellent archives of environmental and climate changes as well as human impact on lake- and riversystems. Lake Biel is a medium-sized peri-alpine lake in Switzerland, with a maximum depth of 74 m, and lies at an altitude of 429 m a.s.l. Lake Biel, which formed during the Pleistocene by glacial erosion, is situated downstream Lake Brienz and Lake Thun and is currently part of the Aare river system. Our study focuses on the south-west part of the lake basin, where the lake sedimentation was naturally mainly controlled by autochthonous sedimentation, and since the Aare river deviation through the Hagneck canal in 1878, is now under the strong influence of water and sediment input from this river catchment.

A 10.05 m long composite sediment sequence, cored from a 52 m water depth in September 2011, was built from two long cores retrieved with the ETH Zurich/Eawag Uwitec system. The retrieved sedimentary sequence begins in 1975 and spans the last 7500 years, as dated by seven ¹⁴C datings, and correlated to previous short core radioisotope stratigraphy for the 1.5 m upper part (Thevenon et al., submitted). Magnetic susceptibility and density were measured by Geotek MultiSensor Core Logger at 0.5 cm resolution at the ETH Limnogeology Laboratory. Granulometry was measured with a CILAS grain sizer at the University of Geneva every ~10 cm, and X-ray fluorescence was carried out using an Avaatech core scanner at the University of Barcelona at 1-cm resolution. This technique provides semi-quantitative information of the sediment elemental composition and shows how runoff and river input (Ti, Al, Si) or redox conditions (Fe/Mn) vary through time.

Lake Biel sediment record suggests marked environmental changes, with runoff decrease linked to climate and vegetation change during Atlantic chronobiozone, as well as a complex climate-human impact during the 'La Tène' and Roman cultural times. The most remarquable feature, is the 10-times increase of sediment rate which happens after the Aare river was deviated through the Hagneck canal into Lake Biel in 1878, and which is also linked to a massive and sudden Ti increase, and inversely massive Ca decrease, in xrf data. This record reveals the magnitude of sedimentary changes happening in a lake system when it shifts from a relatively closed basin to a river and delta-influenced basin.

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Traces of the Great Lisbon Earthquake (AD 1755) in the sediments of Walchensee (Bavaria, Germany)?

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This study investigates evidences of the Great Lisbon Earthquake. It occurred in AD 1755 and is preserved in the sediments of Walchensee (799 m a.s.l., Bavarian Alps, Germany), a lake located in more than 2'000 km distance of the epicenter. Although strong ground motions are not expected at such large distances, historical reports indicate that strong water movements were indeed observed on Walchensee immediately after the earthquake. Recent paleoseismic studies of other peri-alpine lakes demonstrate that historic earthquake- triggered slope failures caused water waves (tsunamis) and oscillations (seiches), which have been recorded in the fine-grained lacustrine sediments. Consequently, a limnogeological approach has also been performed in Walchensee.

Within the younger sediments of Walchensee, we identified multiple mass-movement deposits intercalated with background sedimentation using high-resolution seismic sequence stratigraphy and multi-proxy analysis of twelve short gravity cores. The reflection seismic survey was made in 2009 using a 3.5 kHz 4-element pinger source. The cores were investigated with 1) GEOTEK multisensor core logger, 2) XRF core-scanner, 3) microscopic grain-size analysis and 4) geochemical carbon analysis. We dated the sediments with radionuclides (²¹⁰Pb, ¹³⁷Cs) and an inventory of historic events, which included nearby earthquakes and anthropogenic disturbances such as the construction of a hydropower plant and the subsequent catchment enlargement in the 20th century.

Geochemical analyses reveal that the turbidites of Walchensee have constant and elevated density and magnetic susceptibility values. These results were confirmed by high-resolution XRF analysis of terrestrial runoff indicators (Fe, K, Si, Al, Sr and Ti), which were also constant for these event layers. High Al and K values at the top of several event layers indicate a higher clay mineral content in the finest topmost layer, most likely transferred to deep lake areas by flood events. One thick deposit, a sequence of repeating coarse sandy layers in the lowest core section may be related to a seismic trigger mechanism. At the base of this megaturbidite, Ca values are very high while Fe, Al, K and Ti are low. It is unlikely, however, that this depositional event was formed during the devastating Lisbon earthquake of 1755 AD because the age model indicates a too young age. Furthermore, a major seismically-caused and basinwide event with multiple mass movements overlain by a megaturbidite with more than 1 m thickness, as seen on seismic data, was not reached by our short cores. Seismic data indicates that it occurs a few centimeters below the lowest core sediment section. This major event thus remains a candidate to be caused by the Lisbon earthquake, though the age model is not conclusive. The overlying event layer with a sandy base then may have been triggered by an earthquake occurring in the vicinity of Walchensee around 1794 AD.

Key words: Lisbon earthquake, lake sediments, Walchensee, Germany, limnogeological approach, tsunamis, natural hazard

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The PASADO sediment record: paleoclimatic and paleoenvironmental changes in Southern Patagonia since the Late Pleistocene

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Laguna Potrok Aike is a maar lake located in the southernmost Argentinean Patagonia, in the province of Santa Cruz. Being one of the few permanent lakes in the area, it provides an exceptional and continuous sedimentary record. The sediment cores from Laguna Potrok Aike (Fig. 1), obtained in the framework of the ICDP-sponsored project PASADO (Potrok Aike Maar Lake Sediment Archive Drilling Program), were sampled for diatom analysis in order to reconstruct a continuous history of hydrological and climatic changes since the Late Pleistocene. Diatoms are widely used to characterize and often quantify the impact of past environmental changes in aquatic systems. We use variations in diatom concentration and in their dominant assemblages, combined with other proxies, to track these changes.

Diatom assemblages were analyzed on the composite core 5022-2CP with a multi-centennial time resolution. The total composite profile length of 106.09 mcd (meters composite depth) was reduced to 45.80 m cd-ec (event-corrected composite profile) of pelagic deposits once gaps, reworked sections, and tephra deposits were removed. This continuous deposit spans the last ca. 51.2 cal. ka BP. Previous diatomological analysis from the core catcher samples of core 5022-1D, allowed us to determine the dominant diatom assemblages in this lake and select the sections where higher temporal resolution was needed. Over 200 species, varieties and forms were identified in the sediment record, including numerous endemic species and others which can be new to science. Among these, a new species has been described: Cymbella gravida sp. nov. Recasens and Maidana. The quantitative analysis of the sediment record reveals diatom abundances reaching 1.5 billion valves per gram of dry sediment, with substantial fluctuations through time. Variations in the abundance and species distribution point toward lake level variations, changes in nutrient input or even periods of ice-cover in the lake. The top meters of the record reveal a shift in the phytoplakton composition, corresponding to the previously documented salinization of the water and the lake level drop, indicators of warming temperatures and lower moisture availability during the early and middle Holocene. The new results presented here on diatom diversity and distribution in the Glacial to Late Glacial sections of the record bring much needed information on the previously poorly known paleolimnology of this lake for that time period.



Figure 1. Map of Patagonia showing the location of Laguna Potrok Aike and bathymetric map of the lake with the location of the two drilling sites from where cores were retrieved.

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New insights into the formation and burial of Fe/Mn accumulations in Lake Baikal sediments

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Lake Baikal is the deepest and oldest lake on Earth. Extraordinary features of the lake are manganese and iron enriched layers and crusts occurring at different depths within the sediment. They can be broadly subdivided into an upper accumulation at the O₂/Mn(II) redox boundary and one or more layers buried within the reducing part of the sediment. The processes leading to their formation and peculiar distribution within the sediment have remained subject of debate, in particular whether the burial of vast amounts of Mn and Fe-oxides results from a steady-state process or if it is the consequence of singular events, such as changes in sedimentation rate, bottom water oxygen concentrations, or the mass accumulation rate (MAR) of organic carbon (C_{org}), Mn or Fe. We retrieved short cores from the South basin, the North Basin, and Academician Ridge, determined sedimentation rates, contents of C_{org}, Mn and Fe, and estimated pore water fluxes from concentration profiles of O_2 , NO₃, Mn(II), Fe(II), SO₄² and CH₄. A consistent picture emerged from the data showing that the upper Fe/Mn layer formed at the lower end of the oxygen penetration depth as a dynamic pattern, moving upwards with the growing sediment. Thereby, reductive dissolution of Mn(IV) occurred at the lower margin. Upward diffusing Mn(II) was oxidised with O₂ forming the upper boundary of the Fe/Mn accumulation. The buried Fe/Mn layers were immobilised within the sediment and underwent slow reductive dissolution mainly driven by the anaerobic oxidation of CH₄. The process leading to the detachment of the 'active' Fe/Mn layer from the top redox interface is not unambiguously clear. However, we suggest a cyclic pattern where the burial of a Fe/Mn layer is accompanied by the generation of a new enrichment at the O₂/Mn(II) redox boundary, which is subsequently nourished by the slowly dissolving old layer (see Figure 1).



······ sediment-water interface at t = 0

Buried Mn layer

- Original level of buried Mn layer

Figure 1. Proposed timeline for the burial and the generation of a new Mn/Fe accumulation in the sediments of Lake Baikal, subjected to a long term cycle. At t=0, Mn- and Fe-oxides have accumulated below the O, penetration depth, driven by the reductive dissolution of both metals and their oxidation once oxidising conditions are encountered. The shaded area represents the section where Mn-oxide can be reductively dissolved by Fe(II) and Fe-oxide precipitates. The next step (1) demonstrates the growth of the enrichment while Feoxides should accumulate at a faster pace. Through a process which has yet to be understood better (see section 5.1), the dissolutionprecipitation dynamic of the Fe/Mn-oxides markedly slow down and the enriched layers get buried within the sediment with on-going sedimentation. Panel 2 shows how an offshoot forms anew underneath the O₂ penetration depth. While the buried enrichment is still dissolving, at a slower pace, Fe-oxide precipitates above the Mn-enriched layer while the more active, upper accumulation is growing further. In the last panel (4), the situation where no reactive Mn is present in the buried accumulation anymore is depicted.

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P 13.9

Can lipids help to reconstruct changes in methane availability and methane fluxes in lakes?

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Methane is a major greenhouse gas and lakes are an important but poorly studied source of methane to the atmosphere. Lipids were used before to identify and quantify methane oxidizing bacteria (MOB) (1, 2), giving insight into methane oxidation and production. However, few studies are available that examine how closely the distribution and δ^{13} C of lipids are related to methane concentrations and fluxes in different lakes. In a multi-lake survey we tried to find a quantitative relationship between lipids, mainly fatty acids, and methane concentrations or fluxes.

Fatty acids (FA) were analyzed in surface sediment samples from eleven Swedish and four Swiss lakes. FA concentrations were examined using gas chromatography with flame ionization , gas chromatography-mass spectrometry (GC-MS) for identification and isotope-ratio mass spectrometry (IRMS) for compound specific δ^{13} C values. δ^{13} C analyses indicated that two groups of lipids, C16:1 ω 9 and C16:1 ω 11 were depleted in ¹³C, suggesting that these compounds were at least partly produced by MOB. The relative abundance of C16:1 ω 9 was related to the methane flux measured at the lake surface and the methane concentration in the bottom water (Fig. 1). This suggests that higher methane content leads to an increased abundance of this fatty acid at least partly produced by MOB. Furthermore, we observe a relationship of the peak area of C16:1 ω 9 with the ¹³C depletion of this fatty acid and with the δ^{13} C value of methane in the sediment.

Further investigations will have to be done to confirm the initial correlations. Ultimately we will include surface sediment samples from 29 lakes in Europe in which methane concentration, flux, and isotope data will be measured accompanied by basic limnological parameters. This will allow for determinations of factors responsible for differences in carbon isotopic composition of lipids within the lakes as well as between the numerous studied lake ecosystems.



Figure 1: Relationship between the relative abundance of the FA C16:1 ω 9 and the methane (CH₄) concentrations at the bottom of the lakes.

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Exploring stable isotope composition of Cladocera and Bryozoa using flotsam from lakes

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Chitinous resting stages of certain aquatic invertebrates are easily collected as flotsam from the lake surface and their isotopic composition contains information about the feeding ecology of these organisms. Since the resting stages are well preserved in lake sediments, they can also give insights in changes in the relative importance of food sources over time, when material from sediment cores is analysed.

Here we present stable carbon and nitrogen isotope data of resting stages from water fleas (Cladocera) and moss animals (Bryozoa). The resting stages were collected as flotsam with a hand net from 20 lakes in Sweden, Finland, Germany, the Netherlands, and Switzerland. We analysed ephippia of *Ceriodaphnia*, *Daphnia*, and *Simocephalus* and statoblasts of *Cristatella mucedo*, *Lophopus crystallinus*, *Pectinatella magnifica*, and *Plumatella* to investigate how these taxa differ in their isotopic composition. Furthermore, we compared their isotopic composition to the physiochemical data collected from the lakes to detect which environmental parameters influence the δ^{13} C and δ^{15} N of the resting stages. To make the collected material comparable to the chitinous external structures of the resting stages preserved in lake sediments, we removed the easily degradable organic material by manually taking out the eggs from ephippia and statoblasts and treating them with 10% KOH for 2h at room temperature.

N content of Cladocera ephippia was on average 8.7% (mass based), which is significantly lower than the average 12.0% for Bryozoa statoblasts. The C content of ephippia and statoblasts were 47.7 and 46.7%, respectively, which was not significantly different. This could indicate that Cladocera produce resting stages with a lower protein:chitin ratio than Bryozoa.

 δ^{15} N of Bryozoa statoblasts, especially that of *Cristatella mucedo* was higher than that of Cladocera ephippia in most lakes. Both invertebrate groups are filter feedersand the differences in δ^{15} N values between invertebrate taxa could reflect a preference for other sizes and species of phytoplankton. The higher δ^{15} N of Bryozoa could also indicate that they feed mostly on settling particles. These particles are likely to be affected by degradation (microbial remineralisation and excretion of ¹⁵N-depleted inorganic nitrogen), resulting in ¹⁵N-enriched organic matter (Goedkoop et al., 2006). The higher δ^{15} N values of bryozoan statoblasts, therefore, suggest that Bryozoa incorporate particles that are more microbially degraded compared with the particles ingested by Cladocera.

Interestingly, δ^{13} C of *Daphnia* ephippia was generally lower than that of other invertebrates, with values as low as -43.5‰, and significantly negatively correlated to profundal methane concentrations (r² = 0.43, p = 0.01). This was not observed for the other invertebrate taxa and suggests that *Daphnia* incorporates more ¹³C-depleted methane-derived carbon in lakes with increasing amounts of hypolimnetic methane. These results agree with correlations found between δ^{13} C of Daphnia ephippia in lake surface sediments and diffusive methane fluxes measured in lakes in Sweden and Siberia (van Hardenbroek et al., in press).

Our results indicate that the δ^{13} C and δ^{15} N of their resting stages can be used to extract information about the feeding ecology of Cladocera and Bryozoa. This also suggests that this method can be applied to investigate changes in the diet of these invertebrates over long time scales using resting stages from sediment cores.

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Surface sediments characteristics survey in the Persian Gulf

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Persian Gulf is a semi-closed forearc basin in South of Iran. The length and width of this Gulf respectively are 900 and 300 km. maximum depth is 98 meter on Hormoz straight. The depth is asymmetric in Persian Gulf. North part of gulf is dipper than south part. For this reason sedimentary environment of north part of Gulf is clastic with some coral patch and south part is carbonate. In this research study area is north (Iranian part) of Gulf. 400 surface sediment samples were taken in systematic 15*15 km network. Granulometry, calcimetry and mineralogy (XRD) analysis have been done in Geological survey of Iran. For measuring coarse grains size (sand and granule) vibratory sieve Shaker and for measuring of silt and clay size, using Laser particle sizer was use. Determining percentage of calcite and dolomite was done by autocacimeter and mineralogy analysis was analyzed by Semens XRD diffraktometer.

Results show that the mean of sediments size are between 0.007 to 4.1 mm including clay, silt, sand and granule. Mineralogy of clay minerals shows that main clay minerals contain respectively Chlorite, Palygorskite, Illite, Kaolinite and Montmorillonite. The main non-opaque minerals contains Carbonates, Quartz, Feldspar and small amounts of Chert, Gypsum and The main heavy minerals contains Mica, Amphibole, Pyroxene, Topaz, Garnet, but Epidote, Aragonite, Zircon, Tourmaline and other heavy minerals are found in much smaller amounts. Maximum Carbonate minerals are 83.4 percent contain 74.94% calcite and 8.46% dolomite. Frequency and cumulative curves of grain size for each sample were drowned and Statistical parameters was calculated were then based on the amount of abundance of sediment particles in the range of sediment types,13 spectrum was seen. Statistic parameters of sediment such as standard deviation, kurtosis, skewness is calculated with sediment size program. Based on statistical calculations, sediments in the Iranian part of Persian Gulf has been detected fine-grain, these results prove the latter. So that over 50% of all samples classified are located within the mud confine. Although Sandy sediment particles, are allocated a third of all bed sediments but amplitude of sandy sediments are less than the mud.

Gravel size particles in the samples are all biological and shell fragments. Generally be said that in the Persian Gulf sediments are mainly fine-grain.

Key words: Persian Gulf, Sedimentology, Mineralogy, Sedimentary environments.

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Symposium 13: Limnogeology: Crystalizing F.-A. Forel vision

14. Environmental Biogeosciences.

Jasquelin Peña, Rizlan Bernier-Latmani

Swiss Commission of Oceanography and Limnology (COL)

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14.1

Lability of monomeric U(IV) species in laboratory and field experiments

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The *in situ* bioremediation of uranium is premised upon the addition of an electron donor, such as lactate, acetate, or molasses, to simulate the growth of indigenous microbes in geologic media, and cause the concomitant enzymatic reduction of soluble and mobile U(VI) to relatively immobile U(IV) species. Although the product of U(VI) reduction was long assumed to be the mineral uraninite, $UO_{2(s)}$, recent research has confirmed the presence of other, non-crystalline U(IV) species collectively called monomeric or mononuclear U(IV) (*e.g.*, Bernier-Latmani *et al.*, 2010; Boyanov *et al.*, 2011). These species can form as a product of uranium reduction by microbes (Bernier-Latmani *et al.*, 2010), biogenic Fe(II)-bearing minerals (Veeramani *et al.*, 2011), and in natural sediments (Sharp *et al.*, 2011). Alessi *et al.* (2012) showed that monomeric U(IV) associated with all of the above surfaces can be extracted with a concentrated solution of bicarbonate, while uraninite remains intact. Thus there is some evidence that monomeric U(IV) species may be more easily mobilized than U(IV) bound in crystalline uraninite.

The goal of this study was to compare uranium mobilization rates from systems containing primarily uraninite, to ones containing primarily monomeric U(IV) species under realistic groundwater conditions. To this end, monomeric U(IV) associated either with *Shewanella sp.* CO-9 or with biogenic magnetite were prepared and embedded in agarose gel pucks. The gel pucks were deployed into two groundwater wells at the Old Rifle field site in Colorado, USA to evaluate the persistence of this product under *in situ* conditions. Gels were recovered at specific time intervals, the uranium loss quantified by digestion, and U L_{III}-edge X-ray absorption spectroscopy performed to monitor changes in uranium speciation. A parallel laboratory study, using Old Rifle groundwater, was conducted to investigate the mechanism of uranium mobilization from monomeric U(IV) and UO_2 . The results from both the laboratory (Figure 1) and field studies confirmed that monomeric U(IV) was more easily remobilized than uraninite. Additionally, monomeric U(IV) mobilization mediated by carbonate was also documented in addition to oxidation. Thus, the consideration of monomeric as a contributing species in the subsurface may be critical in generating accurate predictive models of uranium transport. Future studies quantifying the rate loss kinetics of monomeric U(IV) will be important in informing these transport models.



Figure 1. Uranium removal from *Shewanella sp.* CO-9 cells containing primarily monomeric U(IV) species versus cells containing primarily biogenic uraninite, in anoxic groundwater from Rifle, CO.

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14.2

Plant-soil microbe interactions for nutrient acquisition in peatlands: responses to climate warming and vegetation change

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Ombrotrophic peatlands or bogs are nutrient-poor ecosystems that are strictly dependent on atmospheric inputs. As a result, they present a good model for understanding the effects of climate change on interactions between plants and soil microbes. Here, we investigated the seasonal dynamic of biogeochemistry and interactions between soil microbes and vascular plants in four Swiss peatlands along an altitudinal gradient that simulated a natural gradient of soil temperature. Along this gradient, the peatlands were also characterised by a differences in cover of the main plant growth forms, with decreasing abundance of ericaceous species with increasing altitude. Peat microbial biomass carbon (C) and nitrogen (N), soil enzymatic activity, organic and inorganic exchangeable N, microbial community structure, as well as polyphenol and dissolved organic C (DOC) concentration in pore water, were periodically assessed during the plant growing season.

We found a significant difference in the seasonal trend of C:N ratio in microbial biomass in relation to both altitude and the abundance of ericaceous species. In particular, we observed that, at lower altitude, soil microbes immobilized less N, suggesting a higher competitive ability of plants for N acquisition. Decreasing polyphenol concentration in pore water with altitude was reflected in a lower amount of exchangeable organic N in peat, which is consistent with the capacity of polyphenols to retard N release from decomposing organic matter. We also found a positive relationship between vascular plant production, which decreased with altitude, and DOC concentration in pore-water. Spectroscopic measurement of DOC showed a higher release of labile C compounds at lower altitude, which points to a primary role of root exudates in affecting DOC quantity and quality. The stoichiometry of the main hydrolytic enzymes involved in the degradation of C and N compounds differed along the altitudinal gradient in relation to the structure relative dominance of fungi and bacteria in the soil microbial community structure.

Our data suggest that the presence of important aboveground-belowground feedback in terms of nutrient acquisition, which can potentially destabilize the ability of peatlands to act as C sinks if vascular plants become more competitive than peat-forming mosses with increasing soil temperature.

Endospore-forming bacteria as an indicator of pollution in sediments of Lake Geneva

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Treated wastewater and runoff-water is released by the outlet of the sewage treatment plant of Vidy (Lausanne) directly into the Lake of Geneva via a pipe located 300m from the shore. Even if this water is properly treated with modern technologies, we can observe an accumulation of micro pollutants into the sediments, and in particular of trace and heavy metals. The main objective of this project is to investigate how these elevated concentrations of metals affect both abundance and diversity of prokaryotes in the sediments. A special emphasis was given to endospore-forming bacteria, which could use sporulation as a survival strategy to resist in highly contaminated areas. This study could have implications for understanding the role of endospore-forming bacteria in the environment, their potential as bioindicators of pollution in sediments, as well as in terms of improving bioremediation processes.

Lake Geneva is the largest freshwater lake in Western Europe. Since several decades this lake has been the subject of close environmental monitoring. Different studies from the Forel Institute (Pote et al., 2008; J-L Loizeau et al., 2004) indicate that the sediments of the Vidy Bay contain high level of trace and heavy metals (TM/HM). This is mainly due to the rejection into the bay of runoff surface water, but also the treated wastewater from the city of Lausanne and its suburbs (412'000 equivalent inhabitants). Even if the concentration of TM/HM in the rejected water is low, over time those accumulate in the surrounding sediments. Endospore-forming bacteria (EFB) are well known for their ability to resist to harsh environmental conditions over long periods of time (Vreeland et al., 2000). When conditions are not optimal, endospore formation is triggered. Spores are resistant structures intended to protect and conserve the genetic material of the organisms until the conditions become suitable for vegetative growth (Nicholson, 2002). We hypothesized that thorough the formation of endospores, EFB have an advantage to tolerate and prevail in environments with high pollutants load. However, so far, the effect of pollutants on the prevalence of endospore-forming bacteria is unknown. Therefore, this study aims at evaluating an eventual link between endosporeforming species and the load of trace and/or heavy metals in the environment using as model polluted sediments from Lake Geneva. In addition, considering the fact that recent studies have demonstrated that some redox activities are active at the surface of endospores (Junier et al., 2009; Rosson and Nealson, 1982), a better understanding of the role of this special group of bacteria in polluted areas could lead to improved bioremediation processes in the future.

Two MIR submersibles could be used to monitor the surface of the sediments and to select the more interesting coring zones around the rejection pipe of the wastewater treatment plant of Lausanne. A first set of four cores was retrieved from precisely selected areas by using the robotic arm of the submersible. In order to have more contrasted heavy-metal concentrations, two additional cores were retrieved from a boat during a second sampling campaign. Two depths (0-3 and 3-9 cm) were analyzed independently. The physicochemical analyses show that four out of 12 samples analyzed are clearly separated from the others based on higher TM/HM contents. Multivariate analyses of the physicochemical data and the composition of the bacterial community assessed by 16S rRNA gene pyrosequencing, show a strong link between the prevalence of endospore-forming species and the TM/HM content of the sediments. As a good correlation is also observed between TM/HM and nutrients (represented by C.org and N.total vectors), it is not clear if the first set of physicochemical factors is sufficient to explain the prevalence of EFB in the community of these four particular samples.

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14.3

Symposium 14: Environmental Biogeosciences

Biogeochemical analysis as a tool to isolate extremophilic Archaea

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We studied a microbial snottite biofilm in an abandoned pyrite mine in the Harz mountains. The organisms that build up the biofilm grow at pH about 2.3 and sulfate concentrations of up to 200 mM. The microorganisms are dependent on the oxidative dissolution of pyrite as the primary energy and on CO₂ as the primary carbon source. The microbial community is mostly composed of bacteria, predominantly by the genera Leptospirillum and Acidithiobacillus (Ziegler et al. 2012) which are mostly present in the vicinity of the oxygenated zone. Surprisingly, the respiratory activity of aerobic organisms lead to a large anoxic zone beginning roughly 700 µm away from the outer surface. In this inner anoxic area Archaea are present and comprise a large part if not even the majority of the community. Recent metagenome analysis of the snottite biofilm revealed that deep branching Euryarchaeota and species closely related to so far uncultured ARMAN ("Archeal Richmond mine acidophilic Nanoorganisms", J. Baker et al. 2006) build the archaeal community. Based on our oxygen and pH measurements and further cryo-laser ablation inductively-coupled plasma mass-spectrometry (LA-ICP-MS), ICP optical emission spectrometry (OES) and X-ray absorption near edge structure (XANES) analyses we designed a medium for enrichment cultures which also included 20 mM ferric iron as electron acceptor, casein as well as hydrogen and carbon dioxide in the gas phase. Using CARD-FISH and PCR of the 16S rDNA we could show an enrichment of so far uncultured Achaea from the class Thermoplasmatales. After prolonged incubation time, even ARMAN could be detected and transferred several times. Surprisingly, the enrichment was not possible until autoclaved biofilm material was added as an additive to our cultures. At the moment we focus on establishing pure cultures of the enriched Thermoplasmatales and we further try to isolate the growth supporting substance of the biofilm.



Figure 1. CARD-FISH of a cross section of the biofilm. Bacteria (EUB 338-I) in red (Alexa 546) are evenly distributed across the whole biofilm. Archaea (ARCH 915) in green (Alexa 488) are only present in the inner, anoxic part.

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Biogenic copper and metal sulphide colloid formation in a contaminated floodplain soil

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The fate of metal contaminants in riparian soils is strongly affected by periodic variations in (ground)water level. Associated changes in soil redox state and metal speciation may result in the release of metals into surface and ground-water. In laboratory microcosms, we studied the dynamics of Cu, Hg, Cd and Pb in a contaminated riparian soil over up to 5 weeks of soil flooding. Pore water was withdrawn directly into an anoxic glovebox after certain time intervals and analysed for dissolved and colloidal concentrations of major and trace elements. Colloidal Cu and Hg dominated the pore water dynamics of Cu and Hg and peaked shortly after flooding before the onset of sulphate reduction. X-ray absorption fine structure (XAFS) spectroscopy revealed metallic Cu colloids, which incorporated small amounts of Hg. Transmission electron microscopy (TEM) showed that metallic crystals were always associated with bacteria. Upon sulphate reduction these crystals transformed into hollow Cu-rich metal sulphide particles that also incorporated Hg, Cd and Pb. In parallel, freely dispersed, mixed Cu-Pb-Cd-Hg sulphide colloids with sizes from a few nanometres to ~300 nm formed directly in the pore water. Other metals did not precipitate as sulphides because most biogenic sulphide was bound in poorly soluble Cu_xS. These results demonstrated that metallic and metal sulphide colloid formation may be an important mechanism leading to trace metal mobilization in periodically flooded soils.

To identify the bacteria that were involved in the formation of Hg-substituted Cu metal crystals, denaturing gradient gel electrophoresis (DGGE) analysis was performed as a first approach. Clearly visible bands were excised and sequenced, revealing mainly species of the genus *Clostridium*. A clone library also demonstrated the dominance of the genus *Clostridium* and other gram-positive bacteria in pore water samples of maximal Cu concentration. We previously proposed that metallic Cu crystals are formed via a Cu(I) efflux from bacteria followed by Cu(I) disproportionation and metallic Cu growth on the surface of bacteria (Weber et al., 2009). Typical Cu efflux pumps are Cu P-type ATPases (CopA), which can shuttle the Cu(I) outside of the cell. We therefore isolated spore-forming bacteria by a pasteurisation step and cultivated them on plates for subsequent 16S rRNA gene sequencing and to test the isolates for CopA gene. 16S rRNA gene sequence analysis of the isolates showed that they were all closely related to *Clostridium beijerinckii*, *Clostridium roseum* or *Clostridium acetobutylicum*. A new primer was designed on the basis of the genome of *C. beijerinckii* to test the isolates for the CopA gene. Positive amplification indicated that the isolates have the gene CopA. The isolates will now be tested for their ability to form metallic Cu during growth. Considering that many typical fermenting soil bacteria are from the genus *Clostridium*, metallic Cu formation (with Hg substitution) may be a widely occurring reaction in periodically flooded riparian soils.

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14.6

Signatures of ancient deep microbial activity and applications in the search for life on Mars

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Recent microbial activity in rocks down to significant depths is a well-known fact (e.g. Balkwill 1989; Moser et al. 2005). But how can such deep microbial activity be recognized in geologically old (fossil) cases? After destruction of all live/organic/biochemical material, the recognition of an involvement of biology in the origin of mineral assemblages or geochemical signatures must remain indirect, relying on so-called biosignatures.

Recognizing former biological activity is crucial to understand low-T geochemical processes in terrestrial rocks as well as to search for possible ancient live on other planets, e.g. Mars. The rates of deep subsurface microbial activity in many environments is extremely low (Røy et al. 2012) and signatures from such processes have a low probability to be recognizable. High rates of microbial activity can develop in situations of strong chemical disequilibria and high energy flux, however.

Classical examples for such situations at the Earth's surface are hot springs. In deep environments, strong disequilibria can result from relatively short-term geological perturbations, e.g. the interaction of oxidizing groundwater with sulphide-rich ore-bodies, or the mixing of near-surface and deep groundwater. Signatures from resulting microbial blooms have a much higher potential to be preserved than those from low-level activity due to associated high cell densities and high rates of mineral precipitation.

Examples of microbial signatures that can be related to microbial blooms are subsurface filamentous fabrics (SFF) from the oxidation zone of ore deposits, porous volcanic rocks and redox boundaries in red beds (Hofmann et al. 2008). Redox disequilibria are typically related to infiltration of oxidizing groundwater, but may also include radiolytically conditioned pore fluids containing H_2 (Lin et al. 2005). The formation of some low-T mineral deposits and microbial blooms may be closely linked because both processes are a result of strong redox disequilibria.

As a lesson, in the search for life on Mars, geological situations that represent ancient redox disequilibria in subsurface situations should be considered as promising targets. SFF are easily recognizable in certain cases due to a macroscopic expression of the filamentous fabric resulting from mineral encrustation.



So-called moss agate consisting of filamentous microbial mats transformed into goethite, enclosed in transparent chalcedony. Sample from Mongolian basalts. Field of view is approx. 3 cm.

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14.7

NanoSIMS study of trophic interactions in the coral-dinoflagellate endosymbiosis

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Tropical and subtropical reef-building corals generally form a stable endosymbiotic association with autotrophic singlecelled dinoflagellate algae, commonly known as "zooxanthellae", which is crucial for the development of coral reef ecosystems. In the present work, the spatial and temporal dynamics of trophic interactions between corals and their dinoflagellates was investigated *in situ* and at a subcellular level in the reef-building coral *Pocillopora damicornis*. Transmission electron microscopy (TEM) and quantitative NanoSIMS isotopic imaging of tissue ultra-thin sections (70 nm) were combined to precisely track the assimilation and the fate of ¹⁵N-labeled compounds (ammonium, nitrate and aspartic acid) within each symbiotic partner of the coral-dinoflagellate association. Among our main results, we found that (i) both dinoflagellate algae and coral tissue rapidly assimilate ammonium and aspartic acid from the environment, (ii) however only the dinoflagellates assimilate nitrate, (ii) nitrogen is rapidly and temporary stored within the dinoflagellate cells into uric acid crystals, and (iii) the algae endosymbionts translocate nitrogenous compounds to their coral host. This study paves the way for exploring in details the wide range of metabolic interactions between partners of any symbiosis in the biosphere.



Fig. 1. Nitrogen incorporation and storage by the dinoflagellate endosymbionts of the reef-building coral *P. damicornis*. (a) TEM micrograph and (b) corresponding NanoSIMS isotopic ${}^{15}N{}^{14}N$ image of a dinoflagellate cell after 90 min of exposure to ${}^{15}N{}^{14}N$ ammonium. Highly enriched hotspots of ${}^{15}N$ enrichment are spatially correlated with uric acid crystals within the algal cell (white arrows). ab = accumulation body; chr = chromosome; cyt = cytoplasm; nu = nucleus; nucl = nucleolus; pl = plastid; pyr = pyrenoid; st = starch.

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Isotope effects during nitrogenous gas production by microbes in anaerobic environments

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14.8

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Measuring the nitrogen (N) isotope ratios in NO_x has proven to be an excellent tool to track N transformations in freshwater and marine ecosystems. Organo-heterotrophic denitrification, the bacterial reduction of NO_x ($NO_3^- + NO_2^-$) to N_2O and N_2 during organic matter degradation in oxygen deficient waters and sediments was traditionally considered as the primary metabolic pathway of marine or lacustrine N loss, and as the main factor controlling the isotopic composition of oceanic N. In many aquatic systems, other pathway of N_2 and N_2O production may be comparably important (e.g., sulfide-dependent denitrification, nitrifier-denitrification, anaerobic ammonium oxidation). In this contribution, I will present data that highlight the N isotope effects (or their absence) for some of these N sinks in various natural environments and in laboratory experiments, and I will discuss the observed N isotope signatures in the context of their use to identify N cycle reactions and quantify N fluxes in aquatic environments.

14.9

Micro-spectroscopic arsenic speciation in a highly contaminated, mining-affected river floodplain

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Many rivers worldwide are polluted with trace elements originating from past or present mining. Even after closure and remediation of the mines, highly contaminated floodplains often remain as a source of contaminant release into river and ground water. Arsenic (As) has a high potential for mobilization under reducing conditions, e.g., during soil flooding, but this strongly depends on the speciation of As among other factors.

The speciation and micro-scale distribution of As, Fe and Mn and other elements in alluvial soils and sediments along the river Ogosta in NW-Bulgaria was studied by micro-X-ray fluorescence (μ -XRF) spectrometry, micro-X-ray absorption fine structure spectroscopy (μ -XAFS) and bulk-XAFS.

"Chemical imaging" using hard X-ray micro-spectroscopy was used to visualize the distribution of major As and Fe species in the soils. Disturbed and undisturbed soil samples were collected along transects ranging from the river bed through the lower and upper floodplains, taking special precautions to minimize oxidation. All samples were analyzed for soil pH, mineralogy, elemental composition, and ascorbate-extractable As, Fe and Mn. Additionally, selected soils were size-fractionated to explore the elemental composition, mineralogy, and As speciation as a function of particle size.

Soil As concentrations in Ogosta floodplain ranged between 40 and 37,400 mg kg⁻¹. Highly As-contaminated soils were also enriched in Fe, Mn, S, Pb, Sb, and other trace elements. Bulk and micro-XAFS, combined with ascorbate-extractions, revealed that most As was present as As(V) sorbed to poorly-crystalline Fe(III)-oxyhydroxides, with smaller amounts of As bound in primary As-bearing minerals, such as arsenopyrite. The fine particle size fractions <5 and 5-20 µm were strongly enriched in As (up to 93,000 mg kg⁻¹) as compared to the corresponding bulk soils. These size separates contained only traces of arsenopyrite and exhibited very high ascorbate-extractable As and Fe contents, reaching molar Fe/As ratios of <5. Our results suggest that As and Fe in these soils should be readily bioavailable for microbial reduction upon soil flooding.

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14.10

Authigenic carbonates as dynamic microbial ecosystems: expanding views of methane cycling in the deep sea

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Sulphate-dependent anaerobic oxidation of methane (AOM) is the dominant sink for methane along continental margins and seafloor methane seeps, oxidizing significant fraction of methane in anoxic sediments prior to its release to the hydrosphere (Reeburgh, 2007).

The alkalinity generated during this process frequently results in the precipitation of δ^{13} C-depleted authigenic carbonates, which vary in morphology, size, and mineralogy, ranging from micritic cements and cm-sized concretions to massive 'chemoherm' structures, mounds, and pavements that can cover hundreds of square meters.

These methane-derived structures often persist long after the flux of methane subsides, with remnant methanotrophic biomarkers recovered from paleo-seep carbonates dating back to the Paleozoic (Birgel et al. 2008). While these authigenic carbonates have long served as important indicators of methane seepage, they are frequently discussed as passive recorders of prior seep activity, rather as than an active and dynamic microbial habitat.

Here we will present recent evidence that deep-sea authigenic carbonates are living and actively evolving ecosystems, capable of supporting methanotrophic microorganisms that live endolithically within the carbonate matrix. Using a combination of molecular analyses, stable isotope labelling experiments and nanoscale secondary ion mass spectrometry (nano-SIMS), we demonstrate that authigenic deep sea carbonates 1) host abundant aggregations of methanotrophic archaea and sulphate-reducing bacteria, 2) are actively oxidizing methane 3) are capable of growth and incorporation of methane into biomass 4) provide a unique habitat and food source for seep-associated meio- and macrofauna.

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14.11

Increased nitrate availability in the soil of a mixed mature temperate forest subjected to elevated CO₂ concentration (canopy FACE)

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In a mature temperate forest in Hofstetten, Switzerland, deciduous tree canopies were subjected to a free-air CO_2 enrichment (FACE) for a period of eight years. The effect of this treatment on the availability of nitrogen (N) in the soil was assessed along three transects across the experimental area, one under *Fagus sylvatica*, one under *Quercus robur* and *Q. petraea* and one under *Carpinus betulus*. Nitrate, ammonium and dissolved organic N (DON) were analysed in soil solution obtained with suction cups. Nitrate and ammonium were also captured in buried ion-exchange resin bags. These parameters were related to the local intensity of the FACE treatment as measured from the ¹³C depletion of dissolved inorganic carbon in the soil solution, because the CO_2 used for the treatment was depleted in ¹³C (Schleppi et al., 2012).

Over the eight years of the experiment, the CO_2 enrichment reduced DON concentrations, did not affect ammonium, but induced higher nitrate concentrations, both in soil solution and in resin bags. In the nitrate captured in the resin bags, the natural abundance of the isotope ¹⁵N strongly increased. This indicates that the CO_2 enrichment accelerated net nitrification, probably as an effect of the higher soil moisture resulting from the reduced transpiration of the CO_2 -enriched trees. It is also possible that N mineralisation was enhanced by root exudates (priming effect) or that the uptake of inorganic N by these trees decreased slightly as the result of a reduced N demand for fine root growth. In this mature deciduous forest we did not observe any progressive N limitation due to elevated atmospheric CO_2 concentrations; on the contrary, we observed an enhanced N availability over the eight years of our measurements. This may, together with the global warming projected, exacerbate problems related to N saturation and nitrate leaching, although it is uncertain how long the observed trends will last in the future.

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Figure 1. Map of the difference between summer and winter δ ¹³C in the dissolved inorganic carbon (DIC) of the soil solution (contours as distance-weighted least-square estimates). Small squares represent the sampling locations (suction cups and ion-exchange resin bags) along 3 transects (dashed lines). The position of the trees is indicated by circles, whose size is proportional to the breast-height diameter, but enlarged 4 times compared to the map. Thick circles indicate treated trees.



Figure 2. Effect of the CO_2 treatment on nitrate-N concentrations in the soil solution. For each point in time, the indicated effect is the slope of $log(NO_3^{-}N)$ against the ¹³C-based indicator (defined between 0 and 1).



Figure 3: Nitrate N in resin bags after six months in the soil. The locations of bags are grouped in low, medium or high, according to their exposure to the $\rm CO_2$ treatment as measured by the depletion in $^{13}\rm C$ of DIC.

14.12 Biological controls on the product of microbial U(VI) reduction

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Stimulation of indigenous microbes to mitigate subsurface uranium contamination through reductive immobilization of U(VI) to U(IV) is a promising method of remediation. The product of microbial uranium reduction is often reported as uraninite (UO_2) , a sparingly soluble crystalline U(IV) species. However, recent laboratory and field-scale remediation experiments reveal the prevalence of non-crystalline U(IV) known as monomeric U(IV) in the microbial product. This product is less desirable as it is considerably less stable than uraninite. It is therefore imperative that we understand the mechanism of monomeric U(IV) formation in order to favor UO_2 formation. The work presented here utilizes scanning transmission X-ray microscopy (STXM) to provide direct evidence of a biological response modulating the chemical nature of the U(IV) product. Our key mechanistic insight is that monomeric U(IV) is formed by enzymatic U(VI) reduction in the extracellular polymeric matrix (often referred to as extracellular polymeric substances or EPS) whereas UO_2 is formed at the cell surface. Thus, the cellular localization of the U(VI) reduction step appears to determine the ultimate chemical characteristics of the product. The presence of EPS fundamentally alters the U(IV) product of microbial U(VI) reduction. This finding implies that there is a form of biological control on the product of microbial U(VI) reduction not previously recognized.



Figure 1. Monomeric U(IV) STXM maps. (a) Carbon speciation map where protein is red, lipid is green and polysaccharide is blue. EPS is clearly visible as extracellular mix of green and blue, forming cyan. (b) Uranium map of the same region demonstrating co-localization with EPS. Scale bar: 1 µm.

14.13 Synthetic δ -MnO₂ as a model for biogenic Mn oxides: Ni and Co adsorption

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Biogenically produced manganese oxides are ubiquitous in the environment and greatly influence the environmental fate of nutrients and contaminants via sorptive, redox, and/or electrostatic mechanisms. The large metal-sorption capacity of layer-type Mn minerals arises from the negative surface charge created by Mn(IV) vacant sites in the MnO₂ layers and compensated by adsorbed countercations. The sorption reactivity and coordination geometries of adsorbed metals depend on factors such as pH, surface loading, and the presence of competing ions. For example, extended X-ray absorption fine structure (EXAFS) spectroscopy showed that Ni binds to biogenic Mn oxides predominantly via coordination at vacancy sites as a triple-corner-sharing complex (Ni-TSC), but increasing pH and surface loading favours the coordination via Ni incorporation (Ni-Inc) into the MnO₂ sheet (Pena et al, 2010).

In addition to sorption at vacancy sites, metal adsorption can occur potentially at the particle edges (Manceau et al, 2007) and on the bacterial cells and extracellular polymeric substances (biomass) responsible for mineral precipitation (Pena et al, 2011). Based on these studies, surface loadings close to or greater than vacancy content should favour metal partitioning between the vacancies, the particle edges and the functional groups of the biomass. Thus, in biogenic Mn oxides, the presence of organic functional groups associated with the biomass complicates the determination of the coordination modes of metals at the particle edges.

The goal of this project is to understand the reactivity of MnO_2 particle edges. We approach this question through sorption studies using a chemically synthesized d- MnO_2 free of any organic material and through competitive sorption experiments on both δ - MnO_2 and biogenic MnO_2 . We studied adsorption of Ni and Co at the surface of δ - MnO_2 , a close analog of biogenic Mn oxide with similar structural characteristics and a vacancy content of up to 6% (Villalobos et al, 2003). We investigated the adsorption mechanism of Ni by δ - MnO_2 as a function of pH and surface loadings using a combination of wet chemistry methods and EXAFS spectroscopy. In addition, we tested whether we can minimize the number of surface complexes formed on MnO_2 by blocking the vacancies with a high-affinity metal (Co). We compare these data to the Ni/ Co adsorption at the surface of the biogenic birnessite produced by *Pseudomonas putida* strain GB-1 and discuss the possibility of using δ - MnO_2 as an model for reactivity studies of biogenic Mn oxides.

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14.14

Zooming in on trace metal bioavailability to phytoplankton in surface waters

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Trace metals (TMs) play a central role in the aquatic ecosystems. TMs interact with a broad spectrum of biotic and abiotic components via dynamic interrelated processes. As a result they exist in various forms with different reactivity and biological availability. The present study zooms in on the TM bioavailability to phytoplankton in surface waters, which are subject of natural variability and multiple sources of stress. It can be anticipated that the physical stressors such as solar radiation and enhanced TM concentrations will operate additively, however there is a paucity of systematic knowledge on the underlying processes, as well as lack of adapted methodologies for exploration of their combined effects. In such a context, an array of novel and powerful technologies was used to determine how the interacting effects of TMs, variable solar radiation and dissolved organic matter (DOM) alterations will impact the phytoplankton population in surface waters.

Experiments were performed in specially designed radiation system consisting of microcosm and solar simulator units. Solar radiation intensity was varied to represent the dose received by the phytoplankton in a euphotic zone corresponding to the clear sky day of winter and summer at mid-latitude for Europe. Cd, Cu and Pb concentrations were varied in the wide range from 10⁻⁹ to 10⁻⁵ mol/L, representative for the natural and polluted surface waters. The effect of solar radiation intensity on the DOM structure and characteristics and thus DOM capacity to bind TMs were studied in parallel. Green microalgae *Chlamydomonas reinhardtii* and *Chlorella kesslerii* were used as representative phytoplankton species. Bioavailability was characterized by measuring cellular metal contents, algal population structure, esterase activity, and membrane integrity and lipid peroxidation by using flow cytometry.

Obtained results demonstrated that the variability of solar radiation intensity affects TMs bioavailability by influencing both TM speciation, via photo-transformation of DOM in the medium, and by affecting the vital cellular functions of phytoplankton. Increased sunlight intensity resulted in an alteration of the algal cell population structure and growth inhibition. Cell bleaching, membrane damage, oxidative stress and increased lipid peroxydation were pronounced at higher radiant dose. Similar effects were also observed in algae exposed to high concentrations of Cd, Cu or Pb. Combined action of the enhanced solar radiation and high metal concentration was found to operate synergistically. In addition, sunlight of increasing intensity degraded DOM, thus resulting in increase of the free metal ion concentrations in medium and cellular metal content. The findings of the present study are discussed from biogeoscience view point in a context of changing environment.

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Dynamic Fe precipitation by Fe(II) oxidation in water

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The oxidation of Fe(II) at biogeochemical redox interfaces results in the formation of nanoparticulate Fe(III)-precipitates that act either as immobilizing sorbents or colloidal carriers for contaminants and nutrients.

In earlier work on Fe oxidation products in neutral aqueous suspensions, we concluded that nanoparticulate amorphous Fe(III)-phosphate is the first precipitate that forms during Fe(II) oxidation in the presence of phosphate (P). At initial dissolved P/Fe ratios less than ~0.55, the precipitation of Fe(III)-phosphate is followed by the precipitation of amorphous to poorly crystalline Fe(III)-(hydr)oxides (depending on silicate/Fe ratio). In recent work, we studied the dynamics of precipitate formation during Fe(II) oxidation in aerated phosphate-containing solutions (bicarbonate-buffered to pH 7.0) in more detail by investigating a larger range of initial P/Fe ratios and by performing time-resolved experiments. Precipitates collected during and after complete Fe(II) oxidation were characterized by a suite of complementary techniques, including X-ray absorption spectroscopy and transmission electron microscopy.

Our new results confirm the initial formation of an amorphous Fe(III)-phosphate with a P/Fe ratio ~0.5 even in solutions with lower P/Fe ratio, but also show that in solutions with initial dissolved P/Fe ratios less than 0.55, initially formed Fe(III)-phosphate is transformed into a precipitate with higher degree of Fe(III) polymerization during continuing Fe(II) oxidation in P-depleted solution. At initial dissolved P/Fe ratios less than ~0.2, initially formed Fe(III)-phosphate is completely transformed into a ferrihydrite-like precipitate. However, even at low dissolved P/Fe ratios, Fe-phosphate may dominate locally at spatial redox interfaces where low O_2 concentrations limit the extend of Fe(II) oxidation.

In future work, we will further explore Fe precipitation dynamics during Fe(II) oxidation and the aging of fresh precipitates, also with respect to the influence of silicate and Ca and implications for trace elements such as As.

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14.16

Robust method for quantitative trapping of volatile organic selenium and sulfur species

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Selenium (Se) is of key importance to human health but its global biogeochemical cycle is largely unknown and unstudied. Chemical analogies between Se and sulfur (S) have recently led to the hypothesis that volatile Se compounds could be formed similarly to the biogenic gas dimethylsulfide.

This compound is naturally produced in the oceans by certain types of phytoplankton and plays an essential role in the Earth's biogeochemical cycles. However, in order to measure the production of these gaseous compounds in low concentrations, both in the lab and in the field, a trapping and pre-concentration method is required that is reproducible and preserves information about speciation.

We tested a liquid chemotrapping method that uses concentrated nitric acid as a trapping medium, based on an earlier developed method (Winkel et al. 2010). The naturally relevant organic Se and S volatile compounds dimethylselenide (DMSe), dimethyldiselenide (DMDSe), dimethylsulfide (DMS) and dimethyldisulfide (DMDS) were injected in a set up consisting of three nitric acid impingers in series. The trapping liquids were analyzed by ICP-MS (for total Se and S) and HPLC-ICP-MS (for speciation determination).

First results indicate that the trapping recoveries for DMSe ($92\% \pm 2\%$), DMDSe ($50\% \pm 7\%$), DMS ($96\% \pm 4\%$) and DMDS ($73\% \pm 6\%$) are high and that results are reproducible. The largest amount of inject S and Se (>90%) is retained in the first trap. Furthermore, information on the speciation of all volatile Se and S compounds is retained via the formation of oxidized derivatives: dimethyl sulfoxide (DMSO) and dimethyl selenoxide (DMSeO) for DMS and DMSe, and methyl sulfonic acid (MSA) and methyl seleninic acid (MSA) for DMDS and DMDSe, respectively.

The presented method is quantifiable and reproducible and will be applied to trap Se and S compounds in experiments with phytoplankton cultures. Due to its simplicity and robustness this method can potentially be applied to qualitatively and quantitatively study Se and S volatilization in a wide range of natural environments.

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Winkel L., et al. 2010: Quantitative and Qualitative Trapping of Volatile Methylated Selenium Species Entrained through Nitric Acid, Environ. Sci. Technol. 44 (1), 382–387 Symposium 14: Environmental Biogeosciences

P 14.1

Soil organic matter dynamics: bridging the gap between Rock-Eval pyrolysis and chemical characterization (CPMAS ¹³C NMR)

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Being a source of mineral nutrients, organic matter contributes to soil chemical fertility and acts on soil physical fertility through its role on soil structure. Soil organic matter (SOM) is a key component of soils. Notwithstanding this paramount importance of SOM, information on its chemistry and behaviour in soils are still incomplete. Numerous methods are used to characterize and monitor OM dynamics in soils using different approaches (Kogel-Knabner, 2000). Two of the main approaches are evaluated and compared in this work. Rock-Eval pyrolysis (RE pyrolysis) consists of the description of SOM general evolution using its global thermal stabilities. The second tool (¹³C CPMAS NMR) aims to give precise and accurate chemical characterization information of OM.

The RE pyrolysis technique was designed for petroleum exploration (Lafargue et al., 1998) and because of its simplicity, it has thus been applied to a variety of other materials such as soils or Recent sediments (Disnar et al., 2000; Sebag, 2006). Recently, RE pyrolysis became a conventional tool to study OM dynamics in soils. In RE pyrolysis, a peak deconvolution is applied to the pyrolysis signal in order to get four main components related to major classes of organic constituents. These components differ in origin and resistance to pyrolysis: labile biological constituents (F1), resistant biological constituents (F2), immature non-biotic constituents (F3) and a mature refractory fraction (F4) (Sebag, 2006; Coppard, 2006). Main advantages are rapidity and repeatability of this technique to give a general view of OM properties and stocks. However, do the four major classes used in the literature reflect a pertinent chemical counterpart?

To answer this question, we used ¹³C Nuclear Magnetic Resonance Spectroscopy in the solid state (¹³C CPMAS NMR) to collect direct information on structural and conformational characteristics of OM. NMR resonances were assigned to chemical structures according 5 dominant forms: alkyl C, O-alkyl C, aromatic C and phenolic C and carbonyl–carboxyl C. Moreover, in order to avoid the influence of pedogenesis, we decided to use "less complex OM", *i.e.* compost samples already studied in a previous work (Albrecht, 2009).

Significant and high correlations are observed between classes, or indices, from RE pyrolysis and main classes of organic matter detected by NMR *e.g.* F1 and labile / easily degradable components (alkyl C et O-alkyl C); F3/F4 and humified OM (aromatic C and phenolic C); R index (contributions of bio-macromolecules) and phenolic and aromatic C; I index (related to immature OM) and labile / easily degradable components (alkyl C et O-alkyl C).

This work confirms interests of RE pyrolysis in soil science (notably with used of R/I index ratio). The next step consists of using more complex samples such as bulk soil samples.

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P 14.2

Biogeochemical cycling of trace elements in a tropical montane rain forest in Ecuador

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Many trace elements are essential micronutrients for plants and microorganisms. However, nearly all trace elements become toxic when they occur in high concentrations. Therefore it is of interest to study trace element fluxes in ecosystems to reveal imbalances and possible effects on ecosystem functioning.

We calculated trace element budgets for important micronutrients (e.g. Cu, Cr, Ni and Zn) and for purely toxic trace elements (e.g. Pb, Cd) in a small catchment in remote montane rainforest in South Ecuador, which developed on trace element poor bedrocks. All relevant ecosystem solutions (rainfall, throughfall, litter leachate, soil solution in 15 and 30 cm depth and surface runoff) and litter fall were sampled for one hydrological year (2001/2002) in monthly resolution. Water fluxes for the different compartments were directly measured or taken from the literature (Boy et al., 2008). Additionally organic and mineral soil horizons were sampled. Samples from organic horizons and litterfall were digested in HNO₃ under pressure and digests were measured together with solution samples by ICP-MS. Element composition of mineral soil and local bedrock samples were analysed by using RFA. Element budgets were calculated from element concentrations and water/litterfall fluxes. Dry deposition was calculated according to Ulrich (1983).

Especially Cd, Cu and Zn showed high deposition rates, despite the remote location of the catchment. The fluxes between the different compartments were comparatively high, while Cu and Zn were concentrated in the aboveground part of the cycle and retained in the organic layer. In the opposite, Cr input to the catchment was comparatively low and high fluxes occur only within the soil system. The mass balance at the catchment scale indicates retention for all of the investigated metals, reflecting the enrichment of metals in the ecosystem. The high input and the enrichment of trace metals might on the long-run effect the ecosystem by supplying micronutrients to the naturally poor system (low bedrock and soil concentrations) and especially extremely trace element poor habitats e.g. for epiphytes and lichens. On the other hand increasing concentrations of toxic trace elements e.g. in the organic layer might affect organic matter turnover by sensitive microorganisms.

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P 14.3

The oxalate-carbonate pathway: at the interface between biology and geology

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The formation of calcite in otherwise carbonate-free acidic soils through the biological degradation of oxalate is a mechanism termed oxalate-carbonate pathway. This pathway lies at the interface between biological and geological systems and constitutes an important, although underestimated, soil mineral carbon sink. In this case, atmospheric CO, is fixed by the photosynthetic activity of oxalogenic plants, which is partly destined to the production of oxalate used for the chelation of metals, and particularly, calcium. Fungi are also able to produce oxalate to cope with elevated concentrations of metals. In spite of its abundance as a substrate, oxalate is a very stable organic anion that can be metabolized only by a group of bacteria that use it as carbon and energy sources. These bacteria close the biological cycle by degrading calcium oxalate, releasing Ca²⁺ and inducing a change in local soil pH. If parameters are favourable, the geological part of the pathway begins, because this change in pH will indirectly lead to the precipitation of secondary calcium carbonate (calcite) in unexpected geological conditions (Figure 1). Due to the initial acidic soil conditions, and the absence of geological carbonate in the basement, it is unexpected to find C in the form of calcite. The activity of the oxalate-carbonate pathway has now been demonstrated in several places around the world, suggesting that its importance can be even greater than expected. In addition, new roles for each of the biological players of the pathway have been revealed recently forcing us to reconsider a global biogeochemical model for oxalate cycling (Martin et al., in press).

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Fig. 1. Schematic representation of the oxalate-carbonate pathway showing the main biological players and the chemical reactions involved (modified from Aragno and Verrecchia, 2012). The unknown contribution of fungi as calcium oxalate producers and the role of their interaction with bacteria are indicated by a question mark. CaOx = calcium oxalate. a = processes leading to the formation of CaOx in the plant and fungi, oxidation of CaOx by bacteria and arrows indicating the unknown contribution of fungi; b = effect of oxidation of CaOx on soil pH over time; c = final product of the oxalate-carbonate pathway. The reactions leading to the formation of calcium carbonate are indicated below.


P 14.4

Influence of plant diversity on polycyclic aromatic compounds and their metabolites in temperate grassland soils

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Polycyclic aromatic hydrocarbons (PAHs) and their polar oxygenated (OPAH) and nitrated (Nitro-PAH) derivatives are generated by incomplete combustion of fossil fuels. Furthermore, OPAHs and Nitro-PAHs can be formed in the atmosphere and in soils by photochemical and microbial transformation of PAHs. OPAHs and Nitro-PAHs are more mutagenic and carcinogenic than their parent-PAHs. Plants can influence the concentrations of organic pollutants in soil by scavenging them from the atmosphere and fixing them in soil "filter effect", releasing enzymes that degrade organic compounds and favoring PAH-degrading microbes associated with plant roots (Dietz et al., 2001; Van Aken et al., 2010). The use of mixtures of plant species for clean-up of soil contaminated with parent-PAHs "phytoremediation" has been frequently reported, but the effect of such procedures on metabolites such as OPAHs and Nitro-PAHs has not been reported (Meng et al., 2011). It is known that plants frequently do not release suitable enzymes to mineralize parent-PAHs completely. Hence, accumulation of intermediate products is a possibility (Van Aken et al., 2010). It can be assumed that the nature and extent of transformation of organic pollutants (PAHs, OPAHs & Nitro-PAHs) in soil differs amongst different plant species because of differences in the morphology, enzymes they exude and number/kind of microbes associated with their roots. The objective of this study was to understand how plant diversity and plant functional group composition influences the accumulation/transformation of parent-PAH/OPAHs and Nitro-PAHs in temperate grassland soils.

To achieve this we analyzed the concentrations of PAHs, carbonyl-OPAHs and Nitro-PAHs in soils from the Jena Biodiversity Experiment plots. In the Jena Experiment, the composition of plant cover has been manipulated to create a gradient in plant species richness and number of plant functional groups. The experimental design consists of 82 plots with plant mixtures of varying species numbers (1, 2, 4, 8, 16 and 60 species), functional group diversity (1, 2, 3 and 4) and plant functional group identity (grasses, legumes, tall herbs, small herbs) composition (Roscher et al., 2004, Bandowe and Wilcke, 2010). The influence of plant diversity (species number, functional group number, presence or absence of specific functional groups: grasses, legumes, small herbs and tall herbs) on the concentrations of parent-PAHs, carbonyl-OPAHs and Nitro-PAHs was explored with the help of Univariate ANOVA followed by posthoc tests.

The concentrations of Σ 28 PAHs (471-2289 ng/g), Σ 15 carbonyl-OPAHs (123-405 ng/g) and Σ 7Nitro-PAHs (42-337 ng/g) in Jena soils were comparable to those of other urban sites in Europe. Plots with higher species number had significantly higher 1-naphthaldehyde concentrations (F=4.358, p=0.013). Increases in functional group number only caused a significant increase in concentration of 6H-benzo(cd)pyrene-6-one (F=3.302, p=0.047). The functional group identity seems to play a more important role in transformation of PAHs, OPAHs and Nitro-PAHs in soil than species richness and number of functional groups. The presence/absence of legumes and small herbs had different effects on the different compound groups. The concentration of 2-methylnaphthalene was higher when legumes were present (F=4.309, p = 0.05). The concentration of 6H-benzo(cd)pyrene-6-one (F=7.104, p=0.02), several individual Nitro-PAHs: 2-nitrobiphenyl (F=4.98, p=0.04), 3-nitrofluoranthene (F=5.35, p=0.03), 2,7-dinitrofluorene (F=4.88, p=0.04) and Σ 7Nitro-PAHs (F=6.803, p=0.02) were lower in the presence of legumes. This is an indication that the legumes either directly release enzymes to their root zone capable of degrading Nitro-PAHs and 6H-benzo(cd)pyrene-6-one or the presence of legumes enhances microbial activity in their rhizosphere, mainly because of the improved nitrogen supply. Presence of small herbs decreased concentrations of anthracene but increased those of 1-nitronaphthalene and 6-nitrochrysene. This could mean that 1-nitronaphthalene and 6-nitronaphthalene are formed by enzymes associated with small herbs while anthracene is biodegraded. This knowledge might help to develop and improve phytoremediation for soils contaminated with atmospheric pollutants like PAHs, OPAHs and Nitro-PAHs.



Figure 1: Jena Biodiversity Experiment Site (www.the-jena-experiment.de)

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Biologically induced vs. biologically influenced mineralization of carbonates from a hypersaline microbial mat, Pernambuco Lagoon, Brazil

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In microbial mats, microbes mediate the formation of laminated structures, most commonly composed of carbonates, a process defined as organomineralization. It includes (i) biologically-induced mineralization resulting from the interaction between biological activity and the environment; and (ii) biologically-influenced mineralization which is defined as passive mineralization of organic matter (biogenic or abiogenic in origin), whose properties influence crystal morphology and composition (Dupraz et al., 2009). Cell walls, sheaths and extracellular polymeric substances (EPS) are currently thought to be the main templates involved in mineral formation that may be partially preserved in the geological record. This study focuses on organomineralisation in a living hypersaline non-lithifying microbial mat from Lagoa Pernambuco, Brazil. Microscopic, spectroscopic and microelectrode studies of the microbial mat provided information on the microbial population and the biologically-influenced vs. biologically induced mineralization processes, specifically the formation of Mg-calcite and dolomite, which are present in different horizons of the microbial mat.

Chemical imaging of biological materials is advancing our understanding of biochemical processes and the role of microbes in mineral precipitation. Using NanoSIMS, we aimed to link microbial metabolism to molecular structures and produce a detailed view of the role of these organisms during the formation of the carbonate cortex in ooids. Coordinated NanoSIMS-microscopy studies make it possible to obtain simultaneous information on the mineralogy, structure compositions, and petrographical context of the different organomineral layers. Mapping of O, S, Si, Ca, Mg and C/N was accomplished at specially targeted sites bringing unique information about the relationship among these elements.

Results highlight photosynthesis, exopolymer degradation and sulfate reduction, which play important roles in element cycling in specific layers of microbial mats and which have a crucial role in amorphous Mg-Si and $CaCO_3$ precipitations. Moreover, this study reports viruses that become mineralized and it discusses their potential on mineralization and preservation.

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Effects of P, Si and Ca on composition, structure and As uptake of fresh and aged Fe precipitates

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The oxidation of Fe(II) in aerated water leads to the formation of amorphous to poorly-crystalline Fe(III)-precipitates. Such precipitates control the cycling of major and trace elements in a wide range of redox-dynamic environments, but also play an important role in engineered systems, such as drinking water treatment for As removal from anoxic As-rich ground-waters.

Previous work has shown that the composition and structure of fresh Fe(III)-precipitates from Fe(II) oxidation strongly depend on the concentrations of phosphate (P), silicate (Si) and Ca in solution. However, systematic quantitative information is still limited with respect to:

- effects of Si and Ca on the composition and structure of fresh Fe oxidation products over a range of P/Fe ratios
- changes in composition and structure of different precipitates with aging
- effects on uptake and solubility of co-transformed As.

To fill this knowledge gap, we perform batch experiments on Fe oxidation, precipitation and precipitate aging in bicarbonate-buffered solutions at pH 7.0. At initial dissolved P/Fe ratios from 0 to 2, we investigate the effect of the Si and/or Ca on the composition and structure of fresh Fe precipitates (sampled after 4 h, i.e., complete Fe(II) oxidation) and on the uptake of arsenate (initially 500 µg/L As(V)). The same types of precipitates will also be analyzed after aging in their synthesis solution for 30 d at 40°C.

First results confirm that the presence of Ca substantially enhances P and As(V) uptake by fresh precipitates formed at high P/Fe ratios. Si on the other hand seems to markedly slow down precipitate crystallization at low P/Fe ratios. These results will be complemented with data for aged precipitates, as well as with results from precipitate characterization by Fe K-edge X-ray absorption spectroscopy and transmission electron microscopy.

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Evidence for a life-influenced Dead Sea during the last glacial-interglacial cycles

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The ICDP Dead Sea Deep Drilling Project aims to reconstruct the paleoclimatic and paleoseismicity records of the Levant region. Within this frame, a geomicrobiogical investigation is undergoing in a 450m-long core retrieved from the deepest part of the hypersaline modern Dead Sea. One goal of this investigation is to constrain the microbial influence on the precipitation of authigenic minerals.

Lake level fluctuations during the two last glacial-interglacial cycles have allowed the development of microbial life in both the water column (Oren & Shilo, 1982) and the sediments (this study). While today's hypersaline conditions hardly favor the development of sustained life in its water column, preliminary geomicrobiological results argue for an impact of microbial life on the water and the sediments of the Dead Sea and its predecessors.

Although formerly thought to be abiotically driven (Barkan et al., 2001), it has been acknowledged that algal blooms have influenced the carbon cycle in the Dead Sea and its precursors (Kolodny et al., 2005). New carbon isotopic data from Holocene and Pleistocene aragonite corroborate this interpretation, additionally supported by C/N ratios indicating lacustrine algae as the main source of OM. It appears that these variations have been driven by relative changes in the contribution of photosynthetic activity, aerobic and anaerobic organic matter decomposition, as well as changes in evaporation and rainfall that have triggered numerous water column turnovers.

Furthermore, SEM investigations of modern microbial mats associated with aragonite laminae along the emerged Dead Sea shores show a co-occurrence of EPS and aragonite needles possibly arguing for an additional mode of precipitation. These EPS may act as a template for aragonite nucleation and needle growth. Carbonate ions may also be released by SRB degradation of EPS in the sediment allowing aragonite precipitation, which could further explain the negative shifts in aragonite δ^{13} C. Authigenic pyrite is commonly found within these laminae supporting an active biologic S cycle.

Ongoing processes in the newly emerged Dead Sea shores provide plausible explanations for the observed lithological patterns and microbial imprint in the retrieved sedimentary core. These data may further help understanding the occurrence of aragonite within laminated and non-laminated sediments as well as of native sulfur concretions and framboidal pyrite. Finally, the combined dataset of this unique hypersaline system witnesses the high variability of the carbon cycle throughout time.

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Are the spectacular speleothems of Asperge biogenic?

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Asperge Cave is 7 km long, 126 m deep and it is located in the region of the "Montagne Noire" - Hérault (Fr). The cave opens in Cambrian terrains at the contact between the "Calcaire marmoréen massif, cristallin de La Garrigue" (marble) and the "Schistes et calcaires phylliteux" (schist) (Alabouvette et al., 1982).

Pits and meanders of the Asperge Cave develop within marble and schist, and limited zones of the cave present groups of concretions formed by bouquets of acicular-, coralloid- and bulb- shaped aragonitic speleothems (Fig. 1). Thanks to the spectacular morphology and colors of these concretions, Asperge has been proposed as UNESCO World-Nature-Heritage (IUCN, 2007). Speleothems with shapes as those found in Asperge are not unique and have been described elsewhere in the world (e.g. in Hidden Cave, New Messico (Hazel et al., 2007)). Hazel et al. (2007) suggested that morphologies such as u-loops might be the result of a biological process. However, this hypothesis remains quite speculative. Testing it is the goal of our study.

Here we present preliminary results of a series of field observations, mineralogical-chemical and microbiological analysis of the Asperge concretions. Yeast Extract Agar plates were used to sample the living organisms from different location of the cave. Various bacterial and fungal species that need to be classified have been successfully isolated from the speleothems. We speculate that these organisms might play a central role in the formation and the shaping of the concretions.

With this contribution we aim to emphasize the importance of biology in apparently inhospitable underground environments. Speleothems thus far regarded as abiotic concretions might instead be the product of yet unknown living organisms.



Figure 1. The spectacular speleothems of the "Galerie des grandes aragonites bleues" in Asperge Cave (Fr)

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Stratification of active methanogenic consortium along the Holocene record of Laguna Potrok Aike, Patagonia

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Methane and carbon dioxide within anoxic lake sediments are the final products of organic matter degradation. The biogenic production of these end members depend on both the refractoriness of the organic sources and the metabolic pathways used by the microbial consortia. During early diagenesis, fermentation and reduction processes can gradually convert primary inputs into simpler molecules, which can sometimes mask the initial signals of the bulk organic fraction (Freudenthal et al. 2001; Lehmann et al. 2002). Moreover, in anaerobic habitats, a stepwise degradation of complex organic compounds takes place via hydrolysis, fermentation or acidogenesis, acetogenesis and methanogenesis (Garcia et al. 2000). McInerney et al. (2008) have shown the occurrence of competitive and syntrophic relationships between microbes depending on local physical and chemical conditions. For example, methanogenes can bond to chemoheterotrophic bacteria in low nitrate and sulfate environments producing methane at various stages. While methyl fermentation seems to be a favored pathway in freshwater environments (Whiticar et al. 1986), acetogenesis appears to dominate in cold environments (Kotsyurbenko 2005). Thus, the total amount of methane measured in the sediments depends on complex interactions between sedimentary substrates (Conrad et al. 2010), bacterial activity and metabolic pathways (Whiticar 1999). Furthermore, microbial assemblages tend to evolve toward energy conservation at depth, (Schink 1997), while developing at the same time the ability to use refractory substrates (McInerney et al. 2009). However, until recently geomicrobiological investigations of methane-bearing lacustrine sediments have been limited to their most surficial portion.

We investigated the microbial methanogenic population along the uppermost 10 meters of sediments of Lake Potrok Aike, a subsaline maar located in southern Patagonia. To determine its impact on the sediments we measured methane content and its relative carbon isotopic composition (Fig. 1A). Different microbial substrates were identified and characterized by analyzing their bulk organic fraction and pore waters chemistry. Variable degrees of sediment colonization were observed in relation to organic sources refractoriness. Living microbial activity in the sediments was first assessed using in situ ATP detection, and microbial populations further quantified via cell counts. DGGE and archaeal clone libraries allowed defining their overall diversity and a phylogenetic tree was further established based on retrieved sequences of methanogens. Bacteria dominated the microbial assemblages while methanogenic populations appeared strongly stratified within the sediments. Phylogenetic attributions revealed that species such as *Methanolinea* (Imachi et al. 2008) and *Methanoregula* (Bräuer et al. 2011) are tolerant to Potrok Aike's cold and subsaline conditions (Fig. 1A). The predominance of *Methanomicrobiales* shows that CO₂ reduction has been the major pathway leading to methane production (Borrel et al. 2011), although the highest methane content measured in the sediments appears to be associated with *Methanosarcinales* (Fig. 1A). Methane isotopic values in shallow sediments were similar to those of the bulk organic fraction (approximately -24 ‰), but much more negative at depth (approximately -65 ‰ to -68 ‰). The concomitant presence of *Syntrophus*-related sequences (Jackson et al. 1999) suggests that syntrophy could gradually lead to more negative $\delta^{13}C_{cred}$ values.

Figure 1B shows a proposed stepwise model that summarizes the main stages of organic matter degradation.

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Figure 1. A) Methane content and its corresponding carbon isotopic values. B) Model showing the stepwise organic matter degradation with hydrolysis, acidogenesis and acetogenesis while methanogenesis can take place at different degradation stages. Methanogens are placed on the diagram with respect to their substrate and depth.

15. Biogeochemical cycles in a changing environment

Ansgar Kahmen, Werner Eugster

ACP – Commission on Atmospheric Chemistry and Physics

TALKS:

- 15.1 Burri S., Sturm P., Baur T., Prechsl U., Knohl A., Buchmann N.: Tracing carbon through grassland: the impact of drought on the short-term carbon flow from photosynthesis to soil respiration
- 15.2 Gentsch L., Sturm P., Hammerle A., Siegwolf R., Wingate L., Ogée J., Barthel M., Peter Pluess P., Baur T., Buchmann N., Knohl A.: Photosynthetic 13C discrimination of Fagus sylvatica branches: Insights from continuous, high-frequency field measurements and a Bayesian modelling approach
- 15.3 Halder J., Pralong C., Vennemann T.: δ¹³C (DIC) profiles of Lake Geneva, Switzerland/France
- 15.4 Mills R.T.E., Durand H., Gavazov K., Speigelberger T., Buttler A.: Snow-cover effects on substrate-induced respiration and SOM density fractions in transplanted pasture soils.
- 15.5 Prechsl U., Kahmen A., Hammerle A., Burri S.,Gilgen A., Buchmann N.: The water sourcing strategy of drought affected temperate grasslands
- 15.6 Rodríguez-Murillo, J.C., Filella, M.: Temporal trends of organic carbon in Swiss rivers, 1974-2010
- 15.7 Schilder J., Bastviken D., van Hardenbroek M., Rinta P., Stötter T., Heiri O.: Diffusive flux of methane and other greenhouse gases from lakes has a distinct within-lake spatial distribution
- 15.8 Wilcke W., Leimer S., Schwarz M.T., Valarezo C.: Response of carbon and nitrogen cycles of a tropical montane forest in Ecuador to environmental change

POSTERS:

- P 15.1 Blattmann T., Griffith D., Martin W., Eglinton T.: Modeling 14C of Organic Carbon in Marine Surface Sediments
- P 15.2 Blazina T., Berg M., Winkel L.: Loess as an environmental archive of atmospheric selenium deposition
- P 15.3 Gavazov K., Mills R., Durand H., Spiegelberger T., Buttler A.: Soil respiration and microbial biomass constrained by warmer winter climate and reduced snow cover in transplanted subalpine pasture turfs

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Mean summer precipitation in Switzerland is projected to decrease by the end of the 21st century and there is a tendency towards more frequent dry spells during summer (CH2011, 2011). However, large uncertainties exist in terms of how extreme events like heat waves or drought periods influence the carbon cycle. Ostle et al. (2009) stated that plant-soil interactions need to be further integrated into global carbon models in order to improve climate change predictions. However, plant-soil interactions themselves have a high level of complexity and many processes are subject to current research.

Here, we present results from a project where we investigated the effect of drought on the short-term carbon transport within the plant-soil system of an intensively managed lowland grassland in Switzerland (ETH research station Chamau) using rainout shelters. A pulse labeling experiment with ¹³CO₂, performed in June 2011, allowed tracing the flow of fresh-ly assimilated carbon from above-ground biomass to the roots and finally to soil respiration. Our key method were continuous measurements of soil respiration and its isotopic composition with a laser spectrometer (QCLAS-ISO, Aerodyne Research Inc., MA, USA) coupled to a custom-built chambers. These measurements were complemented by sampling community above- and below-ground biomass and subsequent stable isotope analysis.

Soil respiration showed a diurnal cycle with highest fluxes during the late evening/night, lagging 5-6 hours behind soil temperature under both control and drought treatments. The labeling experiment clearly identified the high nocturnal fluxes as autotrophic. While photosynthesis and soil respiration were reduced under the drought treatment, the appearance of ¹³C- label in soil respiration was not delayed. Thus, there was no sign of any influence of drought on allocation speed. Our results suggest that during a dry spell, less carbon is entering the system while allocation belowground seems to be maintained, although less carbon is released to the atmosphere by soil respiration. If these results can be generalized is currently investigated. Since grasslands are widespread agroecosystems in Switzerland and beyond, such results are important for carbon sequestration considerations or for the modeling of the future carbon cycle.

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Photosynthetic ¹³C discrimination of *Fagus sylvatica* branches: Insights from continuous, high-frequency field measurements and a Bayesian modelling approach

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Isotopic discrimination against ${}^{13}\text{CO}_2$ during photosynthesis (${}^{13}\Delta$) causes the overall ${}^{13}\text{C}$ depletion of the terrestrial biosphere compared to the atmosphere. ${}^{13}\Delta$ varies in response to environmental variables that influence photosynthetic gas exchange. For C₃ plants, ${}^{13}\Delta$ mainly reflects the balance between the CO₂ supply to and the CO₂ demand by the carboxylation sites, but it is, to a smaller extent, also influenced by carbon isotope fractionations occurring during mitochondrial and photo-respiration. Understanding and predicting ${}^{13}\Delta$ variability has gained relevance for CO₂ flux partitioning on the global and the ecosystem scale, for tree ring analysis or for insights into plant/soil dynamics. Estimates of ${}^{13}\Delta$ are commonly obtained by combining carbon isotope measurements of plant-derived organic matter or air profiles with ${}^{13}\Delta$ -models. In contrast, direct, gas exchange-based measurements of ${}^{13}\Delta$ under field conditions are sparse, due to the technical deployment involved. Hence, we have little experimental verification of diurnal and seasonal variabilities of ${}^{13}\Delta$ and their relation to environmental drivers. We further lack a thorough field-based evaluation of the Farquhar et al. (1982) ${}^{13}\Delta$ -model.

Here, we present continuous, hourly field measurements of ${}^{13}\Delta$ of *Fagus sylvatica* L. branches, conducted with three custommade open branch bags and a laser spectrometer for CO₂ isotopologue measurements (QCLAS-ISO, Aerodyne Research Inc.). Data from two field campaigns (in total 38 and 60 days) in a mature, temperate mixed-deciduous forest in Switzerland during August / September 2009 and 2010 are shown. We observed a high diurnal variability of ${}^{13}\Delta$, with average diurnal amplitudes of \approx 10‰ and maximum diurnal amplitudes of \approx 20‰. Highest ${}^{13}\Delta$ were generally observed during dawn and dusk, and lowest ${}^{13}\Delta$ during midday. Morning and afternoon ${}^{13}\Delta$ commonly displayed intermediate values. Day-to-day variations were summarized with flux-weighted daily means of ${}^{13}\Delta$, which ranged from 15‰ to 23‰ in 2009 and from 18‰ to 29‰ in 2010. Regression analysis suggested that CO₂ assimilation (and hence CO₂ demand) played the dominant role in driving ${}^{13}\Delta$ variability at the branch level, as long as trees were not water-limited. For the environmental drivers, changes in incident *PAR* appeared to strongly determine changes in the branch gas exchange, and hence ${}^{13}\Delta$.

Using data from the 2010 field campaign only, we explored the applicability of three versions of the commonly used Farquhar *et al.* (1982)-model (comprehensive: ${}^{13}\Delta_{comp}$, simplified: ${}^{13}\Delta_{simple}$ and revised: ${}^{13}\Delta_{revised}$ versions) for predicting observed diurnal and day-to-day ${}^{13}\Delta$ variabilities. ${}^{13}\Delta_{comp}$ predicted the mean diurnal variability of ${}^{13}\Delta$ much better than ${}^{13}\Delta_{simple}$ (RMSE_{simple} $\approx 3.4\%$; RMSE_{comp} $\approx 2.5\%$). Furthermore, ${}^{13}\Delta_{comp}$ was more suitable than ${}^{13}\Delta_{simple}$ for predicting flux-weighted daily means of observed ${}^{13}\Delta$. For model calibrations, a Bayesian inference approach was used. This approach allowed us to reliably quantify uncertainties in the model parameter estimation and to reveal the amount of model-relevant information present in our field dataset.

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15.3

δ^{13} C (DIC) profiles of Lake Geneva, Switzerland/France

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There is a growing awareness that lakes may represent significant sinks and sources for atmospheric CO_2 (e.g. Cole et al. 2007). And while the carbon cycling of the oceans is incorporated into climate change models, further understanding is needed to involve carbon fluxes of lakes in the global carbon balance.

A tool to constrain carbon sources are studies of the variations of the stable isotopes (¹²C and ¹³C) of dissolved inorganic carbon (DIC). In general, most studies of $\delta^{13}C_{_{DIC}}$ in lakes show the same patterns: variations in the isotope composition of DIC are closely coupled to the biologic cycle in the lake, as aquatic photosynthesis in the epilimnion preferentially consumes ${}^{12}CO_2$ (e.g. Baird et al. 2001). Respiration in the hypolimnion consumes the ${}^{13}C$ depleted organic matter and produces CO_2 with a similar ${}^{13}C$ depleted composition (e.g. Herczeg 1987). However, recent studies (e.g. Karim et al. 2011) concluded that it does not necessarily imply that the effects of GPP (gross primary productivity) and R (respiration) are reflected in carbon dioxide concentrations and isotopes in lakes. Especially, studies on large lakes are underrepresented in the literature, and therefore the research aim of this study is to evaluate the isotope composition of DIC in Lake Geneva.

Depth profiles were taken between 2009 and 2011 and the results show that even within the same lake, parameters which are indicating photosynthesis, are not necessarily linked to $\delta^{13}C_{_{DIC}}$ values. Moreover, it can be concluded that $\delta^{13}C_{_{DIC}}$ values in summer do not only reflect the amount of PP. This is based on the fact, that the amount of PP in summer shows a strong discrepancy between 2009 and 2010 (CIPEL 2011), but annual $\delta^{13}C_{_{DIC}}$ values of the epilimnion and metalimnion do not indicate variations. However, in shallow bay regions the $\delta^{13}C_{_{DIC}}$ variation correlates with the seasonal cycle of PP. Furthermore, results indicate that the progressive depletion of $^{13}C_{_{DIC}}$, observed in the metalimnion, is dependent on the local variation of temperature and conductivity, thus density stratification. This suggests that the vertical variation of $\delta^{13}C_{_{DIC}}$ may also be induced by turbulent mixing.

The pCO₂ (partial pressure of CO₂) lies below atmospheric equilibrium from April to October and based on this results it can be concluded that Lake Geneva is taking up CO₂ from the atmosphere between spring and fall and is emitting CO₂ from the lake to the atmosphere in winter. A good correlation between pCO₂ and $\delta^{13}C_{DIC}$ values indicates that pCO₂ has a primary control on the isotopic composition of DIC.

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Snow-cover effects on substrate-induced respiration and SOM density fractions in transplanted pasture soils.

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Sub-alpine pasture soils were transplanted from 1400m to three locations along an altitudinal gradient (600-1400m a.s.l) in the Swiss Jura mountains as a climate simulation. Following observations of potential snow-pack effects on in-situ soil respiration along our hill-slope gradient, we collected topsoils from three transplant sites with variable snow cover to investigate variations in microbial biomass stoichiometry, soil organic matter (SOM) characteristics and substrate induced respiration. We hypothesised that addition of an artificial root-exudate cocktail would simulate the spring input of low molecular weight substrate and stimulate respiration in a pattern according to the snow cover regime. Response to substrate addition was highly variable among sites, with persistent snow-cover dampening the substrate response compared to sites which typically experienced lower snow cover and higher incidence of freeze-thaw cycles. We also present edaphic an microbial biomass data along with density fractionated SOM and explore function-driver relations among the transplanted soils. Our results have implications for the seasonal dynamics of C turnover in soils which will, under future climate scenarios, experience a much reduced snow cover, and more frequent freeze-thaw episodes.

15.5

The water sourcing strategy of drought affected temperate grasslands

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In Central Europe, temperate grasslands are agroecosystems of high agricultural, ecological and economic importance. Growth, distribution and yield of this vegetation type depend strongly on the sufficiency of water supply in late spring/ early summer. Until now, water has never been considered as a limiting factor. However, climate models project a change in the future precipitation patterns: until 2070, a reduction in summer precipitation of about 20% (compared to 1961-1990) is projected for northeastern Switzerland. In addition, the frequency of extreme drought periods is likely to increase. The aim of this study was to investigate if herbaceous grassland species adapt their water sourcing to (simulated) drought by exploring deeper soil layers to compensate the decreasing soil moisture. Summer drought was simulated by using transparent shelters (3 m x 3.5 m) at three different Swiss sites along an altitudinal gradient (400 m to 2000 m). Water of soil and plant root crown (xylem) samples was cryogenically extracted. Soil, plant and precipitation waters were analyzed for δ^{18} O using isotope ratio mass spectrometry. Standing belowground biomass was sampled regularly to determine possible shifts in the root mass distribution.

The δ^{18} O values of drought affected plants differed significantly from those of control plants, and often were similar to those of upper soil layers, although upper soil layers were very dry. This pattern occurred at the three sites and during three years in different intensity. Particularly, in the recovery periods, i.e., about 4 weeks after removing the shelters, a very strong relationship with the δ^{18} O value of precipitation could be found. Our results were confirmed by an additional evaluation with a Bayesian calibrated mixing model. Belowground biomass distribution supported the results based on the stable isotopes approach: Under drought stress, a highly dynamic and strong increase of root mass was observed in the top soil. Thus, in contrast to the hypothesized drought adaption to deeper rooting patterns, temperate grassland species shifted root growth and water uptake to the top soil, supposedly towards the next most likely water source: the next precipitation event.

Temporal trends of organic carbon in Swiss rivers, 1974-2010

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Until recently, continental waters have been neglected as significant components of the global carbon cycle. Nowadays, the important role played by lakes and rivers in organic carbon processing, and not merely in transport, is widely acknowledged (Cole et al 2007). Moreover, organic carbon concentrations in rivers and lakes have been reported to have increased in the last decades in many places of the Northern hemisphere. This increase is not without exceptions and its causes are multiple (Evans et al 2005). Most studies have focused on small rivers and lakes of boreal and/or peat-rich ecosystems. We want to expand the scope of studied systems by analyzing the temporal series of organic carbon concentrations in temperate rivers. Switzerland offers a good opportunity for such studies, as extensive long-term temporal series of hydrological data are available through the NADUF program (NADUF).

We have selected data from nine measuring stations in the main Swiss rivers: Rhône (Porte du Scex, Chancy), Rhine (Diepoldsau, Rekingen, Village Neuf-Weil), Inn (S-Chanf, Martina), Aar (Brugg), and Thur (Andelfingen). These stations have at least 10 years (usually more than 25 years), of uninterrupted temporal series of biweekly recorded dissolved (DOC) and total organic carbon (TOC) data. We have analyzed temporal series of DOC and TOC concentrations, discharge, water temperature, conductivity, total suspended solids, phosphate and DOC and TOC loads. Since data are non-normally distributed, with frequent outlying values, and show a pronounced seasonality, robust non-parametric statistical methods have been used, namely Mann-Kendall and Seasonal Mann-Kendall. Temporal tendencies have been described by Sen's slopes of regression lines (Helsel and Hirsch 2002).

We have found a generalized decrease of TOC concentrations in rivers during the time period studied. DOC tendencies are less marked, with DOC concentrations having increased in Rekingen and Chancy. Decreases in TOC and changes in DOC concentrations are small –generally less than 1% of mean TOC or DOC content per year. This is the first time that a different temporal behaviour between DOC and TOC concentrations in continental waters has been reported. It could result in a temporal change of organic carbon quality and processing with the consequence of a higher percentage of DOC and a lower percentage of particulate organic carbon (TOC – DOC) in the rivers.

Loads of organic carbon leaving Switzerland have been calculated. They are a small but significant part of the Swiss forest net ecosystem production. TOC loads experienced a marked decrease in the last decade. This means a small, but probably worth of consideration, potential carbon sink in Switzerland.

Time evolution of DOC and TOC are not monotonic. This has been clearly shown by dividing the time-series in two sub-periods (before 1999 and 1999-2010) and obtaining the corresponding temporal trends. Many time-series in the first period considered show increasing concentrations, whereas all TOC and DOC late series (1999-2010) are decreasing, again with DOC decreasing slower than TOC.

Different temporal behaviour in the two sub-periods suggests a cyclic evolution of TOC and DOC concentrations. This hypothesis is supported by the calculation of moving averages of annual TOC and DOC concentrations, which show the probable existence of two cycles of increasing and decreasing organic carbon in the period studied (1974-2010).

As of yet, we have not been able to ascertain the causes of the observed temporal behaviour of river organic carbon concentrations. Statistical relationships of TOC with river discharge do exist but they are weak (30% of explained TOC variability at most, and usually 10-15%). Relationships with water temperature and phosphate concentrations are even weaker and non-significant in many cases. Discharge only explains a few percent of DOC variation, and water temperature and phosphate do not increase much the fraction of explained DOC variability.

Both the similarity of the recent trends in TOC and DOC concentrations in all the rivers studied and the probable existence of temporal cycles in DOC and TOC, point to a climate-related driving variable of their evolution. We are now trying to relate TOC and DOC data with precipitation data in the river basins to get a better insight in this challenging part of the global carbon cycle.

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Diffusive flux of methane and other greenhouse gases from lakes has a distinct within-lake spatial distribution

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Lakes are responsible for a significant amount of the natural production of the greenhouse gas methane. Methane can escape lakes through gas bubbles (ebullition) and plant-mediated gas transport. A third pathway, which becomes increasingly important with increasing lake size, is gas exchange on the air-water interface (diffusive flux). Estimates of diffusive methane flux from lakes are obtained through various methods, most of which rely on extrapolations from measurements done in a specific part of the lake (often the deep, central part). It has been suggested that diffusive flux, which depends on the concentration gradient from the water to the atmosphere and turbulence caused primarily by winds, shows a within-lake spatial variability. If true, this variability needs to be investigated to assess the validity of the estimates that are based on extrapolations. Moreover, the process of diffusive flux is not only relevant for methane, but also for other greenhouse gases (e.g. carbon dioxide). Improving our understanding of the greenhouse gas footprint of lakes might allow for lakes to be incorporated in the terrestrial greenhouse gas balance, something that has been called for in various papers.

We measured methane fluxes from the surface of 32 lakes in Europe along a transect from the shallowest to the deepest zones. Of 13 lakes we obtained reliable (i.e. not affected by ebullition) measurements of diffusive flux at all sampling locations. We found a distinct within-lake spatial pattern as the deeper zones typically had higher diffusive methane fluxes than the shallower zones. This pattern appears to be caused by large differences in turbulence driven diffusive flux. Moreover, this spatial gradient in turbulence driven diffusive flux was larger in bigger lakes. This means that calculations of whole basin diffusive methane flux based on extrapolations of measurements done in the deep, central zones tend to produce overestimations. To illustrate the implications of our findings, we plotted the overestimation of whole basin diffusive flux only in the central part of our 13 lakes compared with our spatially resolved measurements (Fig. 1).

Our findings indicate that estimates of whole basin diffusive gas fluxes need to be based on measurements at various sites along a spatial gradient. Also, more research is needed to improve our understanding of the variability in diffusive gas fluxes from lakes in order to incorporate lakes in the terrestrial greenhouse gas balance as accurately as possible. Therefore, future studies will address the spatial variability of diffusive gas fluxes in more detail, as well as explore the temporal (diurnal and seasonal) variability.



Figure 1. Bar plot showing the amount of overestimation (%) of whole basin diffusive methane flux (mmol m-2 day-1) had we extrapolated based on measurements done in the central, deep zone only. For 10 out of 13 lakes, this overestimation is considerable and it can be up to 77%.

Response of carbon and nitrogen cycles of a tropical montane forest in Ecuador to environmental change

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Global environmental change reaches even the most remote ecosystems like the east-exposed tropical montane forests in the north Andes on the rim of the Amazon basin. Between 1998 and 2010, we observed increasing N deposition and soil dryness in line with predictions for the study region on the east-exposed slope of the eastern cordillera of the Andes in south Ecuador (Vuille et al., 2003; Galloway et al., 2008). Our objectives were to explore the responses of biogeochemical cycles of C and N to these changes. We equipped a ca. 9-ha large microcatchment at 1850-2150 m a.s.l. (MC2), which is entirely covered by native old-growth lower montane forest with all devices needed to determine the major ecosystem fluxes in 1998 (Beck et al., 2008).

C cycling.

From 1998 to 2008, TOC concentrations decreased and C/N ratios of DOM increased in litter leachate (i.e. the soil solution of the thick organic layers harboring almost all plant roots) of three study sites in MC2 (Fig. 1A) and in mineral soil solution at the 0.15 and 0.30 m depths. In litter leachates, simultaneously (i) pH decreased by one unit, (ii) NO₃⁻ concentrations increased, and (iii) the increasingly drier conditions reduced water flow and TOC input to the mineral soil. We attribute the changes in quantity and quality of DOM to a fertilizer effect of the improved N availability stimulating microbial DOM degradation. In an hierarchical ANOVA, mean TOC concentrations in litter leachates were significantly explained by H⁺, dissolved inorganic N (i.e. $NO_3^{-}-N^+ NH_4^{+} -N$), and base metal concentrations of soil solution suggesting a microbial control of TOC concentrations. In mineral soil solutions, in contrast, Na (both depths), EC (0.15 m), and H⁺ (0.30 m) contributed significantly to explain TOC concentrations suggesting a physical control of TOC concentrations by ionic strength and dispersion effects. This is corroborated by the observation that TOC concentrations, C/N ratios and Δ^{14} C values indicating a young age of ca. 1-2 yr of the DOM did not change between 0.15 and 0.3 m in the mineral soil.

N cycling.

In parallel to the decrease in DOM concentrations, the contribution of dissolved organic nitrogen (DON) to total N and DON concentrations decreased significantly in rainfall, throughfall, and soil solutions (Fig. 1B). This inorganic turn of the N cycle was most pronounced in rainfall and became weaker along the flow path of water through the system until it disappeared in stream water. The reason for decreasing organic contributions to the N cycling was not only the increasing inorganic N input – NH_4^+ and NO_3^- deposition increased by a factor of ca. 4 and 2, respectively, in the last decade – but also reduced DON production and/or enhanced DON decomposition. Accelerated DON decomposition can be attributed to improved living conditions for microorganisms (less waterlogging as indicated by significantly decreasing soil water contents and frequency of water saturation, higher nutrient availability). Significantly increasing NO_3^-N/NH_4^-N concentration ratios in throughfall and litter leachate below the thick organic layers indicated increasing NH_4^+ immobilization and nitrification. In contrast, NO_3^-N/NH_4^-N concentration ratios in mineral soil solutions decreased significantly, reflecting NO_3^- uptake by increased biomass production as indicated by rising fine litterfall rates.

Our results demonstrate that the C and N cycles of the very remote study ecosystem underwent significant changes in only one decade.

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Figure 1. Mean temporal course between 1998 and 2008 of (A) total organic C concentrations (TOC) and C/N ratios of dissolved organic matter and (B) the contribution of dissolved organic N (DON) to total N concentrations (TN) in litter leachates. N = three measurement stations; sampling interval of zero-tension lysimeters was weekly. Trends were tested with the nonparametric Seasonal Mann Kendall test (Hirsch et al., 1982). Significant trends are indicated with straight lines and Kendall's t and error probability are given.

Symposium 15: Biogeochemical cycles in a changing environment

Modeling ¹⁴C of Organic Carbon in Marine Surface Sediments

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Mixed-layer ¹⁴C content is predicted by assuming a homogeneously mixed surface sediment whose carbon content is dictated by influx of fresh, marine organic carbon, radioactive decay of ¹⁴C, degradation of organic carbon, and burial. Organic matter is divided into three pools of reactivity: labile, semi-labile and recalcitrant, which all reflect surface water, marine DI14C. The program requires the input of sedimentation rate, mixed-layer depth and sample collection year to run. Integration from 1950 to the given year allows the anthropogenic ¹⁴C perturbation to be projected into the sedimentary organic carbon pool. Modeled fraction modern values are compared with measured fraction modern values of 81 surface sediment samples; discrepancies between the two are used to constrain organic matter sources and sedimentological controls. In particular, tracing inputs of pre-aged (e.g. soil) organic carbon or organic carbon bearing near-atmospheric signatures become real possibilities. The model builds upon previous work by Griffith et al. (2010) and includes experimentations with non-marine input terms, data-fitting and accounting for mixed-layer heterogeneity.



Figure 1. A study by Griffith et al. (2010) along NW African Margin exemplifies the strengths of investigating discrepancies between modeled and measured ¹⁴C signatures in organic carbon. In the north, the model overestimates ¹⁴C content and vice versa in the south. Speculatively, this could be due to influx of soil runoff (pre-aged organic carbon) in the north and influx of aeolian (near-atmospheric ¹⁴C fingerprint) in the south.

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P 15.2

Loess as an environmental archive of atmospheric selenium deposition

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The element selenium (Se) is of key importance to human health but it has a very narrow range between essential and toxic levels. Selenium concentrations in soils and food crops show extreme geographical variations, which have led to serious health problems. In order to prevent future health hazards due to unsafe environmental Se concentrations it is essential to understand what factors control the distribution of Se in the terrestrial environment. Estimates of global Se fluxes indicate that biologic processes in the marine environment play a key role in the global biogeochemical Se cycle. Biogenic Se species produced in marine environments are thought to be volatilized and transported through the atmosphere and could thus be an important source of Se in the terrestrial environment. However, thus far there has been virtually no research that quantifies terrestrial deposition of naturally derived Se and how this has fluctuated through time. This study investigates the relationship between the distribution of Se in the terrestrial environment, wet and dry atmospheric deposition of Se and the influence of climatic factors.

Past climatic variability has been well recorded in the alternating layers of loess and paleosols at the Chinese Loess Plateau (CLP). The CLP is the largest deposit of wind-blown sediment in the world and represents up to 7Myr of continual atmospheric sediment deposition. The CLP can serve as an invaluable record of atmospheric Se deposition and may provide unique insights into how the global Se cycle is influenced by climatic factors and changes in these factors. Presented here are the Se concentrations along with other trace and major elements in the Lingtai loess-palaesol sequence of the CLP, which has been intensively studied in paleoclimatic studies. The data are examined in relation to paleoclimatic proxies (e.g. magnetic susceptibility and grain size) and first interpretations of depth-concentration profiles are presented. Insight in the role that climate plays on atmospheric Se deposition will lead to a better understanding of the global biogeochemical Se cycle and will pave the way for future predictions of terrestrial Se distribution.

P 15.3

Soil respiration and microbial biomass constrained by warmer winter climate and reduced snow cover in transplanted subalpine pasture turfs

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Overwinter degradation of soil organic matter is an important component of carbon and nutrient turnover in cold biomes where soils lying under a thick snowpack remain decoupled from the often times rough atmospheric conditions. Data from our 3-years experiment simulating an in situ year-round climate warming provides clear evidence about the beneficial effects of snow on soil microbial abundance and activity. We report up to 10 times higher heterotrophic soil respiration from plots experiencing an ambient climate and remaining under a stable cover of snow for 5 months compared to those subjected to a milder climate with intermittent frosts and snowpack accumulation. These high rates of CO_2 efflux under the snow could not be explained by any of the classically used soil microclimate parameters (i.e., soil temperature and moisture) and were tentatively attributed to the presence/absence of snow. Such a decoupling of soil respiration from its seasonal temperature dependence in the presence of snow has broad implications for the modelling of global carbon cycling. Our data provide insights on the importance of snow for soil microbial abundance and activity in winter, and hints on possible feedbacks on the turnover of organic matter and the overall functioning of ecosystems in a future warmer climate.

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Michael Sprenger & Tobias Grimbacher

Swiss Meteorological Society

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17.1

Hailstorm Studies in Switzerland Using a High Resolution NWP Model

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Three hailstorms which caused significant damage in Switzerland were simulated with the COSMO (Consortium for Smallscale Modeling) one-moment microphysical scheme as well as with the new COSMO two-moment microphysical scheme and qualitatively verified with real radar measurements of the operational Swiss radar network in order to investigate the model capability to realistically simulate convective storms. To this end, a new COSMO radar forward operator was implemented and applied within this study to compute synthetic radar volume data which are then directly compared with the radar derived reflectivities. This is the first time the COSMO two-moment scheme as well as the COSMO radar forward operator is used for COSMO-2 simulations over Switzerland.

Using the COSMO two-moment microphysical scheme in forecast mode, resulted in the almost complete absence of convective cells in the simulations. Using the same model in analysis mode and investigating the synthetic radar reflectivities, realistic structures were observed. The reasons why the COSMO two-moment scheme does not simulate any convection for all three cases are not understood. Investigations of the vertical structure showed the capability of the COSMO twomoment scheme to simulate hail in the strong updraft areas. High reflectivity cores (≥ 55 dBZ) are simulated similar to the radar data.

The COSMO one-moment microphysical scheme shows the capability to predict the three hailstorms with small deviations in terms of the location and time, but with too low intensity, lifetime and geographical extension. Applied radar-based hail detection algorithms highlight the capability of the COSMO one-moment scheme to forecast whether and where hail can occur within the next hours. The analyses of the COSMO one-moment scheme showed better results than the forecasts but not as good as the case of the COSMO two-moment scheme analysis.

The study also found that probably a wrong mass-size parameterization of the COSMO one-moment scheme results in an underestimation of the convective vertical extent in terms of synthetic reflectivity. In both schemes too high synthetic reflectivities were simulated close to the ground mostly due to high hydrometeor densities of rain.



Figure 1: Left panel: maximum reflectivities [dBZ, mm/h] of the COSMO two-moment scheme analysis on July 23, 2009, at 14.45 UTC. Right panel: radar derived reflectivities [dBZ, mm/h] on July 23, 2009, at 14.45 UTC.



Figure 2: Left panel: Synthetic daily maximum POH (Probability of Hail) product [%] of July 23, 2009, of the COSMO one-moment scheme 12 UTC forecast. Right panel: Daily maximum POH product [%] of the radar on July 23, 2009.

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People love spring! Can Facebook and a diversity of responses to climate change make them love phenology networks?

Bolmgren, Kjell

17.2

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Signs of spring make people happy! Every year every newspaper, every radio and TV show and all the different social media channels are full of pictures and exclamations when spring signs show up. This creates an interesting opportunity for geographically dense as well as spread-out phenology data collection. We already know that many keep notes on spring signs and during the last two decades such notes have generated a long list of scientific publications. So, do we need more data?

I will present results from a collaborative project, where we have analyzed phenological time series for over 1600 species (Wolkowich et al. 2012; Cook et al. in press; Mazer in review; Davies et al. in prep.). The data was collected in tropical to alpine regions and we analyzed phylogenetic and geographic patterns as well as contrasted observational with experimental data. The geographic and phylogenetic studies suggest some potential for generalizations, thereby reducing the need for additional data collection. However, an important contrast between the observational and experimental studies, where experimental studies seems to have underestimated phenological sensitivity, highlights the importance of continued collection of observational data for validation purposes. In another study, where we analyzed a 73-year long dataset (Bolmgren et al. 2012), we show that good statistical estimates of phenological temperature sensitivity need to be based on fairly long temperature series, again supporting continued efforts for collecting phenology observation data.

Our research has originated from the idea that biological diversity will also lead to a diversity of responses to changing climatic conditions. This diversity of responses will have fundamental effects on many aspects of society in addition to effects on nature itself. It is easy to communicate to the public that increasing temperatures lead to phenological changes. Still, most people are surprised when they hear about the far-reaching effects of such simple changes, ranging from pollenrelated health effects, effects on the biosphere/atmosphere gas exchange, economic effects for forestry due to changing growth conditions and frost risks and to effects on timing-dependent ecological interactions.

When building the Swedish National Phenology Network, we have used the public interest for nature's calendar. We use this obvious interest for symbolic seasonal signs and patterns when recruiting, and the easily understandable links between phenology and fundamental ecosystem services and processes to spur observers and increase motivation. We also highlight the lack of knowledge about the diversity of responses between phases and between seasons as an important reason for documenting phenological variation.

By using social media, we have reached far beyond the networks traditionally available via NGO:s, and I will present some of the web applications and social media strategies the network has been using. The obvious focus is to canalize anyone interested in nature's calendar to the web application (www.blommar.nu), where they can submit observations. We prioritized making it simple to submit an observation (also anonymously) as well as easy to visualize data from the database. This makes it easy to do campaigns and for journalists to access and understand the operation. The fact that the public can assist climate change research and environmental monitoring by straightforward observations of spring signs etcetera helps making the operation attractive for media both at the local and national level. We added a Facebook-group to create an interactive group for the 'community', and we just released a smartphone application, which we expect will make the operation more accessible and at the same time improve the accuracy of geographic positioning of the submitted reports.

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17.3

Altdorf foehn climatology: the long series (1864-2008) and comparison to further sites

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In Altdorf, in the Uri part of the Reuss Valley, foehn observations have been recorded from 1864 to 2008 at stations whose positions changed only marginally during this time. Hence, with 145 years, this is the longest time series of foehn events in the Alpine massif.

First, the method by which foehn was observed, the changes of the foehn definitions during the course of time, and the different locations of the station are presented. Based on the three main parameters temperature, humidity, and wind, the occurrence of foehn was originally determined subjectively at the so-called climate observation times in the morning, at noon, and in the evening. Today, in the time of automatic observation networks, special software allows the identification of foehn in 10-minute intervals.

The main part deals with the climatological aspects: Over the 145 years, there is no discernible significant trend in foehn occurrence. Foehn frequencies show a high variability both in time and location. In the long-term mean, there were 60 occurrences per year (minimum 1955 with 27, maximum 1872 with 114). The months March to May, in recent times April and May, show the highest numbers of foehn events during the year. During the summer months June to August, foehn is rare. The diurnal variations are extreme in the months April and May (minimum in the morning, maximum in late afternoon). As for wind speed, the gust maxima for each hour were analyzed: neither a long-term trend nor a clear interannual variation was found. The highest gust speed since 1955 was measured on December 13, 1981 with 157 km/h.

Finally, the occurrence of foehn in Altdorf is compared with different stations north of the Alps. During the period 1973 to 1982, 20 stations were investigated using a semi-quantitative method; Guttannen in the Haslital had 116 (maximum), Interlaken and Sarnen had each 3 (minimum) foehn events at the three climatological observation times, these numbers being the yearly means. During the 25-year period 1984 to 2008, the automated, quantitative method was applied to 15 stations. As yearly means, Davos had 86 (maximum) and Zurich had 2 (minimum) foehn occurrences.

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Interpolation of surface air temperature in mountainous terrain: A kmscale, daily dataset for Switzerland

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17.4

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Surface air temperature is a key factor for many natural processes and there is a popular demand for spatially distributed datasets of temperature as input for models of environmental system components (e.g. in hydrology, glaciology, agronomy). Meteorological phenomena in mountainous terrain are often accompanied by strong horizontal variations and nonlinear vertical temperature dependence, which poses a significant challenge to the construction of such datasets.

In this contribution a new technique is presented for the spatial interpolation of temperature in high-mountain regions. It's modelling design involves two steps: The first addresses the meso-beta scale vertical-only structure and builds on a non-linear parametric profile function, capable of describing inversions of variable height, depth and contrast. The second step addresses the smaller-scale structures and adopts a weighting scheme with non-Euclidean distances. To this end a novel distance metric is introduced, which can account for the topographic obstruction of air mass exchange in the interpolation (e.g. pooling of cold air in valleys). The interpolation scheme is systematically applied for the construction of a km-scale dataset of daily mean temperature for the period 1961-2010 over the territory of Switzerland.

Results of the interpolation technique are illustrated for a series of challenging meteorological conditions in Switzerland. They show empirically plausible temperature distributions, including the signatures of cold-pools at the floor of high-Alpine valleys, inversions over the Swiss Plateau and anomalous warmth in valleys during Föhn. The presentation will also discuss results of a systematic cross-validation and provide aids for the application of the dataset. The dataset is available from MeteoSwiss.

17.5

Atmospheric Precursors to Floods in Switzerland

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It is important to learn more about flood triggering weather patterns in Switzerland for two reasons: (i) projections of flood frequencies in a warmer climate are strongly limited by the ability of climate models to represent the complex small-scale processes associated with typical flood triggers like heavy precipitation and snow melt. Information about flood triggering weather situations can be used in a more indirect approach to estimate changes in future flood frequencies.

(ii) Flood frequencies in Switzerland show strong decadal variability suggesting that decadal variations in the synoptic atmospheric flow might influence flood probabilities (Schmocker-Fackel & Naef, 2010). However relations with temperature trends or typical climate indices are complex and ambiguous and Schmocker-Fackel & Naef expressed the need for a better understanding of the synoptic-scale atmospheric flood triggers.

We aim to determine typical atmospheric flood precursors for specific regions of Switzerland and specific types of floods by combining atmospheric reanalysis from the ECMWF with dense networks of rain gauges and river discharge measurements and existing hydrological classifications of annual maximum floods in Swiss rivers (see Diezig & Weingartner, 2007 and Helbling et al., 2006 for more information).

We performed a series of case study analyses which showed promising results. Four catchments have been selected, each representing a preferred hydrological flood type (e.g. shower, long lasting rain, rain on snow, pure melt) and for each catchment many of the annual maximum floods share a common weather triggering situation (see Fig. 1 for a typical example). This weather situation varies moreover remarkably between the different catchments.

In a second step, we will extend the investigation by comparing the flood relevant atmospheric parameters (rain and properties of atmospheric flow) with their climatological distribution. We also aim to determine objectively the best set of atmospheric flood precursors and end up with an ingredient-based flood forecasting model. To reach that goal we consider diverse approaches including weather types classifications, composites over several events and principal component analysis.

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Figure 1. So-called atmospheric rivers are typical precursors to winter floods over the Jura mountains. We call "atmospheric rivers" thin bands of high precipitable water spreading from the tropics towards the extratropics. Here an atmospheric river (yellow-green band) makes landfall and brings very moist air to North-Western Europe, triggering (together with other factors) the highest recorded flood in the Suze river (Jura) in December 1991.

Precipitation measurements with the new fourth-generation Swiss weather radar network: strategy and first results

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Measuring precipitation at ground in an operational manner is one of the most demanding tasks of a weather radar network, especially in a mountainous region such as the European Alps. It puts high requirements on many aspects in the whole system design. This goes from optimum siting, rapid volumetric scanning, high hardware stability, automatic hardware monitoring and remote control, to meticulous quality control and physically-based radar-reflectivity-to-precipitationat-ground transformation techniques. In the Alps particular attention must be given to visibility and ground clutter issues.

MeteoSwiss is presently renewing and extending its operational C-band weather radar network. The radar systems are replaced by state-of-the-art polarimetric Doppler radars with receiver-over-elevation design. Two new radar sites are built on mountain tops in order to improve radar coverage in the inner-alpine regions. The software architecture is completely renewed and the algorithms are re-written. This is a welcome opportunity to revisit the strategy for quantitative precipitation estimation (QPE) by combining experience from the past with recent findings from science and technology.

- The paper presents the adopted QPE strategy and first results from the new fourth Swiss radar generation. The major elements of the strategy are:
- a new scan program to obtain over the whole country as many high quality measurements close to the terrain as possible,
- an external transceiver system which is used as part of the acceptance test procedures to verify several system specifications including polarimetric parameters,
- a revised algorithm for the rejection of non-weather echoes and the combination and compositing of all remaining valid measurements in order to get robust estimates of precipitation at ground,
- a plan how to obtain quantitative precipitation measurements from the two new inner-alpine radar sites at 2900 meters above sea level,
- a (co-)kriging-with-external-drift technique developed for real-time radar-raingauge merging in the Alps, and finally,
- first thoughts about the benefits and limitations from polarimetry in a mountainous context.

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Heavy precipitation events in northern Switzerland

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Heavy precipitation events in Switzerland often cause floods, rock-falls and mud slides with severe consequences to the population and the economy. Breaking synoptic Rossby waves located over western Europe, can trigger such heavy precipitation events in southern Switzerland (e.g. Massacand et al. 1998, Martius et al. 2006). In contrast, synoptic scale structures triggering heavy precipitation on the north side of the Swiss Alps and potential precursor Rossby wave trains have so far not been studied comprehensively.

An observation based high resolution precipitation data set for Switzerland and the Alps (Frei and Schär 1998) is used to identify heavy precipitation events affecting the north side of the Swiss Alps for the time period 1961-2010. For these events a detailed statistical and dynamical analysis of the upper level flow is conducted using ECMWFs ERA-40 (Upala et al. 2005) and ERA-Interim (Dee et al. 2011) reanalysis data sets. For the analysis north side of the Swiss Alps is divided in two investigation areas north-eastern and western Switzerland (Fig.1) following the Swiss climate change scenarios CH2011 (Bey et al. 2011). A first analysis of the basic properties of precipitation data set shows that the seasonal distribution of heavy and extreme precipitation events in western part of northern Switzerland differs from this of north-eastern part. The highest frequency of extreme events is found in autumn in western side and in summer in north-eastern side. There is no trend in the frequency of heavy precipitation events during the time period 1961-2010. In a next step a subjective classification of upper level atmospheric precursors triggering heavy precipitation events for the northern part of Switzerland and its sub-regions is held.



Figure 1. The two investigation areas: Western and North-Eastern Switzerland. Accumulated daily precipitation (mm) on 17/07/1961, a heavy precipitation event occurred in northern Switzerland.

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Mountain size and atmospheric Conditions' Impact on the diurnal Cycle of Clouds and Precipitation

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The influence of different topography sizes and wind profiles on the diurnal cycle of mid-latitude, summertime, moist convection is investigated in an idealized framework using cloud-resolving model with a horizontal grid spacing of 2 km. In this framework, the atmosphere is continuously relaxed towards prescribed reference profiles of temperature, specific humidity and wind speed. This relaxation mimics the influence of a steady large-scale flow. The strength of the relaxation varies with height. It is relatively strong in the stratosphere and upper troposphere (relaxation time is 2 days), but very weak in the lower troposphere. Apart from its influence on the mean environment, the relaxation has only a minimal influence on the diurnal evolution of the planetary boundary layer and moist convection. The simulations are run for 30 days. During the last 20 days a quasi-steady diurnal cycle is obtained, the diurnal equilibrium. Here, we investigate the influence of different topographies (mountain height and half-width) and wind profiles on the diurnal equilibrium evolution of clouds, precipitation and the associated net vertical fluxes of energy and water. As expected, in comparison to the simulation of flat terrain clouds and precipitation occur earlier over topography and total precipitation amounts are substantially increased. A particular focus will be on the analysis of the mountain effects as a function of the distance from the mountain (e.g. near-field and far-field effects).

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Precipitation in the Alpine region as seen from a trans-national multidecadal rain-gauge dataset

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The analysis and monitoring of precipitation is fundamental for meteorology and climatology, and for applications such as hydrology, energy and agriculture. It is a challenge to obtain precipitation fields of high-resolution in space, in particular in mountainous regions such as the Alps.

The utility of currently available climate datasets in Europe is further complicated either by the constraint of regional data products to national territories, or by restrictions in the station data available to continental scale data products. These limitations are particularly relevant in the Alpine region, because of the complex and non-congruent geo-political and climatological segmentation.

In this presentation we report on the development towards a gridded trans-Alpine dataset of daily precipitation that covers the entire Alpine area and utilizes data from high-resolution national rain-gauge networks. The station dataset encompasses more than 6000 stations from Austria, Croatia, France, Germany, Italy, Slovenia and Switzerland. In this recent effort the data coverage could be significantly enhanced in space and time compared to the dataset presented in Frei & Schär (1998). Regions and periods with previously inferior coverage could be improved. The data set now covers the entire period 1971-2008. The processing chain from data collection and data organization and the chosen approaches for quality control will be presented.

This unique data set will then be employed for a climatological analysis of selected heavy precipitation events and extreme precipitation indices such as the frequency of intense precipitation days and long consecutive dry periods. The analysis offers interesting insights into regional peculiarities, topographic effects and the annual cycle of the Alpine climate of precipitation with unprecedented detail and spatial coverage.

It is foreseen to generate a new gridded data set of daily precipitation on a 5-km grid. By the time of the conference, a preliminary version of the complete daily grid dataset is expected to be ready for first evaluations. This work has been undertaken in the framework of the EU FP7 project EURO4M.

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Temperature and Humidity trends over the Swiss Alps and the troposphere above - from 1959 to 2011

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Recently reevaluated Payerne radiosonde measurements and homogenized series from Alpine surface stations allow investigations of temperature and humidity trends in the Swiss Alps and the troposphere above. The new radiosonde dataset is the result of a technical reprocessing on the basis of detailed station documentation, complemented by statistical homogenization using a break analysis as a diagnostic tool. The comparison between surface stations at different altitudes, particularly Säntis and Jungfraujoch, and radiosonde measurements at corresponding altitude levels provides interesting results with respect to temperature and humidity changes. The two independent data sources show very consistent temperature evolution and almost identical positive trends. Radiosonde measurements extend the temperature trend analysis through the whole troposphere over the entire investigated period. Radiosonde humidity reevaluation is more challenging and the comparison with Alpine surface stations is more difficult in the first two decades. Absolute humidity trends over the five decades are slightly positive, but the increase mainly occurred in the period 1981 to 2011.

17.11 Heavy precipitation in the Alpine area

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Heavy precipitation events in the Alpine area are often high-impact events that cause significant socio-economic damages. Heavy precipitation events can result in floods and they can trigger avalanches and a wide range of geomorphological activity. This presentation will give a brief overview of the current state of research regarding the dynamical and microphysical processes that govern heavy precipitation evens in the Alpine area and a very short discussion of future trends. The main focus will be on the interaction between the topography and the atmospheric flow.

17.12

A Lagrangian Perspective on Orographic Precipitation

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The Lagrangian perspective on atmospheric processes has become a frequently used way to investigate air streams in the atmosphere since the middle of the 20th century. However, in past studies it became clear that the trajectory calculation in mountainous terrain is rather difficult due to the strong spatial and temporal gradients of the velocity fields. It is shown that the representation of flow patterns above orography can be largely improved by reducing the integration timestep to several tens of seconds and by minimizing the temporal interpolation, i.e. by including the trajectory calculation in the Eulerian model (so-called online trajectories).

The air parcel trajectories can now be used to obtain new insights in the basic physical processes involved in orographic precipitation formation. The principals behind this approach are demonstrated with the aid of a strongly simplified model, which represents the essential ingredients of an orographic cloud in stable atmospheric flow.

Classification of alpine hydrometeors in 2 dimensional videodisdrometer data

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Alpine winter storms can produce a large amount of snowflakes of different shapes and sizes. These solid hydrometeors (needles, plates, dendrites, rimed particles, graupel and aggregates) determine the characteristics of the snow pack and furthermore the amount of water stored in mountainous regions. Snowfall (and its liquid water equivalent) is difficult to measure. The variety of shapes and densities of snowflakes makes radar remote sensing of snowfall a challenging task.

A 2 dimensional video disdrometer (2DVD) providing two perpendicular side views of each recorded particle can be used to automatically classify the dominant hydrometeor type within a precipitation event. This reveals new possibilities to study the microphysical structure within a precipitation event in general and for snow events in particular, for example for comparison with polarimetric radar measurements.

In the present approach, a supervised classification technique allows to classify the dominant type of hydrometeors within specified intervals (at 1 minute resolution). A large dataset corresponding to two winter seasons collected in the Swiss Alps is used. After careful filtering and rematching of unrealistic particles, the values for 12 descriptors, related to their respective distribution according to the width, length and velocity, are used to classify each time interval. Furthermore, statistical parameters (mean, variance, quantiles) are calculated to describe the time evolution of each descriptor (and its distribution). The five classes are: large aggregates, normal aggregates, dendrite-like particles, graupel-like particles and small particles. A training dataset according to these classes has been manually determined. The comparison between the automatic classification algorithm and a manually classified reference set consisting of about 190 one-minute intervals (more than 3 hours) shows good reliability. Further work will include a comparison of the classification based on the 2DVD with nearby polarimetric radar measurements.

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17.14

Severe convection in the Alpine region: the approach COALITION for nowcasting the storm severity

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During the warm season of the year, intense thunderstorms regularly affect the Alpine region. Such high impact convective phenomena can produce local flash floods causing considerable damages. The need to increase lead time in predicting severe convection is well acknowledged. Numerical weather prediction models provide good forecasts on regional to global scales, but have difficulties in predicting the exact time and location of small-scale phenomena like thunderstorms. Current heuristic methods such as satellite and radar imagery, model output post-processing, satellite nowcasting products, neuronal methods or other statistical methods focus on specific aspects. For example, existing radarbased solutions are well suitable for detecting and extrapolating already existing thunderstorms, when hydrometeors occur. The detection of convective features in early stage and the nowcasting of the storm severity still remains a difficult task, especially in complex terrain. Information characterizing the storm environment, in particular retrieved by satellite data, can become very useful for detecting the early stages of a convective process and predict their development.

COALITION (Context and Scale Oriented Thunderstorm Satellite Predictors Development) is an innovative object-oriented model developed in the context of the EUMETSAT Fellowship program. The main purpose of this project is to increase the lead time in nowcasting storm severity over complex terrain. Data provided by different sources (e.g. Meteosat Second Generation Rapid Scan, Weather Radar, Numerical Weather Prediction and climatology) are merged into a heuristic model. Furthermore, the orographic forcing (often neglected in heuristic nowcasting models) is considered and included in the system as an additional convection triggering mechanism. This is particularly important over areas characterized by complex terrain like the Alps.



Figure 1. COALITION input data ingested in the current version of the algorithm (CI: Convection Initiation, CTT: Cloud Top Temperature, RDT: Rapid developing Thunderstorm; CTH: Cloud Top Height; CAPE: Convective Available Potential Energy; VIL: Vertical Integrated Liquid content

The COALITION methodology borrows the approach from the physics of general dynamic systems. The algorithm merges evolving thunderstorm properties with selected predictors. The storm evolution is the result of the interaction between convective signatures (objects) and their surrounding environment. The interaction of the environment on the object, e.g. forcing, is modelled as a particle-field interacting system. The results are a probabilistic forecast of intensity evolution of the detected convective cells.

Eight different "object-environment" interactions are described in eight modules, providing ensemble forecast of thunderstorm attributes (satellite- and radar-based) for the next 60 minutes. The different ensemble forecasts are combined with a fuzzy logic approach and then summarized into one single map to facilitate user's interpretation. Convective cells, which have a high probability to develop into a severe thunderstorm, are highlighted on a map, which is provided to the users (weather forecasters) and used for taking important decision about storm warnings.
The first version of COALITION is fully automatic and has been tested on 80 convective cells randomly selected from a database: a preliminary validation shows useful probability of detection (POD) and an acceptable false alarm rate (FAR) for lead-times until 20 minutes before the thunderstorm reaches the severe stage. The system was tested in real-time during summer 2012 and is becoming operational at MeteoSwiss.



Figure 2. COALITION object-based nowcast, which highlights (in red) some cells for which an increase of convection intensity is very probable for the next 30 minutes. As reference the radar based vertical integrated liquid is shown. In this show case a convective cell is developing over south Switzerland: at 17:05 UTC a particular cell shows a VIL value of 15 kg/m² and COALITION indicates that this cell will develop into a severe thunderstorm in the next 30 minutes. At 17:50 UTC this cell increased the VIL values to about 60 kg/m².

17.15

Greenhouse warming and solar brightening in and around the Alps

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At low elevations (500 m a.s.l.) central Europe's surface temperature increased about 1.3°C since 1981. Interestingly, at high elevations (2200 m a.s.l.) in the Alps, temperature rose less than 1°C over the same period. Detailed investigations of temperature, humidity and the radiation budget at lowland and alpine climate stations now show that the difference in temperature rise is likely related to unequal solar- and greenhouse warming. The analysis shows that the important decline of anthropogenic aerosols in Europe since the mid 1980s led to solar brightening at low elevations, whereas inherent low aerosol concentrations at high elevations led to only minor changes of solar radiation in the Alps. In the Lowland absolute humidity and also total net radiation show an about 6 % K⁻¹ Clausius-Clapeyron conform increase with temperature since the 1980s. In the Alps however, the percentage increase rate of humidity and total net radiation is more than twice as large. This large water vapour increase in the Alps is likely related to strong warming and thermal advection in the Lowlands, and may also have increased due to atmospheric circulation changes. Hence, while in the Alps temperature increase at low elevations greenhouse gas and water vapour feedback greenhouse warming led to a higher temperature increase at low elevations in Central Europe.

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Foehn - extremes, trajectories and representation in NWP models

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South Foehn is a well-known phenomenon in the northern Alpine valleys. In this presentation we give an overview of recent Foehn studies, which in particular address the following questions: (i) How well is Foehn represented in the NWP model COSMO-2?; (ii) What is the climatology of extreme Foehn, whereby the extremeness of Foehn is defined in terms of different characteristics - e.g. maximum wind speed, duration, lowest relative humidity?; (iii) In which respect do synoptic weather situations differ for extreme and non-extreme Foehn cases?

17.17

Satellite-based monitoring of solar irradiance over complex terrain

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Surface incoming solar irradiance (SIS) is an essential climate variable highly relevant for applications such as solar energy, agriculture or climate monitoring. SIS retrieved from geostationary satellites has continuous spatial and temporal coverage and complements station-based estimates.

MeteoSwiss calculates SIS climatologies from Meteosat SEVIRI observations on board of the Meteosat Second Generation (MSG) satellites by use of a modified HELIOSAT algorithm, which enables the separation of clouds from snow and which accounts for terrain shadowing and the radiative effects of snow-covered surfaces. This data set is available over Switzerland for 2004 till recently at 15 minute temporal and 0.02 degree (approximately 1.5 x 2.2 km) spatial resolution and will be continuously updated.

A recently developed analysis and visualization application will pre presented. The tool allows the graphical representation of this data for entire Switzerland or a choice of sub-regions. The application offers either a map display or a time series representation of SIS as wells as surface radiation components (direct radiation, diffuse radiation, direct normal irradiance DNI or clear sky radiation, see for instance Figure 1).

The application can calculate climatological quantities such as means or anomalies. Station-based observations can be displayed on top of the satellite data maps for validation purposes. The MeteoSwiss-internal tool is used to serve the climate monitoring products on www.meteoswiss.ch and for user specific evaluations. These public products might be extended based on capabilities of the tool.

It is planned to further enhance the application for the downscaling of surface radiation quantities at specific locations within Switzerland by accounting for local-scale terrain effects. This includes the estimation of surface radiation on tilted planes – a feature particularly interesting for solar energy as well as agriculture applications.



Figure 1. Mean 2004 to 2011 surface incoming shortwave radiation for Switzerland.

P 17.1

Steps toward a process based model for the stable oxygen isotope composition of precipitation over Switzerland

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The stable isotopes of past and present precipitation are important natural tracers in the hydrological cycle on global, regional and local scales. The Alps host the oldest and densest network monitoring stable isotopes of atmospheric precipitation compared to any other mountainous area of the world owing to the good representation of international (GNIP) and national (Switzerland and Austria) networks. Measurements of oxygen isotope ratios in precipitation $(\delta^{18}O_p)$ started as early as 1965 at Thonon des Bains (France) and 1971 at Bern (Switzerland). Detailed assessments conducted on these data substantially contributed to our knowledge about isotopic processes acting and interacting at various spatial and temporal scales in the atmosphere, or more generally in geospheres (Siegenthaler & Oeschger 1980, Longinelli & Selmo, 2003, Liebminger et al. 2007). However, the network was very sparse during the first years. Station density significantly improved only from 1973 when more Swiss and Austrian stations were involved. The late 1990s are the best covered period (Fig.1). Exploring to what extent the early and sparse isotope network can capture the spatio-temporal patterns is an open question, yet (Kern et al. 2012).

The main aim of our research is to develop a gridded data set of monthly $\delta^{18}O_p$ over Switzerland and adjacent areas with high spatial resolution back to the early 1970s. To do so homogeneity was carefully checked first by cross-boundary comparisons between nearby station records. Anomalous isotope values and precipitation amount records were rigorously checked.

When precipitation amount weighted mean monthly isotope values were analyzed in order to determine the seasonal difference of empirical oxygen isotopic lapse rates used for spatial modeling unexpected vertical structure was observed. The expected strong altitude dependence (Siegenthaler & Oeschger 1980) was evident only for summer months. Steeper gradient (0.6-0.7 ‰/100m) was observed for winter months over a low elevation belt, while hardly any altitudinal difference is seen over high elevations. This dichotomy can be observed, though less characteristics, during spring and autumn.

A comparison between station locations and monthly average maximum planetary boundary layer (PBL) height data (von Engeln & Teixeira 2012) suggests that different atmospheric conditions/processes above and below the PBL are responsible for the observed pattern. High wind speeds prevailing above PBL could probably maintain well mixed conditions above PBL and cause the large scale isotopic homogeneity. PBL is usually situated at, or above the Alpine summits during summer hence does not affect the vertical isotopic pattern.

Decoupled regimes below and above PBL received little attention in spatial precipitation isotope modeling efforts. Present results point out that PBL location is recommended to be taken into account for future models developed for stable isotope composition of precipitation.

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Figure 1. Temporal distribution of the available δ^{18} O precipitation records. The Swiss network was run by the Climate and Environmental Physics Division (CEP) since the early 1970s. Since 1992 thirteen precipitation stations were monitored with financial support from the Swiss Federal Office of Environment. Those stations were extended by seven additional stations by the CEP network. Therefore 19-20 stations data were available until 2010. This exceptional data set was completed with 25 neighboring stations (8 Austrian, 5 German, 1 French and 11 although relatively short Italian).

P 17.2

Orographic effects on precipitation and atmospheric water cycle in the Weather Research and Forecasting Model

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The Weather Research and Forecasting (WRF) Model (Skamarock et al. 2008) is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. The WRF Model supports two dynamical solvers, the Advanced Research WRF (ARW) and the Nonhydrostatic Mesoscale Model (NMM). We chose the former dynamical solver ARW, more suitable to conduct high-resolution idealized simulations, to assess the effects on orographic precipitation of the different microphysics schemes which the user can select.

The scenario set for our simulations consists in a 2-D atmospheric flow of saturated air interacting with an idealized mountain ridge placed in the middle of the spatial domain. The interaction of the saturated air with the mountain ridge triggers precipitation and at the same time re-evaporation occurs, under favourable temperature conditions, due to accumulation of liquid water on the ground. For the initial profiles of temperature and pressure we used mid-latitudes zonally-averaged profiles taken from ECMWF ERA-Interim reanalysis data, while for the initial wind profile we used a horizontal, single-component wind speed of 10 m/s for all heights. To foster precipitation, the moisture profile was set equal to the saturation vapour pressure profile (which corresponds to 100% relative humidity), according to the already defined temperature and pressure profiles. At the borders of the horizontal domain, periodic lateral boundary conditions were applied so that the air exiting from one side is reinserted at the other side.

The assessment of long-term effects of different microphysics schemes on the water cycle in regional climate simulations is the main aim of our study (Awan et al. 2011). Long-run simulations have been performed and the results are analyzed to compare the total precipitation generated by each scheme. Furthermore, the balance between precipitation and evaporation is discussed for the different schemes. In this way, the microphysics parameterizations available in the WRF Model can be characterized and understood by means of idealized and comprehensible simulations. This leads to a better knowledge of the microphysics schemes which is a precondition for a reliable simulation of the water cycle with the WRF model.

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Symposium 17: Alpine Meteorology

Quasi-analytical treatment of spatially averaged radiation transfer in complex terrain

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We provide a new quasi-analytical method to compute the subgrid topographic influences on the shortwave radiation fluxes and the effective albedo in complex terrain as required for large-scale meteorological, land-surface or climate models. We investigate radiative transfer in complex terrain via the radiosity equation on isotropic Gaussian random fields. Under controlled approximations we derive expressions for domain-averaged fluxes of direct, diffuse and terrain radiation and the sky view factor. Domain-averaged quantities can be related to a type of level-crossing probability of the random field which is approximated by longstanding results developed for acoustic scattering at ocean boundaries. This allows us to express all non-local horizon effects in terms of a local terrain parameter, namely the mean squared slope. Emerging integrals are computed numerically and fit formulas are given for practical purposes. As an implication of our approach we provide an expression for the effective albedo of complex terrain in terms of the sun elevation angle, mean squared slope, the area-averaged surface albedo, and the ratio of atmospheric direct beam to diffuse

radiation. For demonstration we compute the decrease of the effective albedo relative to the area-averaged albedo in Switzerland for idealized snow-covered and clear-sky conditions at noon in winter. We find an average decrease of 5.8% and spatial patterns which originate from characteristics of the underlying relief. Limitations and possible generalizations of the method are discussed.



Figure 1. (a) DHM of Switzerland (in Swiss coordinates) with coarse grid size L=5 km obtained from a high resolution DHM with fine grid size dx=25m. (b) Mean squared slope (c) Normalized difference between the effective albedo and area-averaged albedo.

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P 17.4

NCCR Climate related research at MeteoSwiss -The Swiss climate of today and tomorrow

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Switzerland as an Alpine country is particularly sensitive to climate change. There is a demand and a social responsibility to present information about specific changes and possible adaptations. MeteoSwiss supports the public, research and decision makers in business and government by providing high quality climate information on the past, current and future climate conditions on different scales. This climate information and support with its interpretation and use is described as climate services (WMO, 2011).

MeteoSwiss is developing the scientific basis making high quality climate services possible bundling resources from different external fundings and a substantial internal contribution. MeteoSwiss is an active member of the C2SM (Center for Climate Systems Modeling) and participant of various research projects, in particular of the SNF NCCR Climate (Swiss National Center of Competence In Research – Climate), COST-Actions and projects funded by the European Union (FP7). MeteoSwiss coordinated the CH2011 Initiative, an update of climate scenarios for Switzerland within the framework of C2SM and NCCR Climate. The Swiss Climate Change Scenarios CH2011 were published on September 28th.

The research project at MeteoSwiss started 2009 and will end this year. It is divided into four subprojects: Preclim, BiotoP, CombiPrecip and EURO4M. According to the key areas defined by the Stern Review (Stern et al., 2006), it is our goal to provide high resolution climate data (EURO4M, CombiPrecip) and to refine climate scenarios for user needs (BiotoP, PreClim) in order to link the scientific community with real world applications.

Preclim provides climate scenarios for Switzerland for the current century based on regional climate models (Fischer et al., 2011; Weigel et al., 2010). BiotoP links climate change scenario data to plant pest models, in order to investigate the potential threat of plant diseases under conditions of a changing climate. First results for codling moth (a key pest in apple plantations) for Northern Switzerland show a shift of important life phases towards earlier dates and a risk of an additional generation in the future (Hirschi et al., 2011). CombiPrecip combines information from the two classical rainfall measurements – radar and rain gauges – with statistical methods for climatological and near-real time applications such as hydrology (Erdin et al., in press; Schiemann et al., 2010). A Prototype will be available in spring 2013. EURO4M will provide a new high-resolution daily gridded Alpine wide precipitation data set over the last 40 years based on rain gauge observations.

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P 17.5

The integration of the automatic foehn index into the longest time series for foehn (starting 1864 for Altdorf, Switzerland)

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For Altdorf Switzerland, foehn events were recorded carefully since 1864. Three times a day - in the morning, at noon and in the evening - observations were made resulting in a "foehn"/"no foehn" information. Since foehn is a very clear event that manifests itself in sudden increases in temperature and wind, and in a simultaneous drop in relative humidity, the data can be regarded as quite reliable. Furthermore, the observations were made by members of the same family for 85 years. The observations were processed to yield a time series consisting of monthly sums for each of the observation time (morning, noon, evening) and year. Recently the results of the investigations of the long foehn series in Altdorf were published by Gutermann et al. (2012).

Since 1981, data from automatic stations is available. An objective method was developed that allows to determine "foehn"/"no foehn" in 10-minute intervals from which foehn hours can be computed (Dürr, 2008). This foehn index is based on wind direction, wind speed, gust speed, and relative humidity. A further criterion is the difference in potential temperature to the reference station Gütsch (situated on the Alpine ridge). Parallel to the foehn index, "manual" foehn observations at the three observation times were continued until 2008. As a result, two different foehn time series are available: (i) a series of monthly sums of triple observations for 1864-2008 (morning, noon, evening) and (ii) a series of foehn observations for every single hour since 1981. For the overlap period 1981 to 2008, correlations between the two time series were analyzed and transformation functions determined. These latter allow to either convert the monthly sums of triple observations to foehn hours or vice versa. In both cases, the time resolution is fixed to monthly values for three time slices per day. As result, the climatologically very valuable, 145-year-long time series, can be continued without interruption into the future, allowing further climatological analyses of foehn in Altdorf, either in terms of foehn observations or foehn hours.

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18. Greenhouse Gases: Linkages between Biosphere and Climate

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ACP – Commission on Atmospheric Chemistry and Physics, ProClim – Forum for Climate and Global Change, IGBP- Swiss Committee

TALKS:

- 18.1 Ammann C., Neftel A., Leifeld J., Jocher M., Fuhrer J.: A decade of continuous greenhouse gas exchange measurements at the Oensingen grassland site
- 18.2 Aslan S.G., Evrendilek F.: Long-term monitoring of CO₂ and H₂O dynamics using Eddy Covariance technique in peatlands of lake Yeniçaga (Bolu-Turkey)
- 18.3 Eugster W., Kling G. W.: A low-cost approach to measure ambient methane concentrations in preliminary studies
- 18.4 Hiller R., Neininger B., Henne S., Künzle T., Buchmann N., Eugster W., Brunner D.: Assessment of the Swiss methane inventory with the help of in situ aircraft measurements and backward Lagrangian particle dispersion simulations
- 18.5 Imer, D., Merbold, L., Eugster, W., Stieger, J., Buchmann, N.: Greenhouse gas flux budget of a managed Swiss grassland
- 18.6 Schnadt Poberaj C., Brunner D., Henne S., Spahni R.: Understanding Atmospheric Methane Variability between 2000 and 2008 using a Global Lagrangian Transport Model
- 18.7 Stieger J., Eugster W., Buchmann N.: Quantification of methane emissions at the farm scale using boundarylayer volume budgets

18.1

A decade of continuous greenhouse gas exchange measurements at the Oensingen grassland site

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Managed grassland ecosystems form a significant part of the European and global land cover. However, long-term greenhouse gas flux monitoring on grassland sites is still rare in comparison to forest sites. Beside climatic factors, also the management regime (and history) have an influence on the trace gas exchange of agricultural ecosystems. We have monitored the greenhouse gas exchange together with the carbon, nitrogen, and water cycle of a sown grassland site on the Swiss Central Plateau since 2002. The experimental field had been divided in two plots, one undergoing intensive management (high nitrogen input), the other extensive management (no fertilization). Continuous eddy covariance measurements of the CO_2 exchange and the quantification of carbon export and import by harvest and manure application allowed for the assessment of the complete carbon budget of both plots (Ammann et al., 2007) which was compared to the temporal change of soil carbon investigated by repeated soil inventory (Leifeld et al., 2011).

Over the entire observation period, the intensive management led to a carbon sequestration, while the extensive management caused a net carbon loss. A positive correlation between C and N sequestration was observed for the two fields corresponding approximately to the soil C/N ratio (Ammann et al., 2009). Although the different management led to a systematic difference between the two fields, it had only little influence on the inter-annual variation of the carbon budget. The latter shows a positive correlation with the net ecosystem productivity and the harvest yield. They mainly depend on the spring temperature and the length of the growing season as well as on the soil moisture content during summer.

The carbon sequestration of the intensive field was counterbalanced to a minor part by an increased N_2O emission mainly related to fertiliser applications (Flechard et al., 2005; Neftel et al., 2007). Therefore and due to the very small methane fluxes, the total greenhouse gas budget of the grassland fields was clearly dominated by the carbon exchange.

The Oensingen data set has also been used in various synthesis studies together with other FLUXNET sites to investigate the effect of environmental drivers and climate variations on the ecosystem and their greenhouse gas exchange on the European and global scale (e.g. Flechard et al., 2007; Soussana et al., 2007; Teuling et al., 2010; Mahecha et al., 2010).

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Symposium 15: Biogeochemical cycles in a changing environment

18.2

Long-term monitoring of CO₂ and H₂O dynamics using Eddy Covariance technique in peatlands of lake Yeniçağa (Bolu-Turkey)

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Peatlands are wetland ecosystems where the rate of production of organic matter exceeds its rate of decomposition (Bubier et al., 1995). The global area of the peatlands is limited (ca. 5-8 %); however, they play a significant role in global carbon (C) cycle. As an important example; Northern peatlands cover only 3 % of the earth's land area, however they store 30 % of the world's soil C as peat (Gorham, 1991). Due to the enormous amounts of C available in the peat great attention has been paid to the quantification of whether peatlands will continue to sequester carbon or will be C sources to the atmosphere.

Eddy covariance is a method that permits direct measurements CO_2 and H_2O fluxes between the surface and the atmosphere. This technique has some advantages that make it popular. Being direct measurement technique, and having a chance to do measurement around the small scale (hundred meters) to large scale (several kilometers) area are the most important reasons for being the popular technique (Baldochi, 2003).

Despite there have been many studies around the world petlands area especially in the subarctic area, there is no study about peatlands in Turkey. In fact the peatlands that are determined around Turkey is a unclear topic, the objective of the project was to determine the H_2O and CO_2 fluxes over two years (2011 and 2013) using an eddy covariance (EC) system in a Yeniçağa peatland, Turkey. The Yenicaga peatland is located about 38 km east of the city of Bolu (40°47N', 32°1'E) in the western Black Sea region of Turkey (Figure 1).

The central to this objective is investigation of seasonal, annual and interannual variation in peatland ecosystem CO_2 and H_2O fluxes and to determine the behavior of the Yeniçağa peatland whether it is sink or source. In addition, with ancillary measurements, the structure of the vegetation and peat soil is aimed to determine for observing valuable information about the characteristic of the system.



Figure 1. Location of the study site "Yenicaga peatland" in northwestern Turkey.

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A low-cost approach to measure ambient methane concentrations in preliminary studies

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Methane is the second most important greenhouse gas after CO_2 with a global warming potential that is 25 times larger per kg than that of CO_2 . Although affordable high-quality sensors exist on the market, low-cost sensors normally were not sensitive enough to resolve ambient concentrations around 1.8 ppm. Recently, the TGS 2600 solid-state trace gas sensor has appeared on the market that is also sensitive to methane at ambient concentration levels. This sensor is a generalpurpose smoke detector sensors that is not exclusively sensitive to methane concentrations.

We tested two such sensors in parallel with a high-quality integrated off-axis cavity ringdown spectrometer from Los Gatos Research (USA, model FMA-100) during two summer seasons in northern Alaska, USA, to assess it's suitability for measuring seasonal variations in methane concentrations.

We will show a performance analysis and address the issue of interferrences with temperature and relative humidity, and its possible cross-sensitivity to CO_2 concentrations and other components of smoke. Our results indicate that although this sensor is not yet perfect for high-quality applications it shows promising performance for preliminary studies as for example to find methane emission hot spots in the tundra that are only active at specific times during the summer season.

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Assessment of the Swiss methane inventory with the help of in situ aircraft measurements and backward Lagrangian particle dispersion simulations

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National greenhouse gas inventories are reported annually to the United Nations Framework Convention on Climate Change (UNFCCC) that monitors the progress of emission reductions defined in the Kyoto Protocol. In Switzerland, anthropogenic methane (CH_4) contributed 7% to the total reported greenhouse gas emissions for 2008. Most Swiss CH_4 emissions originated from the agricultural sector (83%), followed by waste treatment (10%) and the energy sector (7%) (FOEN, 2010). The major natural CH_4 sources are wetlands and lakes, which, in total are estimated to contribute 6% to the total Swiss CH_4 emissions (Hobi, 2011).

Here, we assessed the accuracy of the national inventory. Therefore, we spatially disaggregated the eight most important methane sources accounting for more than 90% of anthropogenic emissions using geostatistical information of source locations. The resulting spatially-explicit CH_4 emission inventory ("cadastre") is the first high resolution (500 m) spatial CH_4 inventory for Switzerland (see Figure 1). Aircraft measurements were performed on 18 days from May 2009 to September 2010, summing up to more than 90 flight hours. CH_4 was continuously measured with a Fast Methane Analyzer (Los Gatos Research Inc., Mountain View, USA) situated in one of the underwing pods of the small research aircraft METAIR-DIMO. To calculate the origin of the sampled air, Lagrangian backwards simulations were issued every 3 minutes along the flight tracks. The transport simulations of the model FLEXPART-COSMO were combined with the high resolution CH_4 inventory to calculate a bottom-up estimate and then compared to the continuous measurements. In an additional step, the available information was combined in a Bayesian framework to obtain a top-down CH_4 flux estimate for Switzerland.



Figure 1: Spatially highly resolved CH4 inventory for the eight most important anthropogenic sources accounting for 90% of the anthropogenic emissions. These include agriculture, landfills, and gas distribution in Switzerland.

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Despite their relatively low atmospheric concentrations, methane (CH₄) and nitrous oxide (N₂O) account for roughly 26% of the global warming. Little is however known about, how fluxes of CH₄ and N₂O from an intensively managed grassland influence the greenhouse gas (GHG) budget (CO₂, CH₄, and N₂O). Commonly used, manually operated static chambers only allow low for sampling frequencies, e.g. daily to monthly intervals. Therefore, temporal integration between samplings of CH₄ and N₂O fluxes is required to estimate seasonal and annual budgets. Yet, the methodology of temporal extrapolation can have considerable influence on GHG specific budgets.

In this study we aim at identifying strengths and weaknesses among temporal integration methodologies for seasonal and annual budgets of chamber based CH_4 and N_2O fluxes. Methodologies vary in complexity, spanning from weekly mean flux integration to uni- and multivariate response functions.

 CH_4 and N_2O fluxes were measured at an intensively managed grassland in Switzerland during a full 12 month period in years 2010/2011. Sampling frequency varied from weekly during the growing season to biweekly during the dormant season. CO_2 fluxes were additionally measured continuously using the eddy covariance (EC) technique.

Net uptake of CH_4 and release of N_2O were mostly observed during the 12 months measurement period, while eddy covariance derived CO_2 was characterized by net uptake during summer and net release during the dormant season. Annual sums of N_2O fluxes differed significantly among the applied temporal integration methods, ranging from 0.7 to 2.7 g N_2O m⁻² a⁻¹. CH_4 sums did not show significant variations with varying integration methods, averaging ≈ 0 g CH_4 m⁻² a⁻¹. EC derived annual carbon budgets for 2010 and 2011 indicated a mean net sink of 471 g CO_2 m⁻² a⁻¹. Thus, the uncertainty contribution associated with N_2O to an integrated GHG budget is considerably higher than that of CH_4 . Depending on the temporal integration method, the annual net carbon sequestration was reduced by at least 44% when including N_2O and CH_4 to the budget. With higher annual sums of N_2O , the annual sequestration rate was completely used up and the grass-land turned into GHG source.

Understanding Atmospheric Methane Variability between 2000 and 2008 using a Global Lagrangian Transport Model

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Methane (CH₄) is the second most important well-mixed greenhouse gas in terms of radiative forcing after carbon dioxide. To improve our understanding of recent CH, growth rate variability, focusing particularly on the latest increase since 2007 after a period of stagnation, we performed a global model simulation in combination with an emission inversion. This allowed us to quantify the temporal evolution of different methane sources during this period. In contrast to previous studies relying on Eulerian models, our simulations were performed with an enhanced version of the Lagrangian Particle Dispersion Model FLEXPART in a global domain filling mode and extended with a simple CH4 chemistry. 3 mio particles (air parcels) were permanently transported in the model over the years 2000-2008 each carrying a set of 44 tracers representing 11 different CH₄ sources in 4 emission age classes each. A priori CH₄ emissions were taken from state-of-the-art inventories and a wetland emission model. In FLEXPART, these are picked up by the particles residing in the atmospheric boundary layer. CH₄ is subsequently lost by reactions with prescribed fields of OH and stratospheric Cl and O(1D) and deposition at the surface. Simulated concentrations are mostly in very good agreement with continuous in situ measurements and flask samples of the networks of NOAA, GAW and AGAGE. Finally, a posteriori emissions were inversely estimated using a fixed-lag Kalman smoother by analyzing modeled CH₄ concentrations against the in-situ measurements. Our results indicate that the renewed growth of CH, in 2007 and 2008 was mainly attributable to positive anomalies in CH₄ emissions from wet mineral soils in 2007/2008, tropical biomass burning emissions in 2006/2007, and an overall positive tendency in rice agriculture CH₄ emissions over the simulation period.

Quantification of methane emissions at the farm scale using boundary-layer volume budgets

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Agriculture plays an important role in the global greenhouse gas budget. Especially emissions of CH_4 from livestock and manure management are of key importance. In Switzerland, roughly 80% of all national methane emissions originate from the agricultural sector. However, methane emissions in Switzerland so far were not measured but were estimated via emission factors for enteric fermentation of livestock and for manure management. Since the uncertainties of these emission factors are high, the total uncertainty of the national methane emission estimate is also high (up to 55%). To improve the Swiss inventory estimates, direct field validation of regional-scale exchanges of methane are needed.

Our study aims at quantifying methane emissions at the farm-scale $(0.5 - 5 \text{ km}^2)$. For assessing the source strength of a typical agricultural site, we measured methane concentrations in the lower atmosphere using a tethered balloon system combined with continuous profile measurements along a guy-wired 10-m mast at the ETH research station in Chamau (Canton of Zug). Based on these concentration profiles, we will present methane emission budgets from several campaigns carried out over two consecutive years (2011 and 2012).

We will show how boundary-layer budget quantifications of methane can be used for the validation of emission estimates, and hence for the reduction of associated uncertainties. The flux pattern of methane followed a clear diurnal course. During the night, when strong subsidence and stable stratification dominated, the CH_4 emissions from the agricultural sector (i.e., ruminants, manure) contributed the most to the flux budget. However, the different source terms did not contribute equally to the whole budget in term of time and space. The source strength estimates revealed a strong dependency of atmospheric processes and emissions on the temporal and spatial variabilities. As a result, budget quantifications differed up to 45% compared to the national inventory estimates.

19. Geoscience and Geoinformation - From data acquisition to modelling and visualisation

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Geological structural model of the Federal State of Hesse (Germany) to evaluate geothermal potentials with consideration of parameter uncertainties

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A three dimensional structural model of the Federal State of Hesse was developed using the software GOCAD (Arndt 2012). It incorporates more than 4150 well data from the Hessian well database hosted by the Geological Survey of Hesse (HLUG) as well as from the Hydrocarbon Well Database of the German Geo-logical Surveys, hosted by the Geological Survey of Lower Saxony (LBEG).

Furthermore, all available geological cross sections from geological maps, from interpretations of seismic 2D profiles and from other literature were taken into account. Additional data such as contour maps, palaeogeographic maps, theoretical models and actual 3D models were used. In order to provide uncertainty information to third party users more easily, it was integrated for each geological unit into the model itself.

Based on the structural model, Stratigraphic Grids were created (Arndt 2012) and parameterised with geothermal reservoir parameters, such as matrix and rock mass permeability, porosity, density, thermal conductivity, thermal diffusivity, heat capacity and temperature including the temperature and pressure dependence of the different parameters (Bär 2012).

This integrated approach makes the model highly capable to evaluate geopotentials. Therefore, a new method for geopotential evaluation based on the Analytic Hierarchy Process (AHP; Saaty 1980) was developed. It uses gridded 3D objects, i.e. SGrids or Voxets (Arndt 2012). The method can identify and visualize different geopotentials from cell based objects using individually chosen sets of parameters included in the model. The hierarchical weighting of the different parameters is adjusted according to the geopotential, which shall be evaluated. Additionally, the method is able to consider parameter uncertainties if the empirical variance of the probability distribution is known from statistical analysis of the input data. An example from the Upper Rhine Graben Area is presented.

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Large scale mapping of 3D deformation structures – a combined remote sensing and field work approach

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Shear zones, faults and joint systems represent important sources of geological information and allow deep insight into the formation history of a rock complex. However, the three-dimensional spatial distribution of these geological structures is a key problem while developing valid geological 3D models, particularly with increasing distance from the surface. That is especially true in regions, where only little or even no "hard" underground data (e.g. bore holes, tunnel mappings and seismics) is available.

The granitic rocks of the Haslital valley (Switzerland) provide excellent outcrop conditions to study such mechanical anisotropies. Furthermore, there is many subsurface data available (e.g. tunnel and pipeline mappings, drill holes, cross sections etc.) allowing the correlation between surface and subsurface information. The present study aims to bring together remote sensing and field data, in order to develop a methodology to improve the reliability of geological 3D models. In a first step, based on a geostatistically verified map of large-scale structural elements (shear zones, faults), a shear zone map was derived and evaluated in the field. Field work was partially done using a GPS based Slate PC and the FieldMove[™] software, in order to ease the subsequent data processing. The second step focused on autocorrelation algorithms (Fernández, 2005 and Fernández et al., 2009), in order to use remote sensing results as a basis for semi-automatic three dimensional shear zone construction. In the third and last step, own field data helped to justify the former findings and to fill gaps in between automatically constructed single patches along shear zones traces.

This surface based approach was amended by the integration of subsurface data taken from mappings from underground facilities. Some ten kilometers of geological maps of tunnels and pipelines were evaluated. Firstly, shear zones and faults were digitized and subsequently served as a source for the construction of small-scale planes representing segments of shear zones and faults. Secondly, surface shear planes were projected to depth and were correlated with the subsurface data.

First results show a good fit between the two approaches mentioned above. It becomes evident that (1) several different shear zone generations are present, which dip in two main directions, (2) shear zones often follow lithological boundaries, (3) the number and spatial density of shear zones increases in the southern part of the working area and (4) own large-scale data fits very well with small-scale structures provided by recent studies in the same area.

Nevertheless, there are some difficulties to be mentioned: (1) Due to ongoing erosion, the traces of the structures is not always obvious, even on high resolution digital elevation models and aerial photos, and partially need to be unraveled by interpretation, (2) the amount of subsurface structures that could be taken into account exceeds by far the number of surface structures obtained by remote sensing and own field work, which complicates the above-mentioned correlation task and (3) the digitization quality of the remote sensing part of the task is crucial and lowers modeling complexity in subsequent steps of the workflow.

The combined use of surface and subsurface data helped to predict their trend with increasing distance from the surface, bypassing a height difference of partially more than 2000m. Yet, the exact interplay of these structures in terms of orientation, kinematics and evolution is not clear. Additional analysis is needed in order to gain more detailed insight into the deformation history of the rocks in the study area (see Wehrens et al. 2012, this volume).

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Figure 1: Coloured overlay (kriging interpolation) over digital elevation model discriminates regions of automatically correlated shear zone construction (green areas, pink patches, based on relief differences) and manual construction of shear zones (red to yellow areas, light blue patches, based on own field data). Transitions between different types of planes are not shown; Dimensions: 7x5km.

19.3

Quantifying landscape changes through the georeferencing of single oblique historical photos

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Since its invention in the early 1800ies, the photography assumed a leading role as an effective instrument of documentation of the real world. With the improvement of the techniques the photography developed into photogrammetry giving the opportunity of georeferencing and mapping landscape elements starting from stereo-couples of photographs. With the introduction of the aerial photography, terrestrial oblique photogrammetry became obsolete and was almost completely abandoned as basic technique for the cartographic survey. Nevertheless, it is unquestioned that terrestrial historical pictures presents a lot of advantages such as the terrestrial landscape perspective of the daily live, the better view on the landscape in mountain regions, the high resolution and detail level, as well as the existence of an extended bulk of photographic material dating back in the late 1800ies and early 1900ies, much time before the onset of the aerial photography.

In recent times, the improvement of the computing power and the production of high resolution Digital Elevation Models (DEM) made the spatial georeferincing of single oblique terrestrial picture (monoplotting) more approachable. We started in 2009 by developing a tool for georeferencing common single historical terrestrial pictures. The basic requirements that have to be feed in the system are the digital version of the historical picture, the DEM of the depicted landscape, and the world coordinates of a suitable number of control points unambiguously recognizable on the picture. In this contribution we will illustrate the present version of the tool and some examples of practical applications we achieved so far, discussing the future developments as well as other potential fields of application. For the analyzed study cases the tool is found to be effective for reconstructing with precision the landscape changes. In particular it allow to georeference and quantify the features of former landscapes simply by mapping it directly on the available historical pictures.

The experimentations that we achieved in two alpine valleys, using photographic views that cover large portions of the opposite side of the valley, allow us to provide the first estimation of the precision of this new mono-photogrammetric approach. By comparing the cartographic results with measurements collected through an accurate topographic survey, we can assess precisely the error for every control point. The accuracy of the method depends on many conditions (e.g. high precision of the DEM, high resolution of the picture, low lens distortion), and if these conditions are respected the mean error in 3D localization can be reduced even below one meter.

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19.4

Deformation and radiometric mapping with terrestrial radar interferometry – From radar-geometry to high resolution 3d-surface maps

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Early detection and quantification of surface deformation on rock slopes is a central element in hazard assessment. In recent years, radar interferometry using ground based systems has demonstrated the capability to measure deformation at mm- to sub-mm scales, thereby opening new possibilities for the early detection of instabilities. Radar interferometry complements existing remote sensing techniques such as photogrammetry and laser scanning, however very few methods exist for data integration between the different approaches. We describe a new methodology for data-acquisition and visualization, using a new portable radar-interferometer (GPRI, Gamma Portable Radar Interferometer), incorporating lidar-based terrain models and photogrammetry (Figure 1).

Ground-based radar-interferometric sensors combine the advantages of resolution and accuracy with flexibility regarding the viewing geometry and repeat measurement period. Deformation analysis of steep and/or overhanging rockwalls is possible with this type of sensor. For terrestrial observations however, simple map geometry for localization and visualization of displacements is not adequate (as is simple image draping on digital terrain models). Therefore we developed a method to locate the 2D-radar image (range and azimuth) in orthogonal 3D space. This was possible with the use of high-resolution elevation data (from photogrammetry and laser scanning data sources), fused with other thematic data (e.g. quantitative displacements) obtained from different sources and sensors.

The GPRI is a fully coherent real aperture radar operating at Ku-band (17.4-1-17.3GHz). Scenes are acquired by rotation of fan-beam antennas with horizontal opening of 0.4 deg around its vertical axis. The 2d radar images (range/azimuth) store quantitative phase and intensity information of the backscattered radar-echo. This Information allows determination of the radiometric signature of the target area and its materials on one hand, as well as information about coherence and phase shifts of objects on the other. The phase shifts allow determination of deformation with accuracies of up to 1/8 mm (1mm for larger distances and/or repeat measurements). In comparison to existing instruments, the advantages of the GPRI lie in its portability (setup at virtually any location), fast image acquisition (seconds rather than minutes), lack of defocussing when imaging moving targets, reduced setup and take-down time and large operational range. The single point suspension allows high reposition accuracy as well as simple geodetic control of the setup.

Several measurement campaigns were successfully conducted where different targets such as an ice glacier, rock glacier, unstable rock slopes, bridge vibrations, flowing river, and corner reflector displacements were investigated.



Figure 1. Schematic workflow from radar-data acquisition to visualization of data products.

3D geological investigations coupled to Lidar data: toward vertical geology

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The acquisition of LiDAR 3D data together with the advent of powerful computers, new graphic cards, etc., are making easier fundamental geological tasks such as mapping and structural analysis. LiDAR devices use an oriented laser beam, measuring the time of flight of successive pulses to obtain the 3D topography relatively to the device location. The acquired data can be subsequently geo-referenced (using for example differential GPS), coupled or not with inertial measurement units.

Currently, Airborne Laser Scanner (ALS) data can provide 2.5D Digital Elevation Models (DEM) of high resolution (HRDEM), i.e. more than 3-4 pts/m². Based on these data, the location of structures (large faults as well as the main discontinuity sets) and geological limits are almost perfectly georeferenced (Fig. 1), being the geological mapping consequently improved. Nevertheless, the main recent improvement comes from Terrestrial Laser Scanners (TLS), which provide high accuracy and high resolution data acquisition (up to more than 1000 pts/m²) of the terrain surface, allowing in addition vertical mapping. By analyzing surfaces, the structural features can be identified in inaccessible areas and in a more precise way than by classical fieldwork. This opens new perspectives in analyzing the real 3D structures (Jaboydoff et al., 2007). In addition to these capabilities, the use of the intensity return value allows distinguishing some of the rock contrasts (Franceschi et al., 2009).

Although some applications are still in development, this technique is already broadly used in many Geosciences disciplines: structural geology, engineering geology, stratigraphy, etc. For instance in landslide applications, LiDAR permits to characterize mass movements volumes and shapes in 3D and allows to monitor movements and deformations (Oppikofer et al., 2008; Jaboyedoff et al., 2012). Recent studies (e.g. Buckley et al., 2010) show how accurate stratigraphic profiles as well as sedimentary bodies can be defined based on LiDAR 3D data. Using both ALS and TLS can monitor Debris-flows and rockfalls. The rockfall activities show a clear link with freeze and thaw cycles, and their locations are controlled by preexisting discontinuities. Geological natural hazard mapping is also greatly improved by using Lidar data.

The recent advances in remote sensing such as hyperspectral images (Kurz et al., 2011), coupled with Lidar data may provide rock type identification. This will lead in a close future to real vertical geology and more precise 3D maps.



Figure 1. Structural analysis with ColtopGIS based on a swisstopo HRDEM in Jura Mountains. (A) Map with colour scheme indicating the orientations. (B) Stereonet extracted from the HRDEM represented in A.



Figure 2. Folds analysis based on TLS scan of the Dents du Midi northwest face (A: Coltop3D view; B: Stereonet extracted from the 3D point cloud in Coltop3D).



Figure 3. Vertical 3D geology of the Dents du Midi in the Morcles Nappe.

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3D Modelling and Visualisation of the Structures within the Préalpine Nappe Stack

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Within the scope of a PhD thesis on the tectonic and neotectonic structures of the Préalpes Klippen, five 3D models of different scales were calculated to represent the complex structures of the allochthonous nappe stack of the Préalpes Romandes, as well as the fold-and-thrust structures of the Préalpes Médianes. The focus of this modelling approach lies in the visualisation of the interpreted structures, applying different specialised software to create not only geologically correct models, but also to develop attractive and easy understandable graphics, useful for professional and didactical purposes.

The 3D models were generated by the 3D GeoModeller Editeur Géologique[®] program, developed by the BRGM (Bureau de Recherches Géologiques et Minières, France) and the Australian company Intrepid Geophysics. Within the general 3D model of the préalpine nappes, a compilation of existing cross-sections and seismic lines, as well as the crystalline basement topography were used to constrain the model, but still leave much room for interpretation. Therefore, the presented 3D visualisation is not a reproduction of unknown structures at depth, but rather gives a suggestion of a possible solution taking into account all available data.

After the creation of a complete 3D Model in 3D GeoModeller, the TSurf Export feature was used to calculate and export TSurf surface models, where each geological unit appears in a unique TS file. Since the graphical export method generates exclusively contact surfaces instead of the entire volume, the 3Dmodel becomes "lighter" and therefore easier to handle. One disadvantage of this export method are interfering contact surfaces at out-thinning layers, which provoke errors such as vacant and redundant facets in the triangular mesh. For this reason the exported model requires a cleaning of the model impurities by the use of a post-processing freeware, such as MeshLab v1.3.0. The purified layers were then reassembled in Paraview and NX Unigraphics for final visualisation (crosssections, exploded views, animations).

The final visualisation of the 3D model was established with a powerful CAD software normally used for engineering purposes. NX7.5 has a several sophisticated visualisation tools allowing dynamic cross-sectionning, smoothing of the triangular mesh structure and fly-through views. In this way it was possible to create aesthetic views of a complex structural context.

The generation of 3D pdfs created in Adobe Acrobat allow a further dissemination of the 3D models regardless whether specific modelling software is available, since these models can be opened by everyone using the free Adobe pdf viewer.



Figure 1. Two 3D representations of the Dent de Broc area generated by 3DGeoModeller. On the left, a view of different sections is exposing the internal structures, and on the right an illustration of the three thrust planes and the normal faults with most influence in this area.

3D visualisation – state-of-the art and perspectives

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The visualisation of multi-dimensional geospatial objects, phenomena and processes has been the focus of research for several decades and in different scientific domains. Subsequently, often highly specialised 3d visualisation software solutions have been developed and extensively used by the different domain experts in the geospatial and geoscience communities. However, the rapid emergence of commercial virtual globes such as Google Earth has brought the subject of webbased 3d geovisualisation to the attention of the mass media and the consumers as well as to a much wider spectrum of scientists. In our presentation we discuss some recent developments in the fields of interactive web-based 3d geovisualisation and virtual globes. A particular focus is placed on the creation, dissemination and exploitation of massive 3d geospatial environments and on recent developments and technologies such as cloud computing, HTML5 and WebGL. Based on the OpenWebGlobe project, an open source virtual globe technology, we discuss current shortcoming of large commercial virtual globes – also from a geoscience and geological perspective – and give an outlook on ongoing and future developments addressing some of these shortcomings.

Virtual globes can be characterized as distributed software environments capable of streaming and interactively displaying large amounts of geo-referenced spatial contents. These contents consist of elevation data, ortho-imagery, 3d objects, points of interest (POI), and possibly 2D vector layers. More recent work integrates 3d point cloud data or data from mobile geo-sensors such as UAV-based videos into virtual globes. Some first examples also include subsea surfaces and some limited support for subsurface structures. However, since virtual globes were and still are predominantly based on 2.5d data and data structures, supporting complex and large geological datasets creates a number of (new) challenges. These challenges are discussed based on the following key functionalities of virtual globes:

- An accurate underlying mathematical model of a global geodetic reference framework permitting the integration of geodata and geosensor data from different reference systems down to the sub-meter accuracy level.
- Global spatial indexing of very large and complex geo-data sets supporting the rapid, often highly parallelized production of large geospatial databases and ensuring highly efficient data access over medium bandwidth networks.
- Level-of-detail and/or multiple representation support for all types of geospatial content providing view-dependent loading and displaying of geospatial contents at suitable aggregation levels.
- Internet-based streaming support for multiple users enabling the constant access to potentially very large public or private geospatial data repositories.
- Smooth interactive visualization permitting the asynchronous dynamic loading of 3D scene contents and spatial partitions.

This functionality and the special requirements of geological data are illustrated using the OpenWebGlobe technology. The open source project OpenWebGlobe (www.openwebglobe.org) was initiated by the Institute of Geomatics Engineering of the FHNW University of Applied Sciences and Arts Northwestern Switzerland (IVGI). It started in April 2011 following nearly a decade of 3d geobrowser development at the Institute.

Core of the project is the OpenWebGlobe SDK consisting of two main parts: first, the Viewer part, based on HTML5 and WebGL, allowing the integration of the OpenWebGlobe into custom web-applications. Second, the Processing Tools, a bundle of tools for bulk data processing, e.g. tiling or resampling of large geospatial data sets. OpenWebGlobe was one of the first projects employing WebGL, a cross-platform, royalty-free web standard for a low-level 3D graphics API based on OpenGL ES 2.0 (Khronos 2012). The first version of WebGL was released in March 2011. Today WebGL – and OpenWebGlobe – runs in desktop and mobile web-browsers like Mozilla Firefox, Google Chrome, Safari, and Opera. Thus, OpenWebGlobe might be the technology of choice for creating future interactive 3d visualisation solutions in geology and in geosciences in general.

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Figure 1. Demonstrator 3D Geoportal "Swiss3D" based on the OpenWebGlobe technology (http://swiss3d.openwebglobe.org)

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19.8

Getting the "logic" out of geological 3D modelling

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Working fully in digital 3D is creating an immense surplus for understanding as well as for raising public and political awareness of geology - not only as an academic science but also as a need to envisage the outstanding societal challenges in environment protection, clean energy and risk prevention. Geological survey organisations (GSOs) are going their way towards dynamic 3D underground cadastres that allow rapid and comprehensive, even probabilistic statements about the possibilities and risks of the subsurface.

Some years ago the main focus in geological modelling was on developing 3D-software and tools for handling geological data, visualise it in real-time and in "real" 3D and constructing static geological 3D models. With software becoming more powerful and affordable to a wider geological community like universities and geological survey organisations (GSOs) outside the e & p industry, seamless data exchange and integration of various data sets of different types and formats have become an issue. This could be summarized by the slogan: Better be detailed than coarse!

From a medium size GSO's point of view the challenge now is to step ahead towards dynamic models that can be recycled and refreshed rapidly in order to reflect new data or different model versions. With provoking words: Better be fast than complex – GSOs have to give advise on decision makers who have (often too impatiently) to decide now and not tomorrow – like it or not, there is no time for waiting new boreholes to be drilled or another study to be underway.

Once that data is harmonised (in its semantics, format and structure) and software is interacting in a dynamic and userdefined way automation is nearby! Running predefined procedures takes modelling to its very core: To establish an exhaustive set of possible solutions to a set of comparatively sparse information about the barely accessible subsurface (e.g. Wellmann et al. 2011). So, what does one have by adding up a bulk of possibilities? Call it a probability map – in this case it should better be called a 3D probability model. Many off-the-shelf software already include tools for handling uncertainty, versions, dynamic updates and stochastics (e.g. stochastic simulation) - better be comprehensively fast than vague!

Revising these developments reveals many parallels to the progress that has been done in the well known field of 2D-GIS. Still, geological 3D modelling is more restricted to a smaller user community but the technological investment is not standing much behind and both worlds are converging more and more: 3D City models, 3D-viewers, 3D data formats, databases and so on.

The technical aspect of geological 3D modeling reflects this history: Early software was very specific regarding data formats and import/export capabilities. Originally developed by the e & p industry it was very focused on seismic data and the construction of models from huge data sets but without taking into account the full set of geological rules and constraints. Having responsibilities at the shallower subsurface as is the case for GSOs, all these tools had to be added with extra workflows, workarounds and programming to be able to utilize a field mapper's inhomogeneous database. However, this time consuming and error prone procedure was not very suitable for any re-modelling triggered by new data or alternative concepts. Furthermore, severe limitations arose from incompatible software, data-formats or databases when working within a regional or (even worse!) national context like projects or overview models. How to take over work on a third party's model? How to include its base data?

Interoperability is therefore a prerequisite for any capitalization of models beyond small problem-driven ones. To achieve this, many parallel activities had to be started with some of them still being ongoing. GSOs have taken over a substantial part by pushing forward technical standards for 3D databases, data formats, semantic and by harmonizing databases resp. data content, stratigraphic correlations etc. (Berg et al. 2011). Also more "geological thinking" by software has been welcome of course. However, the central issue is still to establish formats and standards to store and utilize complete models independently of the software that was used to build them, including the uncomplicated dissemination via the web. Having learned hard lessons on how to bridge the gap between the 2D and the 3D worlds opened concepts and new ideas on how to utilize GIS as a central data hub being able to manipulate, generate and transform all kind of data and handle it through to constrain generic 3D models (Pamer & Diepolder 2010).

The example of generating a state wide 3D model of Bavaria/Germany gives an idea about the complexity of this approach. It shows one way of how to use the automatisms of ArcGIS[®] to harmonise borehole databases, structure geological maps and generate hypothetic geometries to make them ready to use in any 3D modelling software. It is also used as a script generator to preset the whole model environment within the modelling suite SKUA[®].

The concept reveals that most work has to be done apart the modelling task itself. In this example this effort is invested not in the preparation of the data itself but in the algorithms to make it fit!

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Development of a method for the detection of seismic events based on high-rate GNSS network measurements

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Strong earthquakes, among the major natural hazards globally, occur in Switzerland on average every 80 years, with the last strong event taking place in Sarnen in 1964 (Mw=5.3). Furthermore the development of GNSS technology, e.g. the availability of high-frequency receivers recording at a rate of up to 100Hz and the many different systems (GPS, GLONASS, Galileo, Compass, etc.), allow the application of GNSS receivers to accurately monitor the seismic ground motions (Häberling, et al., 2011) and not only to estimate coseismic displacements. This study here is a first attempt by GGL-ETHZ in collaboration with SED to detect strong earthquakes based on high-rate measurements of a GNSS network covering the area of seismic interest.

The methodology is based on an algorithm, which analyses the high-rate GNSS kinematic coordinates to detect possible ground motions and displacements in each GNSS station. Based on the detection of the seismic motion the time of arrival at each station, the maximum coseismic displacement etc. can be derived. The algorithm developed is based on three steps:

- I) the estimation of the measurement noise level for each component (north, east, up) and each station based on the measurements recorded several minutes before the event,
- II) the comparison of the measurements of each station for the examined time interval with the corresponding noise level
- III) if the apparent displacement in one of components is greater than the estimated noise level then this displacement express seismic motion and the corresponding time express the arrival time of the seismic motion at the current station.

In order to avoid possible wrong detections of seismic events caused by other phenomena (e.g. landslides) or outliers in the measurements, several GNSS stations covering the broader area of seismic interest are used in the algorithm.

The method has been assessed based on simulated velocity records corresponding to simulated strong seismic events (Mw>6.0) varying in fault (normal, reverse) and rupture mechanism (depth, angle slip, etc.). These high-rate velocity values were computed from the seismic simulation models for a total of 168 sites covering symmetrically the broader area of 100kmx80km around the epicenter (Dalguer and Mai, 2011). The velocity records were integrated into displacement records and subsequently transformed into series of geocentric coordinates thereby locating the epicenter in the area of the Valais, an area of high seismicity in Switzerland. Using the Bernese GPS Software 5.1 simulated GPS observations were then generated for the 168 simulated stations with their ground motions.

The processing of the simulated GPS data resulted in series of kinematic coordinates, to which the detection algorithm was applied. The ground motion was accurately detected (error < 0.1 sec) for 30% of the stations and with error < 0.5 sec for the 43% of the stations (Fig.1).

Thus, these preliminary results indicate that the developed methodology can be applied for the earthquake detection based on a high-rate GNSS network. It is clear that the algorithm still needs to be improved for a refined, more reliable detection of seismic motions by limiting possible measurement errors and outliers.

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Figure 1. Determination of the time of arrival of the ground motion at the stations of the simulated GNSS network, covering the area of Valais. The triangle marks the epicenter of the simulated earthquake and color scale indicates the accuracy of the estimated time of arrival for each simulated GNSS station.

46.5°

19.10

KarstALEA : a practical guide for the prediction of karstrelated hazards in underground works

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Excavation of tunnels in karst environments commonly meets problems with severe and costly consequences.

The practical guide "KarstALEA" (meaning KarstHazard; Filipponi et al. 2012) aims to provide a practical method for the assessment of ground conditions in karst massifs. This method is an addon to the SIA 199 code and guidelines for tunnels in karst, and is designed for use by geologists involved in underground works. The results are then presented in a longitudinal profile of the tunnel to give clear indications of the probabilities of occurrences of karst voids and conduits within respective sections of the tunnel; they also indicate probable characteristics of the anticipated karst features.

The KarstALEA method synthesizes academic knowledge on karst and combines this in a way to address practical questions related to the underground works. It is based first on the observed fact that karst conduits preferentially develop along a restricted number of geological horizons, known as "inception horizons". Typically, 70% of the conduits may develop along 3 to 5 discrete horizons within the scale of a tunnel project (Filipponi, 2009). A second input factor is that conduit density varies within the karst massif depending on the present and past hydrogeological conditions; there are commonly some concentrations of conduits at elevations corresponding to past base-levels (palaeo-valley floors).

Consequently, the identification of inception horizons and base-levels makes it possible to predict zones of highest probability of occurrences of karst conduit. Any knowledge of the karstification history of a massif helps these predictions and may also indicate some characteristics of the anticipated karst conduits (notably, the sizes and shapes of voids, the quantities and types of sediments, the presence of water and its likely pressure and discharge, etc.).

The KarstALEA method is applied in three main stages:

- 1. Stage 1 "KarstALEA initial assessment" takes place at the beginning of the preliminary study or even during the initial stage of objectives definition (from SIA 197). The aim is to define if the tunnel is to be constructed within the range of its various potential alignments, and whether it presents a karst-related hazard or not. If the hazard is recognized, the KarstALEA method is applied as in stage 2.
- 2. 2. Stage 2 "KarstALEA investigations" starts in the preliminary study and extends all through the project study phase. This stage provides the necessary inputs for the tender documents for the project. Data required for building four 3D-models (geology, hydrogeology, speleogenesis and inception horizons; Fig.1) are acquired as part of the project study. These are iteratively improved until they reach the required level of detail. This stage is the core of the KarstALEA method.
- 3. Stage 3 "KarstALEA construction" continues during the construction phase of the project. The application of KarstALEA remains very similar to that in stage 2, but the nature of the data and of new problems evolves continuously as real facts on the ground conditions are revealed by the construction in progress. During this stage some previously defined construction guidelines may have to be adjusted in order to solve newly recognized problems. The KarstALEA models develop and improve throughout stages 2 and 3, and are very valuable for making decisions. The final report of this stage outlines guidelines relevant to karst hazards that may be encountered during operation of the tunnel.

A hyperlink to download the KarstALEA practical guide for the prediction of karstrelated hazards in underground works is available at www.isska.ch



Figure 1. Principle of the KarstALEA method in 7 successive steps. Four 3D representations of the massif (models) are constructed in steps 1 to 4. In steps 5 and 6 zones with the highest expected densities of karst conduits and their characteristics are interpreted. In step 7 hazards, risks and mitigation measures are identified and discussed between the tunnel geologist and the tunnel engineer (not shown in figure). Throughout progress on the project, this cycle of 7 steps is repeated with increasing precision.

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19.11

Geoscience Data Integration and Visualisation in 3D - GeoVisionary

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Over the past decade, the British Geological Survey has invested significant resources into developing its 3D geoscience knowledge base. One of the ways in which this has been undertaken is by developing specialised software and modifying working practice to maximise the potential high resolution data sources.

For example field mapping was and still is an essential element to understanding geological structure and processes. In order to make best use of available data for pre-fieldwork interpretation, BGS commissioned UK Virtual Reality specialists, Virtalis Ltd., to create an immersive 3-dimensional visualisation and interpretation software environment that has revolutionised the way in which geoscientists can capture linework and descriptive information in a virtual 3D environment either on their desktop PC or in specialised 3D suites. This software, GeoVisionary, is a platform in which terabytes of the highest resolution data can be combined in one environment for seamless visualisation and analysis (Giles *et al* 2010). Some of the types of high resolution data that can be integrated include:

- Terrain models including national scale datasets at the highest resolution, and specialist terrain data such as LiDAR
- Aerial Photography and other remote sensing data
- 3D Models including high resolution CAD models, subsurface geological models and voxel models showing property distribution
- GIS data e.g. geological and topographic Maps

GeoVisionary provides all of the essential tools a geoscientist would need to interrogate this plethora of data, and capture knowledge as they would in the field (Vye *et al* 2008). These include many of the standard GIS tools plus a host of others that allow the user to interrogate and immerse themselves in the data. GeoVisionary can be used not only as a reconnais-sance tool but also to re-assess past observations, field maps and data.

By integrating all of these datasets and tools in a virtual desktop environment, it becomes particularly advantageous to study areas that are difficult to reach in reality. This opens the possibility of studying extreme environments using realistic 3D visualisations be it the remote mountainous regions of Tajikistan (Jordan *et al* 2009) or even Mars (Figure 1).

GeoVisionary has been proven to reduce resource expenditure in geological field mapping and other geoscience field studies. The 3D visualisation of both natural environmental data with human infrastructure has been an important way of communicating geosciences to stakeholders. GeoVisionary will continue to augment fieldwork, help increase our understanding of subsurface processes and deliver realistic visualisations of geosciences data.

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Figure 1. The Valles Marineris (Mars) with a geological map drape and terrain measurement. Geological Map: The Valles Marineris, USGS Astrogeology. Elevation Data: MOLA (Mars Orbiter Laser Altimeter), Mars Global Surveyor, NASA.

P 19.1

The 3D-model Basel region – a planning tool

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In 2008 started the EU project "GeORG" (www.geopotenziale.eu) with the idea to establish a tool for space planning of the subsurface across political boundaries along the Upper Rhine Graben. The project partners are the Applied and Environmental Geology Group of the University of Basel and the geological surveys of France (BRGM), Baden-Württemberg (RPF-LGRB) and Rheinland-Pfalz (LGB).

The aim of the project was the development of a geological 3D model between Basel and Mannheim (D), which can be used as a tool for evaluation of the possibilities and risks of the deeper underground.

The geological 3D-model of the Basel region (600 km²) was established as the Swiss contribution to the "GeORG"-project. 12 geological horizons between the Quaternary and the crystalline basement were modelled and joint with the rest of the GeORG model.

In the Bael area additional 8 horizons were integrated to refine the shallow subsurface for a better resolution (e.g. top of Gipskeuper, base of Tuellinger Schichten, base of Elsässer Molasse) and to get a better definition of deep aquifers and aquitards (e.g. base of Anhydrit group –Muschelkalk, top of Opalinuston).

Beside the development of a static geological model, from the start it was the aim to establish a flexible tool for subsurface planning in an urban area. Ideally, the model should be easily adjustable with new data and a spatial extension, or a local refinement of the model should be possible at all time. Therefore, the designed data management concept combines database, 3d-modeling and GIS. The developed links between the different software applications allows an easy data exchange, fast integration of new data and quick insights into the model in 2D (maps or sections) and 3D (perspective view).

For each modelled horizon an own GIS-project was generated comprising all relevant basic datasets and the modelled 3D horizon geometries. Additionally, new data (e.g. boreholes) which were inserted into the database are automatically made available to the appropriate GIS-projects. There, an automated routine compares new data points with the geometry of already modelled horizons. The computed goodness of fit (differences) could be visualized and helps to assess future issues.

During the last years the administrative of the cantons Basel-Stadt and Basel-Landschaft have acknowledged the advantage of a planning tool such as the geological 3D-model of the Basel region. The possibility to generate flexible exports to be able to use the subsurface information in other software applications, as well as to combine hydro-geological information with infrastructural data for a detailed analysis gives rise to repeated requests concerning local issues. For example, the subjects are related to potential use conflicts between existing installations and planned activities in the field of use of shallow geothermal energy, groundwater protection or tunnelling.



Figure 1. Planning of a tunnel project in an urban area. Example "Osttangente- Basel": Existing geothermal heat exchangers (boreholes light green) are situated next to a possible tunnel path (red). The combination of various data supports the identification of conflict situations (white circles). Legend: groundwatertable (blue transparent), base of unconsolidated rocks (green), geol. horizons (brownish and yellow)

The EU-project GeORG – products

GeORG-Project Team^{1,2}

P 9.2

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The geological surveys of France (BRGM), Baden-Württemberg (RPF-LGRB), Rheinland-Pfalz (LGB) and the Applied and Environmental Geology Group of the University of Basel initiated in 2008 the EU project GeORG (Geopotentials of the deep Upper Rhine Graben). It is funded by the INTERREG IV A Upper Rhine programme.

GeORG aims at achieving a consistent transnational geological database of the Upper Rhine Graben between about Basel (CH) and Mannheim(D). This effort requires the collection of geological information from the German, French and Swiss regions involved and the harmonization of different standards and terminologies. In order to obtain a coherent geological model, all partners in GeORG focus on a consistent definition of stratigraphic markers, interpretation of seismic lines as well as modelling of faults and geological horizons ranging from the base of unconsolidated rocks to the top of the crystalline basement.

Following the geological modelling, a geostatistical temperature model based on well data (mainly temperature logs, BHT measurements) is generated. A conductive geothermal model is additionally calculated for a subdomain of the model (Fa. Geophysica, Aachen).

Products of the project are:

- Selected cross-sections
- Maps showing the 3D geometry of modelled horizons •
- Thickness distribution maps •
- Facies maps •
- Temperature distribution at certain depths
- Heat in place •
- Storage potential maps (CCS)

In December of 2012 the project will be finished and the products will be available to professionals and the interested public. The project homepage (www.geopotenziale.eu) contains a mapserver and download possibilities. The final report is made available in early 2013.

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P 9.3

Small and Fast Motion Detection using GPS receiver Single-Frequency Carrier Phase Observations

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Movement detection technology was widely applied as an important means to monitor building deformation, research on crustal motion and so on. GPS as one of the most commonly used distance or position measurement tools, of course, can play a role in the monitoring of the movement.

Through continuous positioning the object to monitor the movement was the traditional GPS method, for a complete GPS receiver system, this method is convenient and intuitive, but the disadvantages of this approach are also obvious, on one hand the accuracy of the measured movement is directly affected by the impact of the positioning accuracy, on the other hand, high precision differential GPS positioning required a receiver-network, this virtually increases the cost and complexity.

In 2007, Prof. Dr. Alain Geiger and Dipl.-Ing. Sebastien Guillaume developed a new algorithm called GMoDe, with that the detection of small and fast movements using single-frequency carrier phase observations of one low-cost GPS receiver is possible. The Principle of this method is that through detection of discontinuities in phase observations, which are due to the movements of GPS receiver, to detect the movements. With observations only we can hardly locate or quantify the discontinuities. Nevertheless, if we accurately know the state of the observation model while it keeps continuous, by means of comparing the "known" state with the measured value, we can more easily determine the discontinuities.

To achieve this purpose an observation model was needed to construct first.

The quality of detection is strictly depending on the veracity and stability of the model. How we choose the type of combination of observations and its model would be described and discussed at first in this thesis. For a linear dynamic system dealing with a large number of data such as our observation model the Kalman filter is one of the most optimal and efficient method to estimate or predict the state at a particular point. These predictions would be compared with measured data, through stochastic test and transformation the significant differences would be in displacement reference system delivered, the movements are then detected and quantified. Details on Kalman filter and transformation are described; the C++ realization of this algorithm is presented in this thesis. Some improvements by detecting permanent movements or long-periodic vibration would be also introduced.

To demonstrate the validity and prove the advantages of the method and program we have also applied a simulation test, in that the GPS antenna was mounted on a shaker (Rütteltisch, this set of data was provided by Mr. Simon Häberling), which integrates with an accurate inductive displacement-measure-unit and can generate various kinds of vibrations.

The inductive observations and the output of our C++ program would be compared and analysed (see Figure 1).

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Figure 1 Inductive sensor measurements (Up); GMoDe Results (GPS RINEX File as Input) (Middle); detailed comparison between true value (blue) and result (red)(Down)..

Visualizing vector data: Clustering noisy displacement fields

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The growing number of areal measurement devices and surface displacement studies increase the amount of available vector data in terms of density, coverage, and accuracy. It is known that there is no possibility to obtain noise-free measurements, hence every dataset is contaminated by the measurement uncertainty. Analysing noise contaminated vector field data is a challenging task and often involves assumptions about the signal itself. This limitation can be reduced if the vector field is grouped into domains with common statistical characteristics.

The goal of the present work is to demonstrate a robust vector clustering method. Resulting vector clusters can be used either for direct interpretation of the dataset or for further data processing. For example, when dealing with displacement maps derived from remote sensing devices (f.e. InSAR, optical flow, ect.), data clustering results in discrete boundaries of different types of motions. If the displacement measurements are further processed, noise filtering and other domain specific applications can easily be applied to the individual motion areas.

The proposed clustering algorithm is based on robust statistical and topological analyses and features a variety of optimization routines. One of the main differences to common clustering algorithms, like k-means, is the treatement of input coordinates and vector components as separate clustering criterias. Using the principle of Lloyd's algorithm, clustering is carried out iteratively whereas the statistical properties, i.e. the individual cluster proxys, are continuously recomputed to ensure fast convergence.

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20. Earth System Science related Earth Observation

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Swiss Commission for Remote Sensing Swiss Geodetic Commission

TALKS:

- 20.1 Fatehi P., Damm A., Kneubühler M., Schaepman M.: Alpine vegetation biomass mapping from imaging spectrometer data
- 20.2 König S.J., Fontana F., Seiz G., Foppa N.: Extending Global Monitoring of Essential Climate Variables through the GCOS Cooperation Mechanism
- 20.3 Leinss, S., Hajnsek, I.: Feasibility study on snow property extraction based on differential SAR interferometry
- 20.4 Leiterer R., Morsdorf F., Schaepman M.E.: High resolution retrieval of forest canopy structure using multitemporal airborne laser scanning
- 20.5 Madonna E., Wernli H., Joos H., Martius O., Böttcher M.: Precipitation in extratropical cyclones: the role of warm conveyor belts
- 20.6 Männel B., Rothacher M.: Co-location in space and its impact on the geodetic reference frame for Earth observation
- 20.7 Riffler M., Schulze S., Wunderle S.: Toward a satellite-based climatology (1989–2011) of lake surface water temperature from AVHRR 1-km for European water bodies

POSTER:

P 20.1 Stöckli R., Posselt R., Steger C., Liniger M.: MSG SEVIRI-based solar energy mapping over complex terrain

20.1

Alpine vegetation biomass mapping from imaging spectrometer data

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Aboveground biomass (AGB) of terrestrial ecosystems is an important input to global change and productivity models and is needed to assess carbon stocks and the contribution of vegetation to the global carbon cycle. In the present study, the suitability of imaging spectrometer (IS) data for estimating aboveground biomass of an alpine ecosystem was investigated. The approach of Continuous Fields Mapping (CFM) is a promising alternative to discrete mapping approaches for representing the spatial and temporal distribution of terrestrial ecosystem biomass since it overcomes the limitations of "hard" classes boundaries. In this contribution, a dedicated methodological framework for deriving continuous fields of an alpine ecosystem's biomass is presented.

First, abundance mapping of predominant land surface types was performed using linear spectral mixture (LSM) analysis. Then, linear regression models which are based on measured field data and vegetation indices derived from APEX (Airborne Prism Experiment) IS data were used to generate quantitative maps of aboveground biomass of vegetated areas, Continuous fields of biomass were eventually complied by combining LSM derived abundance maps of land surface types and corresponding biomass from linear regression modelling.

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Extending Global Monitoring of Essential Climate Variables Through the GCOS Cooperation Mechanism

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High-quality climate observations are vital for the international community to take the most appropriate action to detect, adapt to, and mitigate climate change in line with the objectives of the UN Framework Convention on Climate Change UNFCCC. Switzerland has a long tradition in climate observation, ranging from temperature and precipitation series of more than 150 years to glacier measurements since the end of the 19th century. The Swiss GCOS Office at the Federal Office of Meteorology and Climatology MeteoSwiss ensures among others the continuation of such climate relevant measurements in Switzerland. These measurements contribute to the systematic monitoring of Essential Climate Variables (ECV) within the National Climate Observing System GCOS Switzerland.

(Satellite) Earth observation encompasses the monitoring of coupled systems at a global level. Whereas Switzerland features an established network of climate and environmental data, globally, data is highly limited in certain areas. In the framework of the GCOS Cooperation Mechanism the Swiss GCOS Office coordinates an international project to improve climate observation in developing countries where climate (atmospheric domain) and environmental data (terrestrial domain) is sparse. This capacity building project promotes among others in situ glacier mass-balance monitoring in Central Asia and atmospheric measurements in South East Asia supported by Swiss partner institutions. The data obtained will be submitted to the International Data Centers and will be valuable for a wide range of applications, e.g., regional climate modelling, monitoring of climate change, or validation of satellite derived products.

We report on GCOS activities on monitoring atmospheric and terrestrial components through means of an international project in the framework of the GCOS Cooperation Mechanism. The outcomes will contribute to the global network of Earth observation, by extending monitoring of ECVs, such as glaciers and atmospheric composition, and will ultimately establish a sound scientific data basis to improve policy decisions in those countries and at an international level.

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Feasibility study on snow property extraction based on differential SAR interferometry

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Currently the determination of snow water equivalent (SWE) and other snow parameters rely on a network of weather stations, and air- and space borne missions with resolutions on the km-scale. High resolution weather and precipitation models will depend on high resolution input data. Active radar systems, especially SAR-systems can provide high resolution datasets independent of daylight. For a sufficient interaction of microwave radiation with the snow cover, high radar frequencies are needed. The satellite formation TerraSAR-X and TanDEM-X build for the generation of a high resolution globe-covering digital elevation model (DEM) (Krieger 2007) provides X-band data at 9.65 GHz with a resolution on the meter scale. Every time, flying over a certain area two acquisitions are taken which allow a DEM-generation for each pass (single pass interferometry). Further differential interferometry (D-InSAR) is possible between acquisitions of different passes. Here, feasibility studies and results for snow height and snow water equivalent determination by using differential SAR interferometry of multi-pass and single-pass acquisitions will be presented.

D-InSAR is a known method to detect height changes (Gabriel, 1989) on the wavelength-scale (l = 3 cm) by comparing the measured phase with a reference, here a synthetically calculated phase, based on the best available digital elevation model (DEM). Atmospheric disturbances cancel out in single-pass interferograms, but remain visible as long-range phase patterns in multi-pass interferograms. Still, they cannot explain small scale phase patterns, which correlate with local topographic features. These phase patterns are caused by the changing penetration depth of microwaves but also height deformations, both resulting in different location of scattering centers. Various properties of the cryosphere change over time and affect the location of scattering centers. Soil freezing, water content of snow, snow height and snow water equivalent but also vegetation cover are discussed to explain the detected phase patterns. Further, the interferometric coherence, which measures changes between two acquisitions, allows the detection of snowfall and melting periods.

In single pass interferometry, due to zero temporal difference between the two acquisitions, the bistatic mode of the TanDEM-X formation provides a very high coherence and phase accuracy. Therefore, elevation changes on the sub-meter scale can be detected, by comparing two obtained DEMs. This might not work in early winter when the snow layer is very cold (not conducting) and thin, but with some content of liquid water in the snow, a height difference should be possible to detect.

For validation, ground measurements are essential and have been acquired. The test sites Sodankylae in northern Finland and Churchill in Canada, MB, have been chosen as already intensive ground measurements were done there within the framework of the CoreH₂O mission (Rott, 2010). Snow height, snow water equivalent, air temperature, soil moisture, wind speed and even snow profile data are available. For both test-sites exists a set of 20 - 25 TerraSAR-X multi-pass acquisitions and 6, resp. 8 single-pass TanDEM-X acquisitions during the winter 2011/2012.

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Symposium 20: Earth System Science related Earth Observation

20.4

High resolution retrieval of forest canopy structure using multi-temporal airborne laser scanning

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Forests play a pivotal role in the global biogeochemical and -physical cycles between atmosphere and the land surface (Toda et al. 2011). Particularly the complex three-dimensional distribution of geometric objects and their topology within forests canopies, here termed forest canopy structure, influences the fluxes of energy and matter between the atmosphere and forests (Xue et al. 2011). Assessing forest canopy structure is difficult: conventional fieldwork is time-consuming and mostly limited in its spatial extent, whereas traditional remote sensing methods are lacking information in the vertical dimension (Jones et al. 2012). Airborne laser scanning (ALS) systems have been shown to be suitable for providing not only horizontal information on the forest canopy structure, but also explicit vertical information due to the canopy penetration of the emitted signal (Leeuwen & Nieuwenhuis 2010). However, existing approaches to derive forest canopy structure using ALS data mostly include manual processing steps or need additional data about stand characteristics. Therefore, an automated and transferable method is basically needed to provide a more efficient monitoring of forest canopy structure as well as to improve the robustness and reliability of derived forest canopy structure information.

In this study, we used full-waveform ALS data under leaf-on and leaf-off canopy conditions in a mainly semi-natural, deciduous-dominated forest stand in Laegeren (Swiss Jura – 47°28'N, 8°21'E). The forest stand is characterized by a high diversity concerning species, age, and diameter distribution. Based on the specific characteristics of the ALS derived point cloud we developed a new adaptive multi-scale algorithm to calculate the digital terrain model (DTM) and the belonging digital surface model (DSM). A canopy height model (CHM) was calculated from the difference between DSM and DTM. Finally, for each point of the point cloud we determined the height above ground as well as the according DTM, DSM and CHM values. Based on the full point cloud, we applied a segmentation algorithm to enable the characterization of the canopy structure on the individual tree/ crown level. As input for the segmentation a set of seed points is necessary, representing the positions of the individual trees. To determine this seed points, we used an iterative, three-dimensional grayscale dilation based on an ellipsoid-shaped structuring element. Accordingly, the resulting points were utilized as initial points for a hierarchical k-means clustering approach. For each obtained cluster, we calculated the alpha shape to derive additional crown specific variables such as crown volume or crown diameter. Based on the crown specific variation in the point distribution between leaf-on and leaf-off acquisition (e.g. percentage distribution in vertical extent), we distinguished deciduous from coniferous trees. The extracted forest canopy structure variables can be used for a complete three-dimensional representation of the forest area (Figure 1).



Figure 1. Simplified visualization of the reconstructed forest scene.

The tree detection accuracy and the delineation of crown variables were assessed based on a stratified random sampling approach using ortho-images, terrestrial laser scanning (TLS) and forest inventory data. The commission and omission errors for the tree detection are 5.2 % and 13.1 %, respectively. The classification of the tree species (coniferous, deciduous) results in an overall accuracy of 89.7 % with a kappa coefficient of 0.74. The crown dimension variables were validated within the TLS plots and results in a mean error of ± 2.8 m. The derived foliage distribution information and bio-physical variables could not be validated yet directly. For this purpose a dense vertical sampling of the full canopy is necessary, which will be carried out in future studies.

We conclude that it is possible to extract forest canopy structure variables on the tree level to a certain extent without any previous knowledge about stand specific characteristics. The validation/evaluation shows that the determination of canopy structure variables was performed with high accuracy, whereas the quantitative validation of specific horizontal crown variables (e.g. crown projection area, crown diameter) and bio-physical variables (e.g. leaf area density) is still difficult, particularly for a dense deciduous dominated forest.

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Precipitation in extratropical cyclones: the role of warm conveyor belts

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Extratropical cyclones are everyday phenomena and are an important component of the atmospheric general circulation since they transfer energy, moisture and momentum poleward. They can cause adverse weather, trigger torrential rains, strong winds, thunderstorms, squall lines and hail and significantly impact our climate.

During their intensification and in the mature stage, extratropical cyclones are typically associated with three coherent major airstreams – the dry intrusion, the cold conveyor belt and the warm conveyor belt (WCB), respectively (Browning 1990).

These airstreams are important for the dynamics of the cyclone evolution, and potentially also for the rapid long-range transport of atmospheric constituents as ozone and pollutants. They are key features for the meridional and vertical transport of water vapor and heat, linking the atmospheric boundary layer and the tropopause region.

WCBs are moist airstreams which originate in the moist subtropical marine boundary layer and ascend polewards ahead of the cold front. They are characterized by a rapid ascent, within about two days, to the upper troposphere (Wernli and Davies 1997; Eckhardt et al. 2004). Moreover, WCBs are the primary cloud-producing flows and are responsible for the major part of precipitation in the extratropics (Browning 1990). In IR- and WV-satellite images, they are visible as slightly S-shaped bright frontal cloud bands (Figure 1).



Figure 1. Meteosat SEVIRI infrared satellite image (0600 UTC 30 January 2009 from http://www.neodaas.ac.uk/) showing a WCB.

Furthermore, from a dynamical point of view, WCBs are important for the evolution of the cyclone and can amplify upper-level Rossby waves leading to the formation of PV streamers. These in turn can act as precursors of extreme weather events.

WCBs will be considered from a climatological point of view, using 32-years of the ERAinterim reanalysis data set (1979-2010). WCBs are identified from comprehensive trajectory calculations that select air parcels in the vicinity of cyclones with a minimum ascent of 600 hPa in 48 hours.

The global geographical distribution of WCB starting regions and their tracks will be presented for different seasons. The importance of these airstreams for precipitation in the extratropics will be pointed out as well as their importance for the climate system.

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20.6

Co-location in space and its impact on the geodetic reference frame for Earth observation

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The realization of a unique terrestrial reference frame (TRF) that is accurate enough to allow the monitoring of the Earth's system is limited on the one hand by individual error sources of the contributing space techniques and on the other hand by the quality of the links between them. In conjunction with the "Global Geodetic Observing System" the accuracy and stability level of the desired TRF were defined to be at 1 mm and 0.1 mm/yr resp. To achieve these requirements, investigations in both limiting factors are necessary. Based on a small number of existing scientific and navigation satellites equipped with sensors of two or more techniques and reasonably known offset vectors, co-location in space can be investigated. The data from GPS and DORIS receivers onboard LEOs and SLR measurements to GNSS satellites and LEOs are available for this purpose. The use of VLBI would become possible as well if a VLBI signal is transmitted by a satellite and received on Earth by radio telescopes.

For our investigations we chose observations from the satellite mission OSTM/Jason-2 because of the high-quality sensor data and the relatively high satellite altitude of 1336 km. In addition to the real GPS and SLR data we simulated satellitebased VLBI observations as mentioned above. After a single-technique processing for all three data types we combined these results on the normal equation level and estimated station coordinates, orbital parameters and other relevant unknowns. We will present first results of this co-location in space and its impact on the accuracy of the TRF.

Toward a satellite-based climatology (1989–2011) of lake surface water temperature from AVHRR 1-km for European water bodies

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The Swiss Global Climate Observing System (GCOS) office has initiated a project to generate a satellite-based lake surface water temperature (LSWT) climatology for the pre-alpine water bodies in Switzerland. In contrast to in situ observations, satellite imagery offers the possibility to derive spatial patterns of LSWT variability. Moreover, the temperature of many lakes in Switzerland is monitored on a non-regular basis. Hence, the extensive Advanced Very High Resolution Radiometer (AVHRR) 1-km data record (1985-2011) of the Remote Sensing Research Group at the University of Bern (RSGB) will offer new insights into the temperature evolution of lakes over the past three decades.

The time series is compiled from the AVHRR/2 (NOAA-11, -14) and AVHRR/3 (NOAA-16, -17, -18, -19 and Metop-A) instruments on board the National Oceanic and Atmospheric Administration (NOAA) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) platforms. Especially NOAA-16 and prior satellites were prone to unwanted noise, e.g., due to transmission errors or fluctuations in the instrument's thermal state. This has resulted in partly corrupted thermal calibration data and may cause errors of up to several Kelvin in the final brightness temperatures. Therefore, a multistage correction scheme has been applied to the data, in order to minimize these artefacts in the satellite observations.

For the LSWT retrieval, we compared three different methods. First, we applied the operational NOAA NESDIS and NOAA Pathfinder global SST algorithms to our data set. In addition, we developed an optimized simulation-based scheme making use of the Radiative Transfer for TOVS (RTTOV) Version 10 together with operational analysis and reanalysis data from the European Centre for Medium Range Weather Forecasts (ECMWF). All methods were validated extensively using in situ measurements from lakes with various sizes between 14 (Lake Sempach) and 580 km2 (Lake Geneva). The simulation-based algorithm helped to reduce the RMSE and Bias for the lakes in the study region of Switzerland compared to the global SST algorithms and even small lakes yield good results.

As a next step the model-based LSWT retrieval shall be expanded to all European lakes, which are covered and recorded by the AVHRR data retrieval station at the RSGB.

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P 20.1

MSG SEVIRI-based solar energy mapping over complex terrain

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Global radiation is an essential climate variable highly relevant for applications such as solar energy, agriculture or climate monitoring. Global radiation retrieved from geostationary satellites has continuous spatial and temporal coverage of high resolution and complements station-based estimates. The Meteosat Second Generation (MSG) based global radiation dataset presented here explicitly treats clouds over snow and accounts for terrain shadowing. Validation results suggest a monthly averaged accuracy of <5 W m-2 over flat and <10 W m-2 over Alpine terrain.

The algorithm (Stöckli, in prep) employs the MSG SEVIRI High Resolution Visible (HRV) channel in combination with 4 near-infrared and infrared chan- nels. The clear sky compositing is based on a probabilistic cloud mask (Khlopenkov and Trishchenko, 2007) and a parametric fit of the diurnal course of clear sky reflectance and brightness temperature. Since snow can be brighter than clouds, an infrared-based cloud index is applied over bright surfaces. Spatially distributed maximum cloud reflectances are calculated with a cloud angular distribution model. Clear sky radiation is calculated with the gnu-MAGIC (Müller et al., 2009) radiative transfer model driven by 6-hourly ECMWF water vapor and ozone and by a monthly aerosol climatology. A SRTM-based digital elevation model is used to calculate the effects of terrain shading and sky view on the direct and diffuse radiation components (Figure 1).

We present validation and inter-comparison results, followed by several examples of how this dataset is currently employed in applied climate research and for solar energy applications.



Figure 1. Mean global radiation (W m-2) for Switzerland (2004-2011) projected on effective area of inclined terrain surfaces of a 100 m elevation dataset.

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21. Landscape and its meanings for society

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TALKS:

- 21.1 Degenhardt B.: What makes a landscape healthy? GIS-assisted mapping and other approaches to better understand the meanings of nearby recreation areas for a healthy society
- 21.2 Garrard R., Kohler T., Wiesmann U., Price., Byers A., Sherpa AR.: Repeat photography as a tool in detecting landscape change and environmental services in Sagarmatha (Mt. Everest) National Park, Nepal
- 21.3 Graf C., Buchecker M.: Photovoltaikanlagen an Lawinenverbauungen: Wahrnehmung und Akzeptanz verschiedener Bevölkerungsgruppen
- 21.4 Ioja C.I., Tudor C.A., Hersperger A., Patru-Stupariu I. G.: People's perception toward externalities caused by potentially conflicting land uses. Case study of Bucharest cemeteries, Romania
- 21.5 Keller R.: Wahrnehmung und Nutzung kultureller Ökosystemleistungen in der Schweiz
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- 21.9 Stroebele M.F., Tobias S., Hunziker M.: Spatial demands of society
- 21.10 Tiefenbach M.: Alpkorporationen traditionelle Institutionen nachhaltiger Landschaftsentwicklung. Das Beispiel der Bergschaften Grindelwalds

What makes a landscape healthy? GIS-assisted mapping and other approaches to better understand the meanings of nearby recreation areas for a healthy society

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Understanding the determinants and underlying mechanisms of everyday near-to-home outdoor recreation behaviour in postindustrial Western European and North American countries is useful for developing public health-related urban designs – designs that encourage physical activity or mental recovery – and landscape management practices such as hand-ling recreational demands or user conflicts.

In Switzerland, similar to Germany and Austria, nearby outdoor recreation areas

(NORAs, German *Naherholungsgebiete*) are environments of agricultural lands, forests, rivers, and lakes that are located around settlements (towns, cities, villages) and are within walking or cycling distance of homes in the community. The land is managed by its private or public owners, and the general right of way makes forest and country paths accessible to the public.

Many researchers have addressed issues related to nearby nature (e.g. Bell, Simpson, Tyrväinen, Sievänen, & Pröbstl 2009; Degenhardt, Frick, Buchecker, & Gutscher 2011; Nilsson et al. 2011), but the empirical evidence remains insufficient for designing intervention measures and for spatial modeling.

Moreover, recreation managers have limited spatially explicit data on recreation potential around cities, and representative field data are expensive to gather.

In this presentation I will sketch different approaches that we have applied in the last eight years at Swiss Federal Research Institute WSL and insights gained through them in order to better understand the different benefits of nearby outdoor recreation areas for people. A GIS model (see Figure 1) will be presented that we (Kienast et al 2012) have developed to support the identification of hot spots for nearby recreation based on representative surveys.

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People's declared presence (DP)



Figure 1. Maps of people's declared presence (DP) and prediction thereof using a GLM Poisson model (1 square = 1 km2). As examples we show the results for the study sites St. Gallen and Langenthal and the socio-demographic groups "all", "young (18–40)", "old (61–80 years)" (from Kienast et al. 2012, p. 395).

21.2

Depicting community perspectives: repeat photography and participatory research as tools for assessing environmental services in Sagarmatha National Park, Nepal.

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Recent intense efforts have been made to provide a scientific basis for using environmental services as a conceptual tool for enhancing conservation and improving the livelihoods of people in mountain protected areas (MtPAS). To date, little attention has been paid to participatory research, particularly the perceptions and concerns of local people as environmental service users and providers. Such perspectives can offer a direct route to better understand the complex interplay between mountain ecosystems, environmental services and the determinants of human well-being.

Repeat photography has a long history in geographical fieldwork but has only recently become popular as a qualitative research tool. This study uses a novel application of repeat photography as a diachronic photo-diary to examine local perceptions of change in relation to selected environmental services in Sagarmatha (Mt. Everest) National Park. Results show a broad consensus among local people regarding adverse changes to important environmental services in the UNESCO World Heritage Site, particularly protection against natural hazards such as landslides and floods.

We argue that the methodology employed in this paper has the potential to complement biophysical ecosystem assessments in MtPAS, especially since assessing environmental services, and acting upon that information, requires integrating the knowledge of diverse stakeholders, recognizing power imbalances, and grappling with the complexity of social-ecological systems.

Keywords: environmental services, repeat photography, perceptions, Sagarmatha National Park, participatory research, qualitative methodology, photo-interviewing, UNESCO World Heritage Site, mountain protected areas, conservation, livelihoods, human well-being.



Figure 1. The pathway from ecosystem function and processes to human well-being (adapted from TEEB 2010) used in the broader research project.



Figure 2. Perceptions of change in relation to selected ES in SNPBZ; the Likert assessment mean, 75% quartile, and ranges are shown N=46).

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21.3

Photovoltaikanlagen an Lawinenverbauungen: Wahrnehmung und Akzeptanz verschiedener Bevölkerungsgruppen

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In der Schweiz existieren rund 600 km Lawinenverbauungen, die sich in der Regel zwischen 1800 und 2500 müM befinden. Mit zwei Pilotanlagen soll getestet werden, ob sich Lawinenverbauungen als Träger für Photovoltaikanlagen und damit zur Produktion von Solarstrom eignen. Projektstandort ist Bellwald (VS), Skigebiet Mittelstation 2000 müM. Bellwald präsentiert sich als Tourismusort und ist Teil der Energieregion GOMS.

Der Fokus unseres Projektes ist auf die gesellschaftlichen Aspekte gerichtet. Die Leitfrage lautet: "Wie reagiert die Gesellschaft auf Photovoltaikanlagen an Lawinenverbauungen?". Das Ziel ist, die Relevanz der Anlagen und ihre Wahrnehmung als bauliche Massnahme beziehungsweise zusätzliche Technik in der Landschaft zu ermitteln. Auch soll der Einfluss dieses Pilotprojektes auf das Image der Region untersucht werden.



Foto 1./2. Pilotanlage EnAlpin, Juli 2012

Die Reaktion der Gesellschaft wird mittels qualitativer Methode erfasst; gleichzeitig wird die bauliche Entwicklung der Photovoltaikanlagen mit Foto-, Film- und Audioaufnahmen dokumentiert. Die empirischen Erhebungen wurden in Form semi-standardisierter Interviews durchgeführt. Insgesamt wurden vier Befragungsgruppen gebildet: Politiker, Techniker, Einheimische und Touristen. Die Erhebungsphase endet Mitte September 2012 und die Analyse der Daten soll im November 2012 zum Abschluss kommen. Die erhobenen Interviewdaten werden den Bereichen "Wissen" über das Projekt, "Meinung" über das Projekt und "Nutzen" des Projektes, lokal und regional, zugeordnet. Innerhalb dieser Bereiche wird die Reaktion der jeweiligen Gruppen auf vier Ebenen untersucht: 1. Energiegewinnung, 2. Standort/Image, 3. Ästhetik, 4. Gruppenidentität.



Foto 3./4. Pilotanlage Lehmann, Juli 2012

Die geführten Interviews innerhalb aller Befragungsgruppen deuten darauf hin, dass die Photovoltaikanlagen auf hohe Akzeptanz stossen werden. Ihr Eingriff in die Naturlandschaft wird als gering bewertet, vor allem weil die Lawinenverbauungen bereits vorhanden waren. Daher werden die Photovoltaikanlagen nicht als abrupter Natureingriff gesehen. Die neue Nutzung der Lawinenanlagen, die bereits als Eingriff in die Natur wahrgenommen wird, betrachten die Befragten als positiv. In den Interviews wurde mehrfach von "Doppelnutzung" und "Aufwertung der Lawinenböcke" gesprochen. Die systematische Analyse der Daten wird aufzeigen, wie die Anlagen auf den verschiedenen Ebenen gewertet werden und wie sich die Gruppen darin unterscheiden. Die Ergebnisse werden erlauben, Schlussfolgerungen hinsichtlich des Mehrwertes und der Grenzen der Akzeptanz von Photovoltaikanlagen auf Lawinenverbauungen aus der Sicht der Gesellschaft zu ziehen.

Schlüsselwörter: Lawinenverbauung, Photovoltaikanlagen, Gesellschaft, Wahrnehmung, Authentizität, Technik in der Landschaft, Relevanz, Image.

21.4

People's perception toward externalities caused by potentially conflicting land uses. Case study of BUCHAREST cemeteries, ROMANIA

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Cemeteries play a vital role in landscape mosaics either through their importance as green spaces in urban areas (Bassa & Kiss, 2010) or through their indispensable function for urban settlements (Uslu et al. 2009). Cemeteries related with stress sources (noise, air pollution, scarcity and degradation of green spaces, insalubrity, etc.) facilitate the development of conflicts. In this respect the meaning of cemeteries depends on their association with neighboring land uses. People's interaction with cemeteries is often due to their lock over the time within residential area. This contact has favored the increase of people exposure to real or perceived problems (Patroescu et al. 2004). Understanding of people's perception has an important place in planning because it can help to recognize potentially conflicting land uses and contribute to an efficient management of the existing situation.

Originally located on Bucharest outskirts, most of Bucharest cemeteries were swallowed up after the great city expansion during the communist period (1970-1990) when tall blocks of flats were built and during the post communist period (1990-2007) when people's desire to replace the collective settlements with those individual lead to a massive individuals ones residences expansion Figure 1.

We investigated people's perception of cemetery externalities and how people evaluate cemetery location. In Bucharest, 23 cemeteries were selected for analysis. In their proximity people were interviewed in order to asses their perception toward different types of cemetery externalities. 475 questionnaires were processed using factor analysis and logistic regression. Results revealed that 58% of respondents perceive at least one environmental externality associated with cemeteries. Three perceived aspects of well being infringement were identified and described using factor analysis (environmental degradation, hygiene problems and discomfort). People perceive predominantly externalities as visual discomfort (28%) and presence of unwanted animals (23%). Logistic regression analysis indicated that distance between cemetery and people home expressed as direct visual contact, number of perceived externalities, respondents' age and some employment categories have a significant effect on explaining that people feel affected by cemetery location. 30% of people were dissatisfied with cemetery location, 58% of them feeling affected by location. 17% of people were satisfied with cemetery location, 99% of them not feeling affected by location. Considerations of people negative reactions toward cemeteries are important for conflict analysis because urban functions which provide indisputable urban benefits can be perceived as spatial conflicts due to their association with neighboring land uses. Improved management or alternative locations might alleviate the conflicts.



Figure 1 Spatial distribution of cemeteries in Bucharest city

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21.5

Wahrnehmung und Nutzung kultureller Ökosystemleistungen in der Schweiz Perception and Usage of Cultural Ecosystem Services in Switzerland

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Das Konzept der Ökosystemleistungen zeigt auf, welche Leistungen die Natur für das menschliche Wohlbefinden erbringt. Breit diskutiert wurde das Konzept in den 1990er-Jahren, mit der Publikation des Millenium Ecosystem Assessments (2005) gelangte es zudem auf die politische Agenda. Im Millenium Ecosystem Assessment wird zwischen den vier Leistungsarten "supporting services", "provisioning services", "regulating services" und "cultural services" unterschieden. Im Fokus meiner Forschungsarbeit stehen die "cultural services", die ich anhand von drei Untersuchungsregionen in der Schweiz näher analysieren werde. Im Zentrum stehen dabei die Fragen, a) was unter den "cultural services" verstanden werden kann und b) wie sie wahrgenommen und genutzt werden.

Die Wirkungsweise von den Ökosystemen zum menschlichen Wohlbefinden haben Haines-Young und Potschin (2010) in ihrem Kaskadenmodell (siehe Abb. 1) dargestellt. Für ,provisioning services' wie Trinkwasser oder Lebensmittel erscheint mir diese Darstellung sehr gut geeignet, im Zusammenhang mit ,cultural services' jedoch nicht, da kulturelle Leistungen nicht von Ökosystemen generiert werden, sondern erst durch die Wahrnehmung und Bewertung der Menschen entstehen.

Aus Sicht der Sozialwissenschaften ergeben sich in der Auseinandersetzung mit dem Konzept der Ökosystemleistungen verschiedene Herausforderungen (Fish 2011). Der Zusammenhang zwischen Ökosystemleistungen und menschlichem Wohlbefinden muss verstanden und operationalisiert werden, die Kategorie der ,cultural services' müssen weiter entwickelt werden, resp. es ist notwendig zu klären, was unter Kultur verstanden wird.

,Cultural services' existieren ähnlich wie ,die Landschaft' nicht per se, sondern sie entstehen durch Interaktionen zwischen Mensch und natürlicher Umwelt und werden durch die menschliche Wahrnehmung konstruiert. Landschaft ist ein zentraler Aspekt der ,cultural services', wobei Landschaft unterschiedliche Pole und Dimensionen der Wahrnehmung enthält (vgl. Backhaus 2010).

Am Symposium "Landscape and its meanings for society" möchte ich einerseits das Outline meines Forschungsprojekts darstellen und andererseits erste Ergebnisse vorstellen, die auf einer Bildanalyse sowie Interviews und Beobachtungen in einer der Untersuchungsregionen basieren.



Abb 1. Kaskadenmodell: Von den Ökosystemen zum menschlichen Wohlbefinden. (Quelle: Eigene Darstellung nach Haines-Young und Potschin 2010)

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Indicator-driven landscape service assessment at various geographical scales

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Recently, the concept of ecosystem goods and services (EGS) has been successfully extended to include the "notion of landscape". This means that traditional ecosystem service accounting, which is commonly done on individual parcels of land, is supplemented with contextual information of the surrounding patches. The supplementary information may include land-use, cultural elements or socio-economic properties. Ecosystem services with this type of contextual information are called landscape services. They can be delineated at different hierarchical levels and have much more planning relevance than ecosystem services on isolated patches of land. Hence the landscape service paradigm is gaining momentum in many parts of the world, and an increasing number of Environmental Agencies are adopting it as planning principle.

In the present paper we highlight the paradigm of landscape services and show how the capacity to deliver a service and the actual flow can be (1) analyzed over time and (2) mapped at various spatial levels (Fig. 1). We give examples on how the exploitation of landscape services is influenced by intrinsic and extrinsic forces and current societal trends. Several examples are presented that illustrate how trade-offs and synergies between services can be analyzed. The paper concludes with a national attempt to measure landscape services with the aid of landscape indicators (LABES indicators) to generate broad-scale multi-functionality assessments.

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21.6

A1 Mean importance score for Crop-based production by NUTS-x region in 2000



Definition of CICES service Crop based production: All eatable crops that are gained through agricultural practices

A2.1. Change of supportive land-use 1990-2000¹ for Crop-based production



A2.2 Change of degrative land-use 1990-2000¹ for Crop-based production



1 for countries where LEAC database applies

A3.1. Change of supportive land-use 2000-2006² for Crop-based production



A3.2 Change of degrative land-use 2000-2006² for Crop-based production



² for countries where GISAT 2000-2006 database applies

A4.1. Expected change of supportive land-use 2000-2030 (scenario A1)³ for Crop-based production



Percent of NUTS-x area 0-1% 1-5% 5-10% 10-20% 20-30% >30%

Percent of NUTS-x

area

0-0.1%

0.1-0.5%

0.5-1.0%

1.0-2.0%

2.0-5.0%

>5%





³ for countries where EURURALIS 2.0 database applies

Figure 1. Maps of the provisioning landscape service "crop-based production" at continental scales. The large map (upper left) shows the capacity for crop-based production. The other maps show where land-use change in three distinct periods (1990-2000; 2000-2006; 2000-2030 prediction) has a supportive or degrative influence on crop-based production (from Haines-Young et al. 2011).

Symposium 21: Landscape and its meanings for society

Die funktionale, ideengeschichtliche und sozialhistorische Substanz von Kulturlandschaften

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21.7

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Kulturlandschaften sind Nutzlandschaften; Nutzung macht die Naturlandschaft zur Kulturlandschaft. Die Natur der Landschaft spiegelt viel mehr als nur den rein handwerklichen Umgang des Menschen mit seiner Umwelt; sie spiegelt soziale Verhältnisse, Geschichte, Geschichten und Denkepochen: Agrarverfassungen, Agrarreformen (z.B. Aufteilung der Allmenden), Landnutzungsänderungen durch Marktanpassung, fehlgeschlagene Versuche (die Landnutzungsgeschichte kennt auch Moden und Nachahmungstrieb), Intensivierungsbemühungen, spiegelt antikes Wissen, Denken des Absolutismus, in unzähligen Formen das Denken der Aufklärung, frühes Nachhaltigkeitshandeln, Widerstand gegen Reformen, Demokratie und Diktatur. Die Natur der Kulturlandschaft ist komplex, divers, vielsagend und besitzt Stile. Die traditionelle Kulturlandschaft insgesamt wurde eher polykulturell genutzt; es gab oft mehrere Nutzen auf einer Fläche. Zwischen verschiedenen kulturlandschaftlichen Erscheinungsformen gab (und gibt es heute eher nur noch rudimentär) funktionale Beziehungen. Fast jede durch handwerkliche Gestaltung geprägte Landnutzungsform hat weniger kunstvolle Komplementärerscheinungen in der Landschaft hinterlassen. Am Beispiel von historischen Terrassenweinbergen, historischen Agroforstsystemen und Allmenden, resp. aufgeteilten Allmenden werden deren funktionale, ideengeschichtliche und sozialhistorische Bedeutung vorgestellt und es wird gefragt, ob und wie sie in die Zukunft transferiert werden können.

21.8 Schutz und Erhalt der Moorlandschaften in der Schweiz

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In Folge der Rothenthurm-Initiative von 1987 sind jene 89 Moorlandschaften in der Schweiz, die als besonders erhaltenswert und daher national bedeutend eingestuft worden waren, durch die Verfassung geschützt (BV 1999, Art. 78 Abs. 5). Dieser besonders hohe Schutzstatus - Moorlandschaften sind als einziger Landschaftstyp verfassungsrechtlich geschützt - soll dazu dienen, in den ausgewiesenen Moorlandschaften jene natürlichen, naturnahen und kulturellen Elemente sowie traditionellen Nutzungen zu bewahren, die den besonderen Charakter der Moorlandschaft ausmachen. Die Realität zeigt jedoch, dass dennoch viele Einzelelemente (z.B. Baumgruppen, Hecken, Streuehütten) verschwinden und Teile der Landschaft entweder gar nicht mehr (v.a. in peripherer Lage) oder zu intensiv (v.a. in Hofnähe) genutzt werden.

Wesentliche Teilziele des Forschungsprojekts bestanden darin, zum einen zu analysieren, wie es gegenwärtig um den Schutz und Erhalt der Moorlandschaften in der Schweiz bestellt ist und zum anderen Ansätze zu erarbeiten, die die oben genannten negativen Trends aufhalten bzw. verlangsamen und zum langfristigen Erhalt der Moorlandschaften beitragen können.

Zentrale Fragestellungen lauteten daher: "Werden die langfristigen Schutz- und Erhaltensziele des Moorlandschaftsschutzes gegenwärtig erreicht?"

"Wie lassen sich naturnahe Kulturlandschaften, die als erhaltenswert ausgewiesen sind, auch de facto erhalten?"

Bisher beschränkt sich der Moorlandschaftsschutz in der Umsetzung der nationalen Vorgaben weitgehend auf die Verhinderung unerwünschter grösserer Eingriffe. Die übergeordneten Ziele des Moorlandschaftsschutzes können damit nicht erreicht werden. Die bestehenden institutionellen Rahmenbedingungen (dies sind vor allem Ge- und Verbote) reichen nicht aus, um die schleichenden nicht zielkonformen Veränderungen in den Moorlandschaften zu verhindern und die Moorlandschaften langfristig zu erhalten. Institutionelle Rahmenbedingungen ausserhalb des Moorlandschaftsschutzes beeinflussen die Moorlandschaften entscheidend mit. Da der Moorlandschaftsschutz jedoch kein übergeordnetes

Steuerungsinstrument ist, kann er die Entwicklungen in den Sektorbereichen nicht mitsteuern. Die heutige Umsetzung des Moorlandschaftsschutzes erlaubt also weder, nicht zielkonforme Entwicklungen im Moorlandschaftswandel zu stoppen, noch zielkonforme Trends zu fördern. Nur Schutzmassnahmen alleine reichen somit nicht aus, um Moorlandschaften langfristig zu erhalten.

Zum langfristigen Erhalt der Moorlandschaften sind Massnahmen und Instrumente erforderlich, die zielkonformes und -unterstützendes Handeln fördern und Innovationen in unterschiedlichen Handlungsbereichen auslösen.

Innovatives Handeln auf verschiedenen Ebenen kann zum Schutz und Erhalt der Moorlandschaften beitragen. Wichtige Ansatzpunkte zur Verbesserung des Moorlandschaftsschutzes wären Innovationen in institutionellen Rahmenbedingungen. Zentral wären Innovationen auf nationaler Ebene; aufgrund des föderalistischen Systems sind jedoch auch ohne Anpassungen auf nationaler Ebene Innovationen auf kantonaler, regionaler und lokaler Ebene möglich und erstrebenswert. Auf nationaler Ebene wird empfohlen, den Moorlandschaftsschutz institutionell aufzuwerten, vom (Moor-) Biotopschutz abzukoppeln und verwaltungsintern auf höherer Stufe zu verankern sowie mit eigenem Personal und Budget auszustatten. Auf regionaler Ebene könnte ein Moorlandschaftsmanagement eingerichtet und ebenfalls mit eigenem Personal und Budget ausgestattet werden.



Abbildung 1: Die 89 Moorlandschaften von besonderer Schönheit und von nationaler Bedeutung in der Schweiz (Quelle: www.ecogis.admin.ch; angepasst von R. Tillmann).

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Spatial demands of society

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The on-going extension of the built environment continuously changes large parts of Western European landscapes. Land use planners are confronted with a multitude of different claims and demands from different stakeholders regarding the use of the landscape. The presented research project spatial demands of society investigates the needs and requirements towards landscape use and future spatial development among the general population, in order to provide a base for land use planning in (Swiss) sub- and peri-urban regions experiencing a high level of building and development pressure. Moreover, the study aims to single out thresholds of landscape change for different groups of society: many landscape developments are acceptable for different groups up to a certain level; i.e. urban sprawl or changes of the agricultural landscape might be tolerated or pass relatively unnoticed up to a certain point, at which people might decide to either move to another place or change certain landscape-related life habits. These thresholds might prove to be useful in the prevention and/or resolving of conflicts related to land use planning, especially in quickly developing rural or peri-urban environments.

Different groups of society have different claims on the landscape, based on demographic, socio-economic, socio-cultural and residential characteristics of the individual citizens. Very likely, these "spatial demands" – claims of different societal groups towards the immediate living environment and the surrounding landscape – might cause conflicts between different stakeholder groups, e.g. suburban single family home inhabitants' preference for a park-like open landscape with small-scale structures as opposed to farmers' interests in intensifying agriculture. Topics covered are: the use of landscape for work and recreational purposes, aesthetic preferences, (landscape) preferences for the residential environment, individual identification with specific types of landscape, and landscape preferences in relation to commuting, small-distance internal migration and international migration.

The study focuses on two predominantly rural and peri-urban case study regions in Switzerland: (1) The Seetal region (canton Lucerne) and the adjacent Freiamt (canton Aargau) and some municipalities of the canton Zug in the Swiss Plateau, and (2) the Linth region at the fringe of the Alps east of the Lake of Zurich, encompassing parts of the cantons of St. Gall and Glarus. Both regions include areas from more than one canton and experience strong developmental pressure both for housing and economic development. The crosscutting political borders and a high level of municipal autonomy are additional difficulties for coordinated land-use planning in Switzerland. However, in both study regions, municipalities have agreed on common mission statements for spatial development.

The initial, inductive phase of the research project consists of a literature review and a series of interviews with local land use planning exponents. In the main phase of the project, the population's landscape preferences and spatial demands are assessed in a survey. The questionnaire is based on a literature review (theory) and the outcomes of expert interviews in the study regions (practice). The survey will cover a representative sample of the Swiss population, with an additional sample in the two study regions. Finally, the results of the survey will provide insight in the Swiss population's spatial demands and preferences, and possible conflicts and thresholds delimiting "acceptable changes" for different population groups. Moreover, the study will also compare experts' and the population's assessment of landscape chance, and contribute to the synthesis of the overarching WSL research project "room for people and nature." The study is in its initial phase. Therefore, the presentation does not yet present empirical results, but concentrates on the research design and provides a base for the discussion of the further research process.

Alpkorporationen – traditionelle Institutionen nachhaltiger Landschaftsentwicklung Das Beispiel der Bergschaften Grindelwalds

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Die Alpenlandschaften prägen in der Schweiz nicht nur ein grosses Gebiet, sie sind ebenfalls zentrales Element der schweizerischen Identität und erfüllen auch vielseitige gesellschaftliche Funktionen. Vielfalt ist eines der wichtigsten Merkmale der alpinen Landschaften und Lebensräume. Insbesondere Alpkorporationen, Alpgenossenschaften, Bäuerten und Bergschaften tragen auf lokaler und regionaler Ebene zur Vielfalt der naturräumlichen und kulturellen Unterschiede bei. Gleichzeitig steht die Berglandwirtschaft, wie ganz allgemein die Landwirtschaft, unter dem Einfluss der fortschreitenden Globalisierung und Liberalisierung. Standortnachteile verstärken sich und stellen die Erfüllung der gesellschaftlichen, wie auch der ökologischen, ökonomischen, kulturellen und sozialen Funktionen der Berglandwirtschaft in Frage.

Grindelwalder Bergschaften sind das Gefüge einer mittelalterlichen Rechtstradition (Urkunde 1404 und Taleinungbrief 1538). Nicht der Besitztum allein, sondern die Gemeinschaft im gemeinsamen Handeln und Entscheiden ist das Besondere. Die Aufrechterhaltung der alten Ordnung, der Taleinung (Taleinung ist eine Alpgenossenschaft und umfasst die sieben Alpen der Talschaft Grindelwald, ihre Rechtsgrundlage ist der Taleinungsbrief), ist die oberste Pflicht des Einzelnen, bis zur Selbstaufgabe der eigenen Interessen. Begründet werden die Bergschaften mit dem Zweck, eine geordnete und nachhaltige Bewirtschaftung der sieben Alpen der Talschaft Grindelwald zu verfolgen, d.h. eine an die Landschaft angemessene Bewirtschaftung zu führen und dabei die festgelegten *,gseyeten*' Besatzungsgrössen zu respektieren. Sie drücken ein exaktes Wissen über ökologische Zusammenhänge aus, was als Erfahrungswissen seit Generationen weitergegeben wird. Flächenmässig gehören Scheidegg, Grindel und Wärgistal zu den grössten drei Bergschaftsgebieten, gefolgt von Itramen, Bach und Bussalp. Holzmatten hat das kleinste Bergschaftsgebiet. Ihr oberstes Entscheidungsorgan ist die Taleinungskommission. Die Verantwortung für die Organisation der Alpbetriebe und die Durchführung der Alparbeiten tragen Besetzer- und Hagpfander. Grindelwalder Bergschaften sind in der Hauptsache gekennzeichnet

- durch den gemeinsamen Besitz mit einem gemeinsamen Zweck (Gemeinschaftsalp),
- durch die Verbundenheit des Besitzes von privatem Talboden mit der gemeinschaftlich gepflegten und genutzten Alp (Bergrechtsregelung),
- durch ein mittelalterlich gelebtes Rechtsgefüge in einer modernen Zeit (Taleinungsbrief) und
- durch den Umgang mit bestehenden und neuen Gegensatzpaaren als konzeptionelle Grundlage für das Arbeiten und Leben in der Gemeinschaft

Der Umgang mit Gegensätzen verdeutlicht eine enge Koppelung aufeinander angewiesener, gleichgewichteter Paare sowie ihr Zusammenspiel und ihre Abhängigkeiten. Für die Nutzung und Pflege der Alpgebiete wirken sie stabilisierend, verlangen jedoch die Auseinandersetzung mit neuen und anderen Bereichen.

In der Gemeinde Grindelwald nehmen die Bergschaften als grösste Land- und Waldbesitzer eine zentrale Stellung sowohl für die touristische als auch für die landwirtschaftliche Entwicklung in der Gemeinde beziehungsweise der Region ein. Auf ihrem Terrain spielt sich heute der Sommer- und Wintertourismus hauptsächlich ab. Ihre Nutzungs-, Unterhalts- und Pflegearbeiten tragen zur Erhaltung der ökologischen Stabilität einer intakten und vielfältigen Kulturlandschaft und eines attraktiven Erholungsraumes zugunsten unserer Gesellschaft bei. Durch ihre Verbundenheit mit der Bergland- und Alpwirtschaft leisten sie einen wichtigen Beitrag an das öffentliche Gut "Landschaft" im Alpenraum.

Bergschaftsmitglieder leben und handeln innerhalb der Bergschaft in unterschiedlich spezifischen Feldern. In all diesen wird der Kollektiventscheid vor das individuelle Interesse gestellt. Dieses übergeordnete Rechtsgefüge, der Taleinungsbrief, ist ein kulturelles Gut. Dieses Gut ist zwar materiell übertragbar, aber nicht die damit verbundene, gezielte Umsetzung, weder das langjährige lokal verankerte Erfahrungswissen noch die damit verbundene Geschichte. Tagwann bietet Ort der Identifikation mit einer alten, vertrauten und tief verwurzelten Umgebung, wo seit Generationen eine wiederkehrende Gewohnheit, die durch die Art und Weise der Bewirtschaftung der Alpen notwendig ist, gepflegt wird.

Innerhalb dieser gemeinschaftlichen Arbeit erhalten Bergschaftsmitglieder durch ihre sozialen Positionen und ihren unterschiedlichen Verfügungsmöglichkeiten über die verschiedenen Arten von Ressourcen (kulturelle, soziale, symbolische,

ökonomische Kapitalien) vielseitige Funktionen. Ökonomisches Kapital garantiert innerhalb der Gemeinschaft keine Machtstellung. Von grosser Wichtigkeit innerhalb der Gemeinschaften sind jedoch die Verfügbarkeit von kulturellem und sozialem Kapital. Sie haben mit ihren Wirkungsbereichen und ihrem gezielten Einsatz in der Nutzung, für die Pflege und Erhaltung der Landschaft eine wichtige gesellschaftliche Bedeutung. Sie leisten im sozialen, im kulturellen und im ökologischen Bereich einen wesentlichen Beitrag zur Aufrechterhaltung, zum Weiterleben und zur –entwicklung von Traditionen, Ritualen und tragen insgesamt zu einer Landschaftsqualität und damit zu einer lokalen und regionalen Identität bei.

Bergschaften mit ihren kulturellen, sozialen und ökologischen Ressourcen leisten nicht nur wichtige Beiträge an die lokale und regionale Kultur, ebenso leisten sie einen wesentlichen Beitrag an die lokale und regionale Wirtschaft. Sie pflegen zusätzlich zum kulturellen und sozialen Kapital auch das ökonomische Kapital "Landschaft". Durch ihre alljährlich wiederkehrenden Tagwannarbeiten grenzen sie Verbuschung, Verwaldung und Murgänge ein, sichern Zufahrtswege und Wasserläufe, pflegen marginale Nutzflächen und tragen so entscheidend zur Aufrechterhaltung einer attraktiven und ästhetisch wertvollen Landschaft bei. Tourismus, lokale und regionale Bevölkerung, wie auch das Gewerbe profitieren davon. Mit ihren landschaftsbezogenen Arbeiten stellen die Bergschaften auch Grundlagen für weitere Wirtschaftsformen (in Grindelwald der Tourismus) zur Verfügung und sind zudem Träger eines starken Regionenbezugs. Die Erhaltung und Stärkung der Berglandwirtschaft sowie der traditionellen Alpkorporationen – der Bergschaften – ist daher für die Landschaft Grindelwalds, die Landschaft der Region Berner Oberland-Ost und möglicherweise auch für weitere Alpengebiete von grosser Bedeutung. Für die Gemeinde Grindelwald ist diese traditionelle Einrichtung – die Taleinung – von unschätzbarem Wert, nämlich ein kulturelles und ökonomisches Gut mit aktuellem Gültigkeitswert.

In einer Zeit, in der die Menschen die Landschaft erschliessen und nutzen, um den entwickelten gesellschaftlichen Bedürfnissen gerecht zu werden und gleichzeitig ungestörte, erholsame Landschaften, in denen sie ihre Bedürfnisse nach ästhetisch-emotionaler Ortsbezogenheit ausleben können, aufsuchen, erhalten Alpkorporationen eine wichtige Bedeutung für eine längerfristig gesicherte Kulturlandschaft. Angesichts der Bedeutung, die Alpkorporationen auf lokaler und regionaler Ebene für die Kulturlandschaft haben, sollten diese in Wissenschaft und Praxis stärker berücksichtigt und unterstützt werden.

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22. Symposium in human geography

Juliet Fall, Bettina Fredrich, Olivier Graefe, Pia Hollenbach, Olivier Ejderyan, Martin Müller, Carolin Schurr, Karin Schwiter, René Véron

TALKS PART I: KNOWLEDGE, POWER AND DECISION-MAKING IN ENVIRONMENTAL POLICY AND MANAGEMENT:

- 22.1 Alms, Eric: Local impact of global conservation governance in Chinese national parks
- 22.2 Johnson, Leigh: Index insurance, climate vulnerability, and risk-bearing subjects
- 22.3 Kayani, Saheeb: Mangla dam raising project (Pakistan): general review and socio-spatial impact assessment
- 22.4 Müller, Martin: How natural disturbance triggers political conflict: bark beetles and the meaning of landscape in the Bavarian Forest
- 22.5 Rattu, Paola: Urban Water in French Switzerland: a Neoliberal Ecological History
- 22.6 Tait-Jamieson, Tim: The hunter and the wolf: Environmental ethics in Switzerland
- 22.7 Zimmer, Anna: Wastewater governance practices and contestations in Delhi's informal settlements

TALKS PART II: PERFORMATIVE GEOGRAPHIES (PAPER AND PANEL SESSION)

- 22.8 Lévy, Bertrand & Gal, Maria: City and Literature
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Symposium 22: Symposium in human geography

Local impact of global conservation governance in Chinese national parks

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Though the notion of conserving nature can be traced throughout history and across cultures, the institutionalization and internationalization of nature conservation has been shaped mostly by Western discourse (Jepson & Whittaker 2002). Today, conservation areas such as national parks are globally recognized as an integral element of nature conservation and a prime destination for nature-based tourism. This recognition is due, at least in part, to the propagation of conservation and tourism concepts through, for example, the UNESCO's designation of Natural Heritage sites and WWF initiatives encouraging sustainable nature tourism, contributing to the establishment of conservation areas worldwide (Backhaus 2005).

As more and more Chinese gain access to the benefits of economic development, the demand for travel opportunities is increasingly falling on China's relatively new national parks (Lew 2003). Consequentially, there is a potential for ecological concerns to give way to political and economic motivations as local governments and stakeholders clamor to attract the wealth and recognition associated with the growth of the tourism industry.

Research on national parks in China has thus far been limited mostly to the work of natural scientists, and mostly in Chinese language, so that there is a significant research gap when it comes to the social, political and economic implications of nature conservation and tourism in Chinese national parks.

Yet the designation of national parks is arguably an entanglement of competing political, economic and social interests, with potentially dire ecological consequences. National parks thereby become the battleground of diverging interests where actors and agencies struggle over power, influence, and entitlements (Peet & Watts 2004). Large intergovernmental organizations and NGOs have, in cooperation with the national government, contribute to conservation and tourism planning, such as WWF's ecotourism and panda conservation projects. Through such involvement, conservation organizations can have considerable influence concerning conservation policy, with significant social and economic consequences for rural areas, including, as in the case of Jiuzhai Valley National Park, the:

- impact of conservation regulations (such as controls on yak herding, harvesting of herbs for Chinese medicine or forest use),
- displacement of people or even entire villages in the name of conservation,
- way the economic benefits of national park activities (such as the revenues from tourism) are shared between people, and
- links between poverty and national parks.

Behind all of these is the issue of the power of ideas about nature to dictate the way conservation is thought about and practiced and the negotiation of power between stakeholders.

In the proposed talk at the Swiss Geoscience Meeting in Bern I would like to elaborate on the local impact of global conservation governance in Chinese national parks, largely based on insights gained through upcoming fieldwork in Jiuzhai Valley National Park in Sichuan Province, China.

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Symposium 22: Symposium in human geography

Index insurance, climate vulnerability, and risk-bearing subjects

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22.2

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In the last decade, a growing number of efforts have been made to insure the weather-related production risks of rural agricultural and pastoral households in the global South via microinsurance contracts linked to weather indices. Such index insurance products are increasingly championed by development agencies, NGOs, and (re)insurance companies for their capacities to "crowd-in" credit and productive risk-taking, increase food security and climate change "resilience". This paper traces how and why the index insurance field has emerged as an *au courant* development intervention since 2005. It then argues that this constellation of index insurance pilot projects must be understood as set of experimental practices creating not only new objects of market exchange – weather indices – but also new, risk-bearing subjects to consume these objects.

Focusing on the process of market creation highlights not only how specifically bounded weather risks must be identified and framed as uniquely ameliorable via financial channels, but also how the economic institution of private insurance depends upon the iterative creation of individuated subjects. This financial consumer identifies "risks" as such, and imagines them as transferable – ergo alienable – by means of a market exchange. The marketing of such insurance-as-development schemes demonstrates a central irony of individuated risk transfer through market mechanisms: project designers often find themselves hoping for seasonal climate conditions to worsen, in order to trigger payouts to insured clients and encourage non-buyers to purchase coverage in the future. This paradox suggests that the structure of individual insurance is a fundamentally inadequate – and at times even counterproductive – technique for reducing the climate vulnerability of rural households.

22.3

Mangla dam raising project (Pakistan): general review and socio-spatial impact assessment

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Pakistan has recently successfully completed the raising of Mangla dam, a major water works system on river Jhelum. This project has restored and even enhanced the storage capacity of Mangla dam reservoir. (The dam is located 115 km southeast of Islamabad at Mangla. It is physically located both in the state of Azad Jammu and Kashmir and the province of Punjab (district Jhelum). The dam can be reached by traveling towards north (about 16 km) from Dina town on the Islamabad-Lahore G. T. road, a section of N-5.)

The towns located on the periphery of the reservoir that are being directly affected as a result of the raising project are Mirpur, Islamgarh, Chaksawari, and Dudial. Mirpur is the largest one, well planned, and the most populated city of the state of Azad Jammu and Kashmir. Other three towns are relatively small and their growth is rather unplanned with living standard inferior to that of Mirpur. The population in all towns including Mirpur is a mix of people from different parts of the erstwhile princely state of Jammu and Kashmir (now administered by Pakistan and India separately) and also those who have settled here after coming from adjoining areas of Punjab due to family, business or any other social/personal reasons. The present day city of Mirpur replaced the old Mirpur town that was inundated when Mangla dam was constructed during 1960s. The new Mirpur that was developed is far better in civic amenities as compared to the old one. Generally resettling in new Mirpur was a pleasant experience for most of the population as it brought with it an improved standard of living and better opportunities. In addition to this, as agreed in the resettlement plan, work permits to displaced people were to be provided for UK by the government of Pakistan. Many people availed this opportunity, they found

work, established themselves, and later not only called for their families but also helped their kinship to travel and settle in UK. These people invested in their home towns by starting businesses and contributed towards development of the whole region. As a result, the building of the dam has been a life changing experience for many displaced people especially those from Mirpur. The contribution of these immigrants has a lot to do with acceleration of urbanization process not only in Mirpur but in the entire state of Azad Jammu and Kashmir (WAPDA 2003a). For the people who were given land as compensation in the provinces of Punjab and Sindh, the experience has been mixed. Many of these people sold their land and returned to areas near their inundated home towns as they were unable to amalgamate with the native communities of remote places where they were relocated (Sheikh 2007).

While planning the resettlement of people for raising project, all lessons learnt from the previous relocation were taken into consideration. All issues were handled with great respect for human sentiment. An unprecedented compensation package has been offered to the affected population and the agencies involved with the project took every step possible to ensure fair play and transparency in their operations. The initial negative response of the affected people was addressed through confidence building measures adopted by Water and Power Development Authority (WAPDA) and firm assurances from the government (WAPDA 2003b). WAPDA has acquired all affected land of the raising project (15,783 acres). On the side of the province Punjab, this land is mostly barren where as on the state of Azad Jammu and Kashmir side although no urban land was acquired yet large populated areas have been affected. The number of houses and other buildings (including shops, schools, basic health units/dispensaries, mosques, shrines etc.) affected by this project is around 8,000. For the land lost by people, WAPDA has agreed to allow the owners to use what they owned during winter (when reservoir waters recede) for agriculture. For houses the replacement cost and an additional 10% was paid along with the provision for owners to take all salvageable material. In case of shanty houses, PKR 300,000 were paid as replacement charges to every resident family (WAPDA 2003a).

In light of previous resettlement experience and through scoping sessions carried out by WAPDA's socio-ecological consultants, the displaced people have been resettled in areas closer to their native towns. A new city has been planned/developed near Mirpur for a population of 30,000 (WAPDA 2003b). This city includes all amenities of a modern town. Four new towns have also been planned to accommodate affectees who would like to relocate to a site that lies in close vicinity of the village/town they used to live in. People willing to have a house in the new city have to pay for the piece of land they wish to acquire. The refugees (of the border conflicts between Pakistan and India) previously living on WAPDA acquired land will be given small residential plots without any charges. In order to address grievances of some old affectees of 1960s displacement, compensation amounts will be paid to about 10,000 families. Over all, the cost of compensation and relocation is about 55% of the total budget allocated for the project as estimated by WAPDA. The restored storage capacity of Mangla dam reservoir will help Pakistan's agriculture. It certainly contributes towards sustaining and improving the livelihoods of thousands of farmers in areas that are irrigated by this water. If the resettlement program as envisaged by the government is successfully carried out, the affected people will be rehabilitated in a short span of time. There is no price for natural feelings of affection of a person for his or her native land, but the suffering can be reduced if there is hope for future prosperity. Renewed economic activity, return to normalcy, and improved standard of living accompanied with opportunities for progress will help the relocated people to settle in their new lives.

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How natural disturbance triggers political conflict: bark beetles and the meaning of landscape in the Bavarian Forest

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22.4

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The incidence of natural disturbance in forests is increasing globally as a consequence of global warming. The concomitant large-scale transformation of landscapes can have profound social impacts and trigger political conflict that interferes with resource management. This paper explores the link between landscape transformations and political conflict using the example of the bark beetle epidemic in Bavarian Forest National Park, Germany. For a significant part of the local population, the bark beetle represented a threat to their homeland and the post-disturbance landscape of dead wood reflected the dominance of outside interests in land management. This resentment sparked the formation of a local political movement, which was successful in pressing for changes in the current land management policy that were based on the ideal of a green forest landscape that needed to be protected by human intervention. An alternative interpretation of the post-disturbance landscape underpin the protracted political conflict over the appropriate management of natural disturbance that has been smouldering for more than 20 years. The article concludes that it is vital to understand the cultural meaning of landscapes before adopting a disturbance management policy in order to avoid paralysing political conflict and social unrest.

Keywords: natural disturbance, conflict, identity, forest, landscape, protected area



Fig. 1. Location, zonation and dead wood areas in Bavarian Forest National Park



Fig. 2. The area between the Lusen (foreground, right) and the Rachel (background, left) in Bavarian Forest National Park is most severely affected by the bark beetle.

So vernichtet die Nationalparkverwaltung unsere Heimat



Fig. 3. "This is how national park management is destroying our Heimat. From monument to stigma": part of the campaign in favour of controlling the bark beetle. (source: Handlos, 2007, p. 47)

Urban Water in French Switzerland: a Neoliberal Ecological History

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Since 1980s, the triumph of neoliberalism has heterogeneously (Brenner & Theodore, 2002) modified the perceptions and the political practices. Water is not an exception: it is an "uncooperative commodity" (Bakker, 2005: 546), and the different ways of managing it are inserted in specific governance styles and contribute to construct them forming what Swyngedouw (2009) has called the "hydro-social cycle".

Swiss example illustrates the fact that water distribution infrastructures are parts of specific socio-political constructions, as public utilities and as "power devices" in a Foucaldian sense. In fact here the water distribution infrastructures can be conceptualized as tools for bodies disciplination (cf. Foucault, 1993, 1997) but also as instruments for the construction of neoliberal governmentalities (cf. Foucault, 1979, 1988, 1991).

In the French part of Switzerland, the management of water and the diffusion of a set of values linked with sustainability proceeded without big upsets since the 1980s and until the 2010s (cf. Luis-Manso, 2005; Pflieger, 2009).

This research aims understanding how and why in French Switzerland big and sudden changes were absent from the landscape of water utilities management, even though neoliberalizations were taking place in other sectors (cf. for instance Burkhalter et al., 1999; Mach, 1999, 2002) and the quantity of consumed water diminished (Pflieger, 2009).

Research was conducted through a historical and sociological approach focused on discourse analysis. Discourse linked to water distribution in French Switzerland has been reconstructed from the archives of the newspaper "La Gazette de Lausanne – Le Temps" for the period 1980-2010. Discourse analysis has been used to identify users' perceptions of water utilities and of the main explicit and implicit political issues linked to water during this period.

Neoliberal governmentality postulates a fundamental role for rationality: this research shows that taking into account this rationality is essential for the success of neoliberal policies. In addition, this research indicates a growing influence of international arenas' discourses on local ones.

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22.6

The hunter and the wolf: Environmental ethics in Switzerland

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In many western industrial societies, recreational hunting (also known as sports hunting) is a contested and controversial issue. This controversy stems from tensions over contrasting moral views of how humans relate or rather should relate with the natural world. Moral questions that concern the natural environment are often dealt with within the broad body of work known as contemporary environmental ethics.

The purpose of this study was to attempt to understand and describe the relationships hunters have with the natural world through the lens of contemporary environmental ethics. To achieve this, the practice of hunting, concepts of nature, and the relationships that Swiss hunters have with the natural environment, with the animals they hunt, the returning wolf, and the morality embedded in these topics were analysed. Results showed that hunters describe hunting as a complex activity, the kill (which hunting is often reduced to outside of hunting circles) being just one of many aspects.

The results further indicated that 'nature' carries a high level of importance for these hunters, so much so that they often refer to themselves as 'nature lovers'. This, paired with the type of action hunting is, reveals a complex and somewhat paradoxical human-nature relationship. Hunters seem to simultaneously love nature as well as kill it. Comparing the hunters' descriptions of hunting and the description of their relationship with the natural environment to the different perspectives of environmental ethics, it transpires that their ethic fit most closely with a weak anthropocentric environmental ethics perspective.

Following on from this, the continued existence of hunting in Switzerland, despite numerous criticisms, seems primarily based on the role that hunter's play in the protection and management of the natural environment. The acceptance of hunting on these terms reveals certain features of human-nature relationships. Generally in society there is a perception that we as people should be seen as stewards and, that we are in charge of protecting and managing the natural environment. This is an asymmetric relationship that seemingly separates society from nature and contains aspects of domination, submission and arrogance over nature. In this context, the hunters of Switzerland reside in a very interesting place. They are both, in a physical and in a symbolic sense, a key feature within important societal discussions that surround our moral and physical relationships to the complex and often difficult to tie down thing that we call *nature*.

22.7

Wastewater governance – practices and contestations in Delhi's informal settlements

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Waste water governance presents a major challenge in India's cities and megacities. High rainfall variability, partial sewer networks, and waste water discharge through often dilapidated and silted storm water drains lead to impracticalities of daily life, health hazards, and environmental pollution, among other problems. Mostly located in the blanks of the sewer map, exposure to waste water is especially high in informal settlements. As everyday lives get affected, governing the waste waterscape becomes a perpetual negotiation process between local bureaucrats, politicians and residents. Against this background, the presentation, drawing on my PhD thesis, investigates how governance processes produce the waste waterscape, understood as a social, constructed and material space. To better grasp the effect of power in governance, Foucault's governmentality approach is introduced. With its help, practices of waste water governance are placed at the centre of analysis. The empirical analysis focuses on two types of informal settlements of Delhi: a squatter settlement and a semi-legal area built in contradiction to the Master Plan (Unauthorised Colony). Results show that waste water is governed through power-laden processes that are predicated on 'Othering' certain groups, labelled as less clean, less ritually pure, or less hygienic. In Delhi, residents of informal settlements are part of these groups, as their waste waterrelated practices are characterised as highly problematic and in need of change. Yet, while squatters are not invited to participate in governance processes, inhabitants of the Unauthorised Colony are seen as potential partners in governance by the government. Both groups, however, have very limited opportunities to participate in framing problems of urban governance.

City and Literature

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The purpose of our presentation is to expose our SNF interdisciplinary research joining geography and literature. The first part of the talk will state the epistemological issue of considering the city as a literary expression. The term of city implies for us geographers and literary critics spatial relations replacing human beings at the center of the topic. Theoretically, this corresponds to the humanistic turn in human geography implying notions such as lived space (Lebenswelt), the experience of space, topophilia, topophobia...

There are several ways to deal with this theoretical question in a geographical perspective as well as in a literary one: semiotical and linguistic, i.e. formalistic, structural methods, or thematic content analysis. These two dimensions, form and substance, are complementary and to be analysed alternatively.

Our project focuses on few cities depicted by writers, as Balzac's Paris or Dostoevsky's St-Petersburg. There have already been numerous works on this subject, like the recent analysis of the radical geographer David Harvey (Paris, Capitale de la modernité 2012). Our approach focuses on a different perspective: it is to work on the literary representation of the city as a weaving of different caracter's points of vue. The text is considerated as a construction that helps the critic to catch the different meanings that the city can produce at the same time. It enables the geographer to capture the thickness of the urban space translated in literature by the writer.

Another part of the research is to consider one city, Geneva (XIXth-XXIth century) as depicted by several authors, several kinds of texts (from travel writing to imaginative literature), i.e. historical and cultural cross-representations. In this letter perspective arise different cultural representations depending on the national-linguistic code of each writer (for instance Hispanic, Italian, French,...), as well as on different historical periods.

In conclusion, our presentation will emphasize on the difficulties of interdisciplinary research (geography/literature) considering that these two fields use the same concepts with different meanings.

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22.8





Figure 1. Dostoevksy, Balzac, Paris, Geneva, Prague

22.9

Performative Geographies

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Theories of performance and performativity have garnered considerable attention within critical human geography since the mid-1990s. The concept of performativity has turned into an important source of inspiration for geographers working on issues as diverse as bodily practices (Longhurst 2000), questions of (gendered, sexualised and racialised) identity (Hubbard 2000; Mahtani 2002; Thomas 2008), homelessness in the city (Cloke et al. 2008), identity performances in workplaces (McDowell 2008, 2009), the performativity of markets (Berndt and Boeckler 2011a, 2011b, 2012) and the performativity of research itself (Gregson and Rose 2000; Pratt 2000).

By now, 'Butler's model of performativity has provided food for thought for many geographers' (Mahtani 2002: 427) and can look back at a 'long and deservedly successful journey' (Thrift and Dewsbury 2000: 413) in human geography. Yet it is only within the past few years that performative theory has made significant inroads within the German-speaking geography community (Boeckler/Strüver 2011, Dirksmeier 2009).

Recent scholarship exploring the performativity of identity formation, and spatial inscription is beginning to rethink the ways in which states, institutions, the market and communities are constructing and contesting political, economic and social spaces, discourses, and practices.

This session will bring together scholars working on the interrelations of performativity and space by offering a space for discussion of key texts in performative geographies. The discussion will turn around the following questions:

- Theoretical implications of performativity for critical geographic research •
- Historical or contemporary case studies that address questions of performativity and space
- The interrelations between theories of performativity and other geographic theories
- Critical reactions to the use of performative theories in critical geographic scholarship

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