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22. Special symposium in honor of Daniel Bernoulli & Albert Matter

Karl Föllmi, Fritz Schlunegger, Helmut Weissert

Conférence universitaire de Suisse occidentale (CUSO)
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22.1

Sediment budgets and fluvial drainage at mountain fronts; examples from the Pyrenees, Alps and Apennines

Philip A Allen

Department of Earth Science & Engineering, Imperial College, South Kensington Campus, London SW7 2AZ, UK

The treatment of the transfer of mass at the Earth's surface, from source to sink, as a bulk diffusive process over geological time scales permits the reconstruction of ancient sediment discharges from mountainous source areas and promotes an understanding of the tectonic and climatic driving mechanisms for long-term landscape dynamics. One of the important aspects of landscape dynamics is the nature of the drainage paths of alluvial rivers and specifically whether they flow longitudinally along the strike of the mountain belt, or transversely across the strike. The routing of sediment towards foreland basin systems and the preservation of stratigraphy in wedge-top and foredeep depocentres, depends on the balance between the sediment supply, which can be modeled as a number of point sources, and the spatial and temporal variations in tectonic uplift and subsidence controlling accommodation.

Frontal zones of mountain belts may consist of an array of regularly spaced anticlines separating narrow wedge-top basins, typically with low sediment discharges and low surface mean slopes, such as the northern Apennines. Early longitudinal sediment routing (Oligo-Miocene) has been replaced by transverse drainage, as seen for example in the Marche region. Other mountain belts are typified by a very narrow depositional wedge-top, with steep average surface slopes, high sediment discharges and a well-developed foredeep, such as the Alps of Switzerland. The mountain front zone is characterized by regularly spaced transverse fan systems such as the Napf and Hörnli. The southern Pyrenees show a diachronous east-to-west transition from longitudinal systems flowing along fault-controlled wedge-top troughs to late-stage transverse sediment routing systems that buried tectonic structures. These various possibilities are shown to reflect the balance between sediment discharge and tectonically generated accommodation.

A generic model is presented that shows how the slope-related sediment discharge from mountain catchments is estimated using a bulk diffusivity based on the length of fluvial concentrative flow. The sediment supply is delivered to depositional basins with spatial distributions of tectonically generated accommodation, which allows solutions of a 2-dimensional volumetric sediment budget for combinations of sediment discharge, depositional length and accommodation. A spin-off benefit is that we are able to make predictions of the regional trend in grain size, or alternatively, to invert tectonic variables from an observed grain size trend (Duller *et al.* 2010) The diffusion model is therefore dominated by parameters that can be constrained by geological datasets derived from sedimentary isopachs, thermochronology, and position of grain-size fronts in the depositional basin, as well as being informed by a range of provenance tools employed to make confident connections between source and sink. When applied to geological examples in the Pobla Basin of the south-central unit of the southern Pyrenees (deposited 42-27 millions of years ago) (Beamud *et al.* ; Whittaker *et al.* 2011), we recognize different types of sediment routing system ranging from small, middle Eocene fans with clasts derived primarily from local carbonate rock sources, filling small, tectonically active wedge-top basins, to an extensive, coalescing, gravel 'drape' of Oligocene age with clasts derived from catchments eroding back to the main drainage divide, built by transverse flow across the entire wedge-top zone. These different sediment routing systems in the Pobla Basin exhibit variations in their sediment budget over time that can be linked to the changing tectonic and topographic history through the mid Eocene to Oligocene interval.

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22.2

From carbonate platforms to margin collapses: Comparing Alpine lake sediments with marine deposits

Flavio S. Anselmetti

Eawag (Swiss Federal Institute of Aquatic Science & Technology), Department of Surface Waters, Überlandstrasse 133, 8600 Dübendorf, Switzerland (flavio.anselmetti@eawag.ch)

Historically, the discipline 'sedimentology' was developed in the marine realm ('marine geology') with Swiss institutions playing a major role at the forefront of sedimentologic research. Lacustrine sedimentology ('limnogeology') is a much younger discipline. It was as well initiated with prominent Swiss participation in the 1970s and thereafter, reflecting to a certain degree the speciality of a landlocked country. The two communities recognized from the beginning the joint methods, concepts and basic principles that underlie the sedimentologic processes, but nevertheless, a partly different terminology was established. This occurred despite the fact, that lakes were recognized early on as 'model oceans' offering small-scale analogues to the larger marine systems.

The greater Alpine realm offers two kind of sedimentologic playgrounds: 1) outcropping strata of various ages provide superb views in sedimentary architecture, which are interpreted using the principle of actualism, and 2) modern lacustrine basins that provide real-time actual sedimentary systems. These lakes allow the study of ongoing processes that can be observed using geophysical and sedimentologic methods so that their immediate sedimentary response can be validated. This symposium contribution compares these two systems: Some analogues will be presented that document the use of either system to better understand the other. As an example, sequence stratigraphic concepts developed in marine carbonate platform systems can be applied towards coastal lacustrine depositional systems from carbonate-producing perialpine lakes. In a similar fashion, high-density underflows, first described in river delta areas, provide a detailed understanding of turbidite processes, which in turn help to better interpret the marine systems.

22.3

Mesozoic radiolarites from oceans to mountains: Facies, ages and palaeo-environments

Baumgartner Peter O.[1]

[1] Institut de Géologie et Paléontologie, University of Lausanne. Anthropole, CH-1015 Lausanne, Switzerland. (Peter.Baumgartner@unil.ch)

Radiolarites are deep water sediments mainly composed of, besides minor amounts of clay, biogenic silica chiefly from radiolarians, but also from sponge spicules near margins, and possibly some diatoms in the late Mesozoic. Radiolarites generally contain few or no carbonate. Radiolarites are the dominant pelagic sediment associated with oceanic basalts of various geodynamic settings ("ophiolites" s.l.) throughout the pre-Late Cretaceous Phanerozoic. The creation of Palaeozoic and Mesozoic radiolarian biochronologic scales during the past 30 years has allowed to unravel the complex history of the Circumpacific oceanic terranes as well as of ophiolitic suture zones of the Alpine-Himalayan mountain ranges. Palaeozoic and Mesozoic radiolarites occur also in Alpine-Himalayan stratigraphic sequences representing marginal basins resting on (often thinned) continental crust.

Based on the observations during the early phase of deep sea drilling in the modern oceans, the calcite compensation depth (CCD) was thought by most geologists to be the key concept to explain the distribution of Mesozoic radiolarites. Based on the Cretaceous-Tertiary distribution of carbonate in the oceans, the CCD-concept predicted that radiolarites had to be deposited at depths exceeding 4-5 km. Obviously, this prediction was difficult to reconcile with palaeobathymetries derived from many plate tectonic settings of radiolarite occurrences such as mid-ocean ridges, oceanic island arcs and, above all, marginal basins.

Biochronologically controlled transects across marginal basins and highs of the Mesozoic Tethys show that the radiolarites accumulated in the troughs cannot be regarded as dissolution residues, formed beneath a hypothetical CCD, of siliceous limestones accumulated on shallower margins and highs: Radiolarians are rare or absent from the condensed pelagic limestones and overall accumulation rates of basinal radiolarites exceed by an order of magnitude those of the limestones.

A modern sedimentation model for radiolarites must take into account several parameters that have fundamentally changed through the Phanerozoic and especially since the Late Cretaceous:

1. The scarcity of calcareous plankton throughout the Palaeozoic and the early Mesozoic must be the principal reason of the dominance of radiolarite sedimentation in open-ocean settings (radiolarites as "default" pelagic sediment). It must be noted that many Mesozoic open ocean radiolarites have very low accumulation rates and contain often important amounts of autigenic clays making them resemble oceanic red clays. The CCD-concept in such a situation has no predictive value for palaeodepth – the CCD could have coincided with the thermocline throughout pre- Late Mesozoic times.
   Calcareous plankton becomes "rock-forming" in the "intra-Pangean" ocean basins (Protocaribbean, Central Atlantic and Western Tethys) with the rise of Nannoconids (Biancone and Cat Gap facies) in the Latest Jurassic. In Panthalassa, radiolarites become replaced progressively by pelagic limestones, due to the growing abundance of calcareous nannoplankton and planktonic Foraminifera since the mid-Cretaceous.

2. Variations in the supply of periplatform carbonate must have controlled the spatiotemporal distribution of cherty limestone vs. radiolarite/spiculite in Mesozoic marginal settings, both on oceanic and continental basement. Here again, the CCD-concept has no palaeobathymetric value, since with high periplatform input calcite compensation may not occur at any depth.

3. High accumulation rates of radiolarites both in intra-Pangean oceanic and marginal basins and along panthalassan margins must be controlled by meso- to eutrophic surface water conditions that simultaneously cause high productivity of siliceous plankton and benthos and the stalling of the carbonate factory. In addition, lateral transport of the very low density radiolarian tests tend to increase their accumulation rates in current-protected depressions, while topographic highs typically show radiolarian-bearing spiculites or no siliceous deposits at all.

Radiolarite occurrences in Tethyan basins have been explained by upwelling either in a peri-equatorial ocean basin or in monsoonal circulation system. However, more elaborate reconstructions of he middle Jurassic Tethys show a complicated system of poorly interconnected oceanic basins with deeply submerged margins separated by submerged shelves on micro-continents. To produce upwelling in these relatively narrow basins, especially the Alpine Tethys, seems very difficult. An equatorial current system cannot be made responsible either, because palaeolatitudes of the mid Jurassic Tethyan basins are, according to most palaeotectonic reconstructions, between 20° and 40° N. Another fact speaks clearly against an equatorial current system crossing ancient Pangea: The Jurassic Central Atlantic and the Protocaribbean are devoid of biosiliceous sediments. This must be interpreted as the consequence of Atlantic surface waters that are more oligotrophic than those of the adjacent Tethys and Panthalassa. The Jurassic Atlantic was a "mediterranean" ocean basin such as the Modern Red Sea. Important bottlenecks (Palaeo-Gibraltar, S-Florida-Bahamas) exist through the middle and late Jurassic and must have prevented a voluminous water exchange between the Atlantic and its neighbouring basins.

Both pelagic and shelf areas of the central western Tethys were beyond the reach of detrital input, but experienced increased nutrient levels throughout most of the Middle Jurassic. While the mid Jurassic global setting is right for meso- to eutrophic (low $C_{carb.}$) sedimentation, we need a mechanism to continuously supply nutrients to the Western Tethys. In analogy with the Caribbean-Gulf of Mexico we can imagine that the Tethyan N-Equatorial Current struck the Arabian Platform, was deviated to the N and may have entered the Jurassic Eastern Mediterranean. On its way, it interacted with freshwater plumes of large rivers draining tropical N-Africa. While the suspended load sedimented in the deep Eastern Mediterranean, freshwater plumes rich in dissolved nutrients were carried into the entire S-Tethyan realm providing a constant nutrient input. This input allowed for high accumulation rates of biosiliceous sediments, caused deep water anoxia during peak intervals and microbial carbonates on platforms.

22.4

The Southern Alps from the Generoso Basin to the Dolomites: a unique natural laboratory for tectonic and structural studies

Bertotti Giovanni[1,2]

[1] *Department of Geotechnology, Delft University of Technology, Stevinweg 1, 2628CN, Delft, Netherlands (g.bertotti@tudelft.nl)*
[2] *Department of Earth Sciences, VU University Amsterdam, De Boelelaan 1085, 1081HV Amsterdam*

Following the work of numerous geologists, among which Ticino-loving Swiss geoscientists played a fundamental role, the sedimentology and stratigraphy of the Generoso basin and surrounding domains were fairly well-known. At this stage Daniel Bernoulli thought is was time for a more tectonic oriented research. Time to provide a quantitative reconstruction of the extension kinematics of the Generoso basin. Key was the intuition that, because of the general southward dip of Liassic to Triassic sediments, the northern part of the Generoso basin was reminiscent of a tilted paleo-vertical section exposing the deep geometry of the basin and its master fault (Bally et al., 1981) (Fig. 1). It was the right approach: in collaboration with S. Schmid we constrained the geometry of the Generoso basin down to depths of 12-15km (Fig. 2) and estimated vertical and horizontal movements. Analysing the fault rocks associated with the entire Lugano-Val Grande normal fault and integrating petrographic and geochronologic techniques the thermal evolution of the area was determined. Expanding our analysis we quantified the stretching history of the entire Lombardian basin, the major structure which developed during the initial stages of Mesozoic continental rifting (Bertotti et al., 1993). Such estimates are still rare in the literature but they are key for quantitative models of rifting.

The Generoso basin work highlighted two general phenomena which are still very much topics of research.

i) Continental rifting began and developed in a frame of generalized cooling, fast during the first 10-20Myr and decreasing afterwards. This phenomenon, not foreseen in classic McKenzie-type models, caused a larger-than-normal Middle-Late Triassic subsidence and a change in the deformation style of the faults rocks associated with the deep segment of the Lugano normal fault (Bertotti, 2001). The occurrence of a thermal anomaly prior to rifting has been confirmed by other studies but its origin is debated. It is also unclear if such a thermal anomaly is a mechanic necessity to activate continental rifting as suggested by some numerical models.
ii) The slow rate of extension enhanced by the mentioned cooling led to the progressive strengthening of the lithosphere underlying the Lombardian basin and the consequent West-ward migration of the site of extension. This phenomenon has been further developed in various margins e.g. Manatschal and co-authors) and modelled (van Wijk and Cloetingh, 2002); the Southern Alps, still remain one of the few places where a quantitative comparison is possible.

The Southern Alps natural laboratory had more to offer. In the Dolomites, the weakly dolomitized Latemar platform, turns out to be an excellent analog to investigate the influence of large-scale heterogeneities on strain patterns. Atoll-like carbonate platforms are of great structural interest because of the lateral juxtaposition of first-order domains (interior, margin and slope) with very different sedimentary architecture resulting in different mechanical properties. Indeed, the distribution of fractures as well as their mode, orientation and spacing, height and length are significantly different in the three domains. This introduces the idea that fractures can be tracers of bulk mechanic properties of platform domains. Interestingly, the geometric characteristics of the two fracture sets present in the Latemar are significantly different even when observed in the same domain (Boro & Bertotti, submitted). The two fractures system track then mechanical changes experienced by the platform from one fracturing episode to the other. These modifications are essentially controlled by the diagenetic evolution of the platform during its subsidence to its maximum burial depth. Fractures become then tracers of these platform-scale processes highlighting the added value of integrating sedimentology and structural geology.

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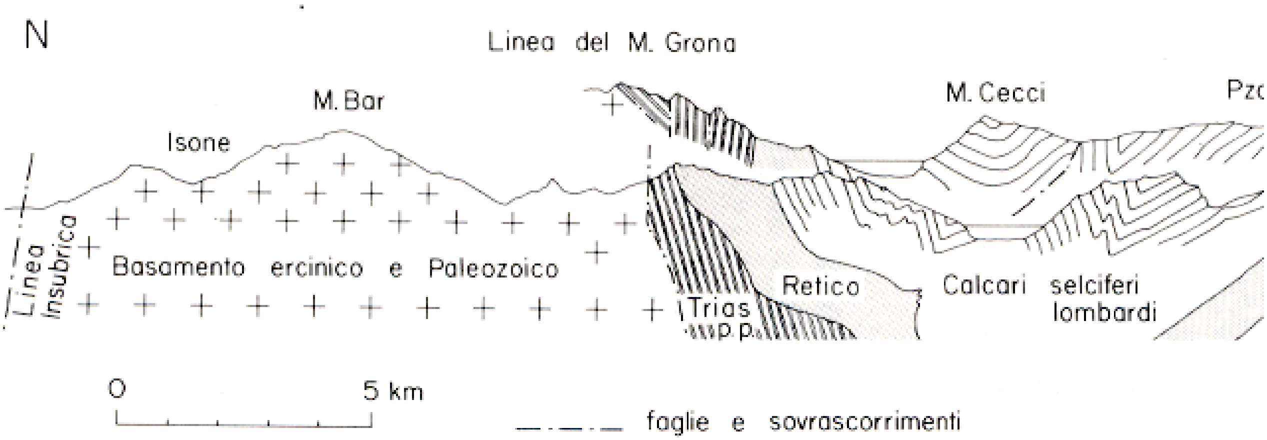

Fig. 1. Section across the N part of the Generoso Basin (Bernoulli 1995)

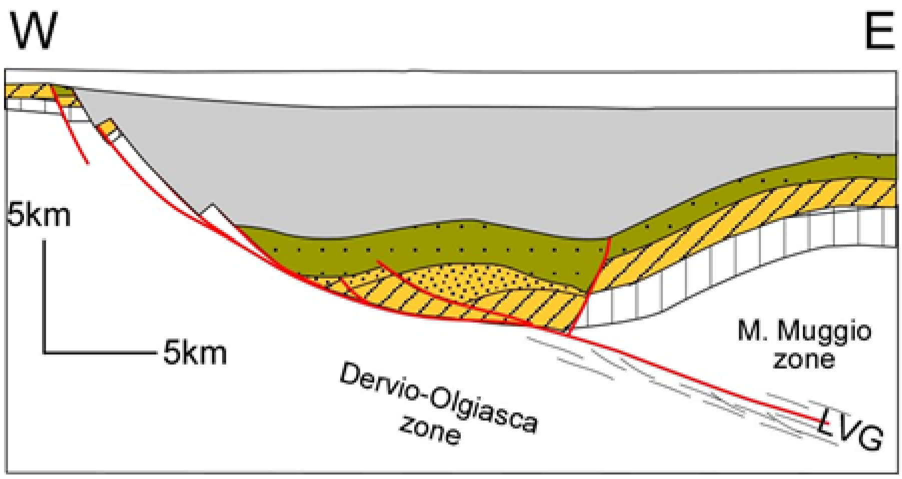

Fig. 2. The Generoso basin in Early Jurassic (Bertotti, 1991)

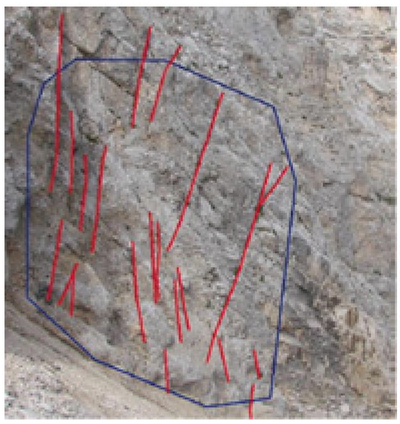

Fig. 3. Fractures in Latemar interior (3a) and slope (3b)

22.5

The long goodbye of carbonate cycles as reliable recorders of orbitally driven sea-level fluctuations

Gregor P. Eberli[1]

[1]*Comparative Sedimentology Laboratory, RSMAS-MGG, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, USA (geberli@rsmas.miami.edu)*

Shallow-water carbonates are deposited in pulses of relative sea-level change during which space is created to accommodate a new layer of sediment. There is, however, increasing evidence that these depositional cycles are unreliable recorders of both the frequency and the amplitude of orbitally driven sea-level fluctuations. Uncertainties in the assessment of the amplitude are caused by unfilled accommodation space and the inability to measure the amount of sea-level fall in these platform-top sediments. Uncertainties in the frequencies are caused by the variable amplitude of sea-level change, producing "missed beats" on the platform, and meter-scale oscillations of sea level within highstands that potentially produce cycles of very short durations.

Shallow-water carbonates often form spectacular vertically stacked, meter-scale depositional packages that are separated by exposure horizons or flooding surfaces. These smallest stratigraphic units, herein called carbonate cycles, vary in thickness and seem to be arranged in a hierarchical matter. Because the facies within carbonate cycles can be precisely tied to water depths, they are considered ideal for reconstructing past sea-level changes. Quantitative approaches include the computing cumulative cycle thickness variations through time (Fisher, 1964; Read and Goldhammer, 1988) and a variety of spectral analysis techniques for assessing their high-frequency cycling (e.g. Hinnow & Goldhammer, 1994). The underlying assumptions in these analyses are at odds with observations in the Holocene and Quaternary carbonate cycles that show a very sketchy record of both the amplitude and timing of known sea-level fluctuations during this time. A case can be made that the uncertainty in assessing both the amplitude of sea-level change from cycle thickness and the frequency from dating is too big to reconstruct a reliable record of past sea-level changes.

In regards to the amplitude of sea level the problem is twofold. First, the accommodation space is filled to different levels within the depositional environment. Most facies with the exception of shallow reefs, shoals and tidal flats are deposited within a certain water depth. This unfilled accommodation space is not recorded and, thus, the upper boundary of the mean sea level cannot be assessed precisely. Second, many carbonate cycles are capped by an exposure horizon that forms when sea level drops. The amount to which sea level drops below the exposed surface is, however, not recorded in the stacked shallow-water cycles. As a consequence, carbonate cycles record only a fraction of the amplitude of a sea-level cycle: a portion of the rise and nothing of the fall. Cores through the Pleistocene cycles on Great Bahama Bank illustrate this shortcoming. While the amplitudes of the last 9 sea level changes are each a hundred meters or more, the thickness of the cycles vary from a few meters to approximately 15 m. Although this lack of correlation between sea-level amplitude and cycle thickness might be extreme in the Neogene Ice House world, the uncertainty is not eliminated for cycles deposited during times of lower amplitudes because they also do not record the unfilled accommodation space and amount of sea-level fall.

In addition to the difficulty of accurate age model, the assessment of frequency has two main problems. The first is what is known as "missed beats". A missed beat occurs when a sea-level rise is too small to produce new accommodation space in the shallow-water environment. This scenario is thought to occur preferentially during times of long-term sea-level fall. The benthic isotope record of the last 57 glacio-eustatic sea level changes documents that the amplitude variability is prevalent and seemingly random (Lisiecki & Raymo, 2005), resulting in many missed beats during the Plio-Pleistocene. The second problem is that new data document oscillations of the sea level during interglacials that occur in a sub-orbital timeframe. For example, Thompson and Goldstein (2005) proposed a sea-level drop of ~ 17 m within the last interglacial (MIS 5e). This sea level drop exposed the entire Great Bahama Bank and is recorded in exposure surfaces within marine deposits of MIS 5e. On Glovers Reef it produced stacked reefs separated by an exposure horizon. The combined effects of missed beats and oscillations within highstands are likely to produce cycles and hiatuses of variable durations that are most difficult to extract from the rock record.

In summary, carbonate cycles are produced by fluctuations of sea level but their incomplete record of both the amplitude and the frequency makes them an unreliable recorder of high-frequency sea-level changes.

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22.6

Albert of Arabia - Climatic and environmental reconstructions on stalagmites and lacustrine sediments from the Arabian Peninsula

Fleitmann Dominik*

[1] *Institute of Geological Sciences and Oeschger Centre for Climate Change Research, Baltzerstrasse 1+3, 3012 Bern, Switzerland (fleitmann@geo.unibe.ch)*

In the late 1990's the Quaternary paleoclimatic history of the Arabian Peninsula was almost unknown. This was somewhat surprising considering that the climate on the Arabian Peninsula is strongly governed by the North Atlantic/Siberian pressure system and the African/Asian monsoon. Arabia is thus ideally situated to study how and to what extent both systems were dynamically linked in the past. Furthermore, Arabia is also a key area for the migration of Homo sapiens "out of Africa" at around 130 kyr before present, whereupon phases of human migration were most likely intimately linked to climate.

Figure 1. Albert Matter working on lacustrine sediments in the Nafud desert (picture taken by Dominik Fleitmann in 2010)

One of the main reasons for this distinct lack of knowledge of the paleoclimatic history of Arabia is the paucity of suitable paleoclimate archives. Fortunately, Albert Matter was one of the first scientists who realized that stalagmites, sand dunes and lake sediments can provide crucial information on paleoclimatic and –environmental changes on the Arabian Peninsula on time scales ranging from a few hundred to several hundred thousand years. Among several milestone achievements, Albert Matter's research on precisely-dated stalagmites from Oman and Yemen revealed that the occurrence of humid periods over the last 350 kyr before present was intimately tied to changes in the intensity of the Asian monsoon and latitudinal shifts of the Intertropical Convergence Zone and monsoonal rainfall belt respectively (e.g., Burns et al., 2001; Fleitmann et al., 2003a, 2007). Furthermore, it could be shown that decadal- to centennial-scale changes in monsoon intensity were caused by rather subtle changes in solar activity (Neff et al., 2001; Fleitmann et al., 2003b), triggering numerous new studies on the sun-climate relationship in the paleoclimate community. Albert Matter was also the first scientist who drilled into a mega dune to establish the timing of arid climatic phases in the Wahiba sands in Northern Oman (e.g., Preusser et al., 2002). His latest and ongoing research activities involved studies on lacustrine sediments in Saudi Arabia and stalagmites from Yemen to establish a link between human dispersal and climate (e.g., Fleitmann et al. 2011; Rosenberg et al., in press.).

The sentences by Benjamin Franklin "Energy and persistence conquer all things" and "To succeed, jump as quickly at opportunities as you do at conclusions" describe perfectly why Albert Matter's paleoclimate research projects on the Arabian Peninsula were so successful. His profound knowledge of the Arabian language and way of life allowed him to create and foster a dense network of collaborators in Arabia. Therefore, it is absolutely justified to call him "Albert of Arabia", in allusion to "Lawrence of Arabia" and his extraordinary variety of activities in Arabia.

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22.7

Magnesium Isotopes: Establishing a new proxy in Earth Sciences

Adrian Immenhauser[1], Dieter Buhl[1], Sylvia Riechelmann[2], Christoph Spötl & Detlev K. Richter[1]

[1] Ruhr-University Bochum, Institute for Geology, Mineralogy and Geophysics, Universitätsstraße 150, D-44801 Bochum, Germany (adrian.immenhauser@rub.de)
[2] Leopold-Franzens-University Innsbruck, Institute for Geology and Palaeontology, Innrain 52, A-6020 Innsbruck, Austria

The potential of magnesium isotope records is at present underexplored. This is mainly due to the analytical complexity related to this non-traditional isotope system and the limited knowledge regarding physico-chemical and biological disequilibrium fractionation processes in natural systems. Work under progress at Bochum involves δ^{26}Mg studies including marine biogenic (bivalve shells) and abiogenic (dolomite) carbonate archives as well as meteoric-vadose systems (speleothems). Here we present Mg isotope data from a monitored cave in Germany (Bunker Cave) and provides data on rain water (δ^{26}Mg: -0.70 ± 0.14‰), soil water (δ^{26}Mg: -0.51 ± 0.10‰) and drip waters (δ^{26}Mg: -1.65 ± 0.08‰) representing time series between November 2009 and May 2011. Field precipitation experiments, i.e., calcite precipitated on watch glasses (δ^{26}Mg: -3.56 ± 0.26‰; August 2006 to June 2010), were found to be of limited use. This is because of several experimental and sampling artefacts, probably combined with crystallographic problems related to the silica glass substratum and disequilibrium processes complicates this issue. Conversely, variations in soil- and drip water δ^{26}Mg over time are predominantly related to seasonal climate variations (mainly water availability and temperature changes) affecting the subtle weathering ratio between Mg-bearing clay minerals in the soil, here mainly chlorite and montmorillonite, and the low-Mg calcite hostrock. For fast drip sites, the direct correlation of $\delta^{26}Mg_{soil\ water}$ and $\delta^{26}Mg_{drip\ water}$ documents a relative short residence time of the fluid in the carbonate aquifer and thus limited isotope equilibration and mixing of different reservoirs. This result is encouraging and adds new evidence to the poorly understood hydro-geochemistry of carbonate aquifers. Slow (seepage flow) drip sites display an annual $\delta^{26}Mg_{drip\ water}$ pattern that is geochemically unrelated to that of the soil water. Bunker Cave $\delta^{26}Mg_{drip\ water}$ displays a significant dependency on the outside temperature, which influences CO_2 levels in the soil and hence rock-water interaction. Further research, including laboratory experiments, must focus on the complex fractionation between drip water and speleothem calcite Mg isotope record.

22.8

Tectonics versus palaeoceanography in the evolution of the Alpine-mediterranean Tethys

Jenkyns Hugh C.

[1]*Department of Earth Sciences, University of Oxford, South Parks Road, Oxford OX1 3AN (hughj@earth.ox.ac.uk)*

One of the major events in the Jurassic evolution of the Alpine-mediterranean Tethys was the drowning of carbonate platforms. Shallow-water platforms installed on the continental margin subsided at different times and were mantled by pelagic sediment. The post-platform subsidence rates were variable, such that some areas rapidly became basinal, whereas others remained as topographic highs or seamounts. Although initially interpreted as a purely tectonic phenomenon, the coincidence in timing between drowning events and major disturbances of the global carbon cycle suggests that environmental change and water quality were contributory factors. Major drowning events took place around the Rhaetian–Hettangian (T/J) boundary, the Sinemurian–Pliensbachian boundary, and the Plienbachian–Toarcian boundary. All of these intervals are associated with negative carbon-isotope excursions, recording the introduction of isotopically light carbon into the ocean–atmosphere system, probably associated with rises in global temperature and, at least in some cases, increased nutrient flux to the oceans and relatively elevated organic productivity. The most extreme case of this phenomenon was the early Toarcian Oceanic Anoxic Event (T-OAE). Where subsidence rates were relatively fast, inimical water quality favoured drowning; where subsidence rates and deepening were less extreme, a platform could re-establish itself when water quality improved. The Trento Platform/Plateau in the Southern Alps is an unusual case in that the T-OAE is registered in some areas by a change in facies to darker more clay-rich sediments, with ammonites, nannofossils and abundant spiculitic cherts, but local recovery to shallow-water carbonate-platform conditions (oolitic and crinoidal limestones) was achieved before ultimate drowning in the middle Jurassic. To understand the drowning of carbonate platforms, the interplay between local syn-sedimentary tectonics and global palaeoceanographic changes needs to be understood.

22.9

Stratigraphic and tectonic architecture of the Alpine Tethys margins

Gianreto Manatschal1, Emmanuel Masini1 and Geoffroy Mohn1

IPGS - EOST, Université de Strasbourg – CNRS, 1, rue Blessig F-67084 Strasbourg Cedex, France

Research into the formation of passive rifted margins is incontestably undergoing a paradigm shift. The discovery of exhumed mantle and hyper-extended crust overlain by shallow marine sediments is proving fundamental in defining the controls and processes that thin continental lithosphere, lead to continental break-up and formation of oceanic domains. At present, little is known about the depositional environments, sedimentary facies, the kinematics and age of structures, or the subsidence and thermal history of syn-rift sediments of deep-water rifted margins. Moreover, the discovery of exhumed continental mantle and hyper-extended crust associated with large sag basins, hundreds of kilometres wide, has not yet been fully integrated in the understanding of collisional orogens. It is important to understand how these hyper-extended rift systems may control the structural and rheological evolution of Alpine type orogens.

In our presentation we present the key observations made along the Iberia-Newfoundland and Alpine Tethys rifted margins, review the paleogeographic evolution of this domain and discuss how the understanding of this domain may impact our thinking and understanding of the evolution of present-day rifted margins.

The study on the Iberia-Newfoundland rifted margins show that the transition from continental to oceanic crusts does not represent a sharp boundary, but is formed by an up to 160 km wide zone of exhumed sub-continental mantle. This observation questions the existence of a sharp and well-defined ocean-continent boundary at magma-poor rifted margins and the validity of the breakup unconformity and nature and significance of magnetic anomalies in ocean continent transitions.

Mapping of rift structures and depositional systems of the most distal parts of the ancient Alpine Tethys margins enabled to identify lithologies and structures similar to those drilled off Iberia. The most prominent structures observed in the Alps are a set of detachment faults. These structures can be traced from relatively little extended continental crust across the distal margin and ocean-continent transition towards embryonic oceanic crust. These faults are far more complex as proposed by the Wernicke model. Detachment faults interact with decollements in ductile layers and only when the crust is thinned to less than 10 km and is completely brittle, detachment faults can cut from the surface into mantle and exhume the latter at the seafloor. Fluids are intimately linked with this process, controlling rheological and thermal evolution.

The lesson from the Iberia-Newfoundland and Alpine Tethys rift systems might not be extrapolated directly to other margins, however, it may help to re-evaluate and rethink some to the concepts, the terminology and the processes that were (are) used to describe rifting and continental breakup along these less investigated rifted margins.

22.10

Sedimentary archives of Northern Alpine and Molasse Basin neotectonics

Strasser Michael[1], Anselmetti Flavio S.[2], Gorin George[3], Monecke Katrin[5], Mosar Jon[6] Schnellmann Michael[7]

[1] *Geological Institute, ETH Zurich, 8092 Zürich (strasser@erdw.ethz.ch)*
[2] *Eawag, Swiss Federal Institute of Aquatic Science & Technology, 8600 Dübendorf*
[3] *Sciences de la Terre, Université de Genève 1205 Genève*
[5] *Wellesley College, Department of Geosciences, Wellesley, MA, 02481, USA*
[6] *Department of Geosciences, University of Fribourg, 1700 Fribourg*
[7] *Nagra, Nationale Genossenschaft für die Lagerung radioaktiver Abfälle, 5430 Wetting*

Switzerland lies tectonically in an intraplate area. Recurrence rates of strong earthquakes exceed the time span covered by historic chronicles. Consequently, they are not sufficient to document the full range of neotectonic processes. However, many lakes are present in the area that act as natural seismographs: their continuous, datable and high-resolution sediment succession allows to extend the earthquake catalogue from instrumental and historic periods to prehistoric times, all the way to the end of the last glaciation, when the modern lakes formed after glacier retreat.

Here we review and compile available data sets and results from more than 10 years of lacustrine paleoseismologic research in lakes of northern and Central Switzerland, and present an outlook of a new study starting in the Western Swiss Molasse Basin. The concept of using lacustrine mass-movement event stratigraphy to identify paleo-earthquakes is showcased by presenting data and results from Lake Zurich. The Late Glacial-to-Holocene mass-movement units in this lake document a complex history of varying tectonic and environmental impacts. Results include the documentation of 3 major (2200, 11 530, 13 840 cal yr. B.P. Strasser et al., 2006) and 3 minor (640, 3300 and 7270 cal yr. B.P), simultaneously-triggered basin-wide lateral slope failure events interpreted as the fingerprint of paleoseismic activity. In all lakes, historic calibrations were used to identify these "seismic fingerprints" in the sedimentary archives (Schnellmann et al., 2002, Monecke et al., 2004) a procedure which here is exemplarily discussed for the 1601 A.D. Unterwalden earthquake. These calibrations indicate that the macroseismic intensity threshold to trigger subaquatic slope failures is I=VII (Monecke et al., 2004). This quantitative calibration is reinforced by subaquatic slope stability assessment back-analyzing seismic ground shaking threshold conditions for landslide initiation in Lake Lucerne (Strasser et al., 2011).

We present a refined earthquake catalogue, which includes results from previous lake studies (Monecke et al., 2006). This compilation shows a non-uniform temporal distribution of earthquakes in northern and Central Switzerland. Higher frequency of earthquakes in the Late Glacial and Late Holocene period documents two different phases of neotectonic activity. They are interpreted to be related to isostatic post-glacial rebound and recent (re-) activation of seismogenic zones, respectively. Magnitudes and epicenter reconstructions for the largest identified earthquakes suggest that the latter may be related to ongoing alpine deformation and the release of accumulated NW-SE compressional stress related to an active basal thrust beneath the Aar massif (Strasser et al., 2006). However, even though these results reveal that also in Central Switzerland strong earthquakes with magnitudes (M) > 6.5-7 can occur, field-evidence for a neotectonically active fault zone capable of producing such large earthquakes remain absent.

In the Western Swiss Molasse Basin, in contrast, there is emerging evidence of neotectonic activity along the Fribourg Fault Zone (FFZ; Kastrup et al., 2007) and possibly also along the La Lance Fault Zone (LLFZ), which constitutes a conjugated fault system to the FFZ (Mosar et al., 2008). If not segmented, the total length of these fault zones may carry the potential of M 6+ earthquakes. Yet, this area so far lacks geological records of significant earthquakes. The obvious next step is to transfer the knowledge gained from studies in Central Switzerland and to apply the concept of "lakes as archive for quantitative paleoseismology and neotectonic reconstructions" in lakes of Western Switzerland (e.g. Lakes Neuchâtel, where airgun seismic data (Gorin et al., 2003) have shown that this lake also is prone for subaquatic landslides, the trigger mechanism(s) of which will be systematically investigated in a new project aiming at paleoseismologic and neotectonic reconstruction of this area).

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22.11

Tracing Alpine sediment sources through laser-ablation U/Pb dating and Hf-isotopes of detrital zircons - an appraisal

Winkler Wilfried[1], Beltrán Alejandro[1], von Quadt Albrecht[2]

[1]*Geologisches Institut, ETH Zürich, Sonneggstrasse 5, CH-8092 Zürich, Switzerland (wilfried.winkler@erdw.ethz.ch)*
[2]*Institut für Geochemie und Petrologie, ETH Zürich, Clausiusstrasse 25, CH-8092 Zürich, Switzerland*

In Alpine research provenance analysis on sandstones always played an important role. Conventional heavy mineral and sandstone modal framework grain analysis in the past have contributed to palaeogeographic reconstructions and geodynamic models. However, these methods appear to have reached their limits of evidence, because of the lack of geochronological precisions. Due to recent developments in in-situ laser ablation methods (e.g. Kosler et al. 2002; von Quadt et al., 2008) significant contributions from single detrital zircons can be gained (Figure 1).

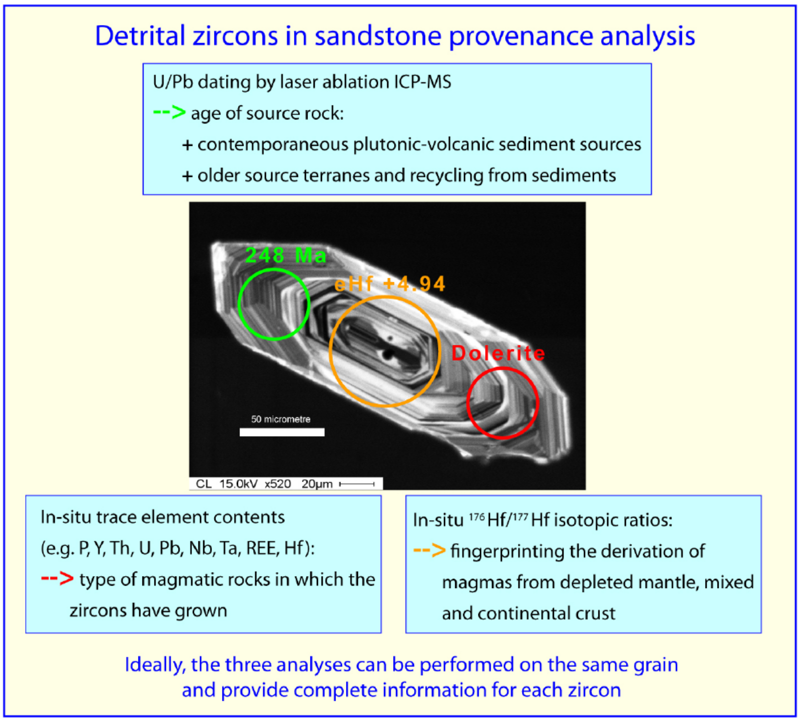

Figure 1: Provenance information on an Early Triassic detrital zircon from a Jurassic sandstone of the Mongol-Okhotsk Belt (Mongolia).

Triassic rifting-related sandstones in various/several Alpine palaeogeographic domains show variable zircon age compositions as major reworking of M. Cambrian - Devonian in the Helvetic Mels Fm (Scheidnössli, 09AB18, Fig. 2), the Lower Austroalpine Fuorn Fm (Punt de la Drossa Mb, 10AB14) depicts a dominating Permian population, and the Val Sabbia Fm in the Southern Alps (10AB08) an exclusive, contemporaneous Middle Triassic crustal magmatic source (Beltrán et al. 2011). Jurassic rifting-related series (Falknis Breccia 09AB28, Saluver Fm 10AB18, Inferno Series/Scopi Zone 09AB19) show prominent/dominant Variscan - late Variscan peaks and intensive reworking of Early Palaeozoic and Proterozoic elements, in particular in the Gotthard Mesozoic para-autochthonous cover (09AB19). In the Prättigau Group (09AB23-27) the Ruchberg Fm is distinctive by a wide and old range of Early Jurassic - Proterozoic zircons revealing the activation of new sediment sources in comparison with older Bündnerschiefer formations. Except for the presence of rare Mesozoic zircons in the Niesen Flysch (09AB08), there is no significant distinction with the E. Jurassic sedimentary basement of the flysch (Leyderrey Conglomerate 09AB06) observed. Pre-alpine Flysches (Médianes 09AB01/02, Reidigen 09AB05, Mocausa/ Rodomont 09AB03) show variable populations of Variscan and Pan-african detrital zircons with affinities with the Schlieren Flysch (Bütler et al. 2011). Bulk modal sandstone framework and heavy mineral analyses complete our data set.

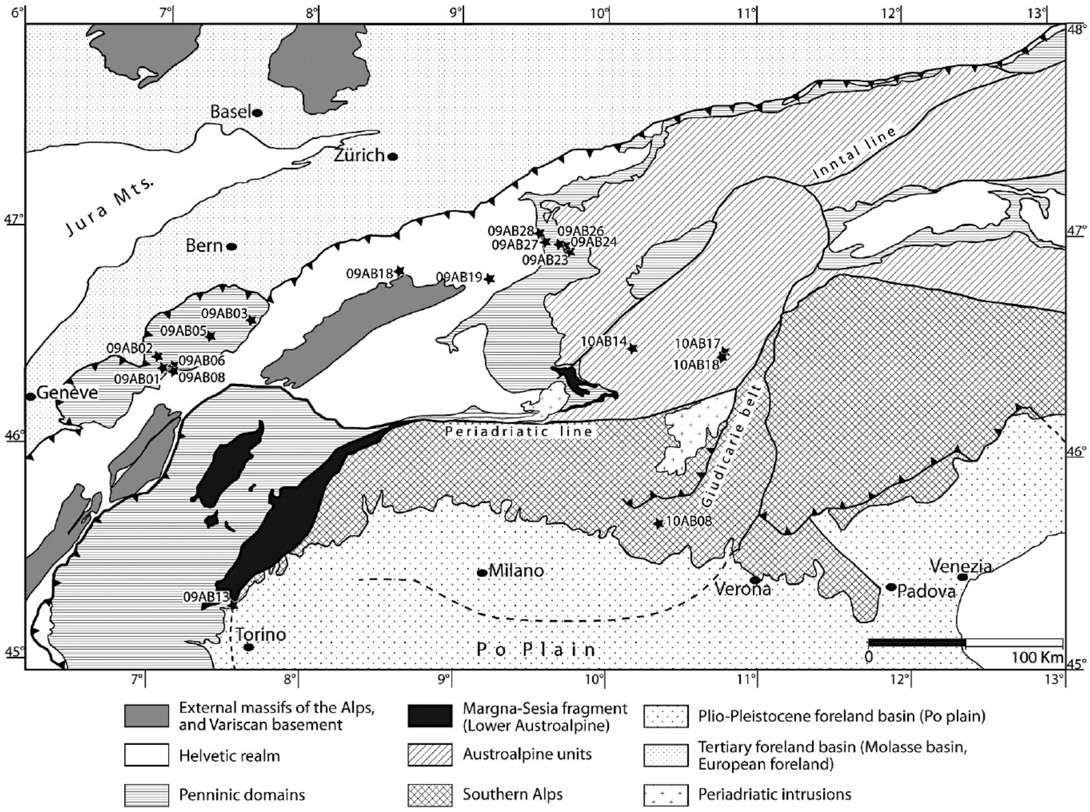

Figure 2: Palaeogeographic location of the discussed sandstone formations.

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P 22.1

The Cretaceous-Tertiary transition in the Alps, new insights from Gams, Austria

Thierry Adatte[1], G. Keller[2], H. Khozyem Saleh[1], J. Spangenberg[3]

[1]*IGP, Lausanne University, 1015 Lausanne, Switzerland*
[2] *Dpt of geosciences, Princeton University, NJ 08544, USA*
[3] *IMG, Lausanne University, 1015 Lausanne, Switzerland*

The Cretaceous-Tertiary (K-T) transition in eastern Austria (Gams, Styria) was analyzed in terms of lithology, mineralogy (bulk and clay minerals), stable isotopes, major and traces elements and biostratigraphy (planktic foraminifera). The Gamsbach section is part of the Nierental Formation and comprises a 6.4 m thick deep-water sequence composed of marlstones, marly limestones interbedded with sandy to silty turbidites, which become more frequent above the KTB. Age control is based on a high-resolution planktic foraminiferal biozonation of which permits evaluation of the continuity of the sedimentary record across the KTB transition based on the presence of relatively short interval zones and subzones. Presence of P. hantkeninoides in the 1.75 m below the KTB at Gamsbach indicates sediment deposition occurred in zone CF1, or during the last 150 ky of the Maastrichtian. Just below the KTB, an irregular wavy surface at the top of the marly limestone marks an unconformity, which is strongly bioturbated (Chondrites-type burrows) coincident with a 2.5 permil drop in $\delta^{13}C$ values and low calcite content (< 2%). Most Maastrichtian species abruptly disappear at this level, except for survivor species that continue into the early Danian and a few reworked specimens. Above this surface, 0.2 to 0.4 cm of yellowish rusty clay marks the basal Danian overlain by 2 – 3 cm thick gray claystones both enriched in Ir, Co, Cr, Sc, Zn, Pb and Ni indicating an extraterrestrial source. Ten Danian species abruptly appear at that level, including P. longiapertura and P. eugubina the index species for zone P1a and abundant Eoglobigerina edita . The high species diversity and presence of Parasubbotina pseudobulloides 3 cm above marks subzone P1a(2). This indicates that zone P0 and subzone P1a(1) are mainly missing at this hiatus. Erosion of the top part of zone CF1 below the unconformity is also likely. Reworked Cretaceous species in Danian sediments are frequent in particular intervals and reflect downslope transport of eroded older sediments in upslope or shelf areas probably during times of intensified ocean circulation Two hiatuses can be therefore identified in the Gamsbach section: 1) at the KTB where the basal Danian zone P0 and subzone P1a(1) are mainly missing above an undulating erosion surface of Upper Maastrichtian marly limestone, and 2) in the lower Danian where most of zone P1b is missing. Bulk and clay minerals indicate reduced detrital input in the Upper Maastrichtian becoming more significant during the lower Danian reflecting increased turbidite activity linked to growing Austro-Alpine tectonic subsidence and erosion. Weathering Index of Parker (WIP) that shows higher values in the Lower Danian confirms this change in detrital inputs.

P 22.2

The Urgonian Formation in the Helvetic Alps (late Barremian to early Aptian): new evidences from the Interlaken area.

Bonvallet Lucie [1], Godet Alexis [1], Spangenberg Jorge E. [2] & Föllmi Karl B. [1]

[1]*Institut de Géologie et de paléontologie, University of Lausanne, Anthropole, CH-1015 Lausanne-Dorigny, Switzerland (lucie.bonvallet@unil.ch)*
[2]*Institut de Mineralogie et de Geochemistrie, University of Lausanne, Anthropole, CH-1015 Lausanne-Dorigny, Switzerland*

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 will examine a selection of stratigraphic sections along lateral and proximal-distal transects for their facies and microfacies, biostratigraphy, sedimentology, and geochemistry (stable isotopes, -phosphorus contents). We will also use high-resolution panoramas from a selection of mountain walls, in order to detect lateral changes in facies and geochemistry and establish a sequence-stratigraphic framework. 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.

P 22.3

The Voirons flysch (Voirons massif, Gurnigel nappe, Haute Savoie, France): a stack of km-sized flysch slices of Ultrahelvetic and north-Penninic origin

Kindler Pascal[1], Ospina-Ostios Lina Maria[1], Ragusa Jérémy & Wernli Roland[1]

[1] *Section of Earth and Environmental Sciences, University of Geneva, 13 rue des Maraîchers, CH-1205 Geneva (Pascal.Kindler@unige.ch)*

New biostratigraphic, sedimentological and petrographic data and a thorough review of existing literature presented here modify existing knowledge on the age, the sedimentology, the petrography, the paleogeographic origin, and the structure of the Voirons flysch (Voirons massif, Gurnigel nappe, Haute Savoie, France).

The Voirons massif is situated in the Chablais Prealps, Haute-Savoie, France. It belongs to the Gurnigel nappe which is commonly thought to derive from an ultrabriançonnais or south-Penninic realm. The massif includes three stratigraphic units that have been dated so far with calcareous nannofossils and dinoflagellates (van Stuijvenberg & Jan du Chêne 1981): the Voirons Sandstones (Danian-Ypresian), the Vouan Conglomerates (Ypresian-Lutetian) and the Saxel Marls (Lutetian-Bartonian). These units have been interpreted as deep-water turbidites and characteristically contain igneous lithoclasts of south-alpine affinity. The Voirons massif is diversely described as one large, eastward-dipping tectonic slice (Lombard 1940), or as an imbricate structure including three slivers named, from bottom up, Branta, Saxel and Tête du Char, respectively (van Stuijvenberg 1980).

During the past 15 years, we have re-examined and re-sampled key outcrops in the Voirons massif to study benthic and planktonic foraminifer assemblages, as well as sandstone petrography and sedimentology. Our biostratigraphic results are the following: the Voirons Sandstones range from the Middle Eocene (planktonic foraminiferal zones P12 to P14) to the Late Eocene-Early Oligocene (P14 to P20); the Vouan Conglomerates span the Late Eocene and the Early Oligocene (P15 to P20); the Saxel Marls extend also from the Late Eocene to the Early Oligocene (P15 to P20). The nannofossil assemblages retrieved from the same samples systematically yielded older ages than those obtained from planktonic foraminiferal associations. Main fieldwork and sedimentological/petrographic results are the following: (1) some of the youngest exposures of the Voirons Sandstones occur near the base of the Gurnigel nappe and are overlain by older strata that are not overturned; (2) exposures of Voirons Sandstones of similar age were deposited in distinctive paleoenvironmental settings (e.g. differences in water depth and oxygenation); (3) the Saxel Marls (distal turbidites and/or basinal contourites) seem to be tectonically, and not stratigraphically, superimposed over the Vouan Conglomerates (proximal turbidites) and may further be affected by a recumbent fold; (4) preliminary petrographic investigation show that all exposures of the Voirons Sandstones do not contain the same heavy mineral assemblage; and (5) petrographic analysis of the Voirons Sandstones revealed the occurrence of rare, but unmistakable fragments of diabase, similar to those found in large quantity in north-Helvetic flyschs.

The occurrence of flysch exposures in reverse stratigraphic order combined with the lack of evidence of bed overturning, the variability of paleodepositional settings inferred from different flysch outcrops of similar age, diverse heavy mineral content, and the anomalous superimposition of distal turbidites and/or basinal contourites (Saxel Marls) over proximal turbidites (Vouan Conglomerates), all suggest that the Voirons massif comprises several stacked flysch units of various paleogeographic origin.

The young age of these km-sized flysch slices precludes a south-Penninic origin, but rather indicates an Ultrahelvetic and/or Valais provenance for these units, confirming previous investigations in the NE part of the Gurnigel nappe (Trümpy 2006). In particular, the Vouan Conglomerates and the Saxel Marls could possibly represent the non-metamorphic equivalents of the Pierre Avoi Unit (Sion-Courmayeur Zone, internal Valais domain) that yielded an assemblage of planktonic foraminifers of late Middle Eocene to possibly Early Oligocene age (Bagnoud et al. 1998), similar to the assemblages found in the younger units of the Voirons flysch, and likewise contains schist and sandstone blocks derived from the Zone Houillière (Bagnoud et al. 1998).

Finally, the absence of nannofossil assemblages contemporaneous with the observed planktonic foraminifer associations suggests the former have been reworked, dissolved, or just simply diluted and not found by earlier researchers. This example from the Voirons massif shows that planktonic foraminifer associations are the most reliable biostratigraphic tool to obtain an accurate age from flysch successions.

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P 22.4

Lithostratigraphic harmonisation – a corner stone for a digital geological map with nationwide coverage

Morard Alain[1], Burkhalter Reto[1/2], Möri Andreas[1] & Strasky Stefan[1]

[1] *Federal Office of Topography swisstopo, Swiss Geological Survey (SGS), Seftigenstrasse 264, CH-3084 Wabern (alain.morard@swisstopo.ch)*
[2] President, Swiss Committee of Stratigraphy (SCS), c/o SGS

For more than 100 years, geologists have been striving to produce detailed geological maps in all parts of Switzerland, as a basis for process understanding, resource exploitation, and territorial management. The production of the *Geological Atlas of Switzerland 1:25'000* (GA25) is still in progress. The published GA25 maps cover about 60% of the area of Switzerland. However, with the *GeoCover* project launched by swisstopo in 2009, the perspective of a nationwide coverage at an "adjusted" 1:25'000 scale is about to become a reality. Indeed, geological vector data sets for the entire surface of Switzerland will be available in 2012 as a result of the compilation and digitalisation of data from many different sources and variable quality (GA25, Geological Special Maps, unpublished original field records).

Although an immense step forward, this long awaited result will not reach its full scope till the individual mapped elements have been tied across the whole territory and uniformly attributed. As concerns rock bodies, the numerous lithostratigraphic units in usage have to be listed, clearly defined and correlated across the sheets of the Atlas. Their description according to the *Data Model Geology* (Strasky et al. 2011) and their consistent chronostratigraphic allocation are also necessary in order to run rapid and extensive queries in the GIS database. This is the basic aim of the HARMOS project (harmonisation of lithostratigraphic units), run by the Swiss Geological Survey (SGS), in close collaboration with the Swiss Committee of Stratigraphy (SCS; Burkhalter & Heckendorn 2009).

The nine workgroups of the SCS (Jura-East, Jura-West, Molasse, Helvetic, Prealps, Penninic-West, Penninic-East, East-/Southalpine, Quaternary), with coordination and support from the SGS, are in charge of this challenging task. Their work will be made available online through the Lithostratigraphic Lexicon of Switzerland (www.stratigraphie.ch), and serve as a harmonised geological map legend. Once achieved, this ambitious project will permit to revise and adapt the *GeoCover* dataset and serve as a basis for the completion of a seamless, nationwide vector data set of Switzerland at a scale of 1:25'000.

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The Meride Limestone (Monte San Giorgio, Ticino, Switzerland): a Ladinian archive of paleoenvironmental changes.

Stockar Rudolf[1,2], Baumgartner Peter O.[1], Kocsis László[3], Ulianov Alexey[3], Dumitrica Paulian[5] & Condon Daniel[6]

[1]*Institut de Géologie et Paléontologie, Université de Lausanne, Anthropole, CH-1015 Lausanne (rudolf.stockar@unil.ch).*
[2]*Museo Cantonale di Storia Naturale, Viale Cattaneo 4, CH-6900 Lugano.*
[3]*Institut de Minéralogie et Géochimie, Université de Lausanne, Anthropole, CH-1015 Lausanne.*
[5]*Dennikofenweg 33, CH-3073 Gümligen*
[6]*NERC, Isotope Geoscience Laboratory, Keyworth, UK-NG12 5GG Nottingam.*

New paleontological data, mainly based on palynomorphs and radiolarians (Figs 1a-b) in addition to daonellids and ammonoids, significantly improve the biostratigraphic resolution of the Ladinian sequence of the Monte San Giorgio (UNESCO WHL site, Southern Alps, Switzerland). Accordingly, the San Giorgio Dolomite and the Meride Limestone are now regarded as a 620 m thick sequence spanning from the *E. curionii* (early Fassanian) to the *P. archelaus* (Longobardian) ammonoid zones. The age of the world-famous fossil marine vertebrate faunas of the Meride Limestone has consequently been resolved to the substage and zone levels.

High-resolution single-zircon U–Pb dates have been obtained using ID-TIMS and CA (annealing/chemical abrasion) pretreatment techniques on volcanic ash layers intercalated in the biostratigraphically constrained intervals of the Meride Limestone.

Our results suggest that the time interval bracketed by the vertebrate-bearing Middle Triassic section at Monte San Giorgio is around 4 Myr and thus significantly shorter then so far assumed. Accordingly, evolutionary rates inferable from the different faunal associations replacing each other throughout the section have to be reconsidered.

The San Giorgio Dolomite and the Meride Limestone prove to correlate with intervals of the Buchenstein Fm. and the Wengen Fm. in the reference section at Bagolino, where the Global boundary Stratotype Section and Point (GSSP) for the base of the Ladinian were defined. The new radio-isotopic ages are by 1.5–2 Myr older than those published for the biochronologically age-equivalent intervals at Bagolino but they are consistent with the recent re-dating of the underlying Besano Formation, also performed using the CA tecnique (Mundil et al. 2010). Moreover, the high-resolution U–Pb ages allow a correlation of the vertebrate faunas of the Lower Meride Limestone with the marine vertebrate record of the Upper Australpine (Prosanto Formation, Switzerland), so far precluded by the poor biostratigraphical control of the latter (Furrer et al. 2008).

The re-measurement of the whole section at the cm-scale and the new high-resolution geochronological constraints allow to assess sedimentation rates. At Monte San Giorgio sedimentation rates are higher by over one order of magnitude with respect to those assumed for the Buchenstein facies of the Southern Alps and its equivalents of the Western Tethys, which formed under sediment-starved, pelagic conditions. Such values mirror prevailing high subsidence and high supply of periplatform carbonate mud stirred up from the adjoining Salvatore/Esino shallow-water platform systems.

Palynofacies analysis has been carried out on the whole section and has been cross-correlated with a new continuous oxygen and carbon stable isotope record. The isotope record, as well as the ammonoid and radiolarian evidence, highlight a basin evolution that reflects open-marine but not deep-water connections for the lower part of the section. A major volcaniclastic event occurring in the *E. gredleri* Zone coincides with the shift to a more restricted sedimentation, recurrently influenced by storm events and increased continental input (Stockar 2010; Stockar & Kustatscher 2010). Finally, the late evolution of the basin is characterized by a sedimentation typical for a proximal, near shore setting with a relative high supply of terrestrial organic matter (Fig. 1c).

Geochemical analyses performed on all the classic vertebrate-bearing Ladinian horizons have been supplemented with the study of new bone material from stratigraphic intervals so far never considered or even regarded as barren. Trace elements and isotope compositions of the vertebrate remains have been analyzed and used as paleoenvironmental proxies. REE concentrations are around 3 orders of magnitude higher than found in modern biogenic apatite. The stratigraphic changes in REE patterns after the mentioned volcaniclastic event provide an useful tool to recontruct variations in early burial conditions.

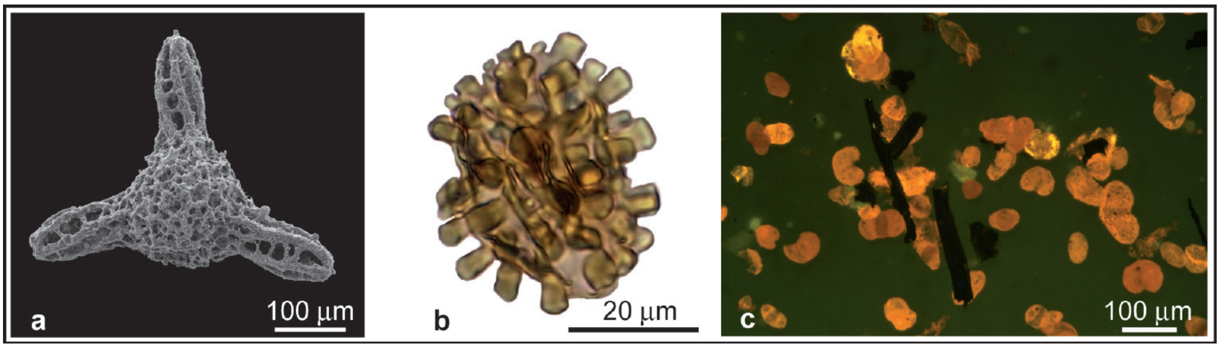

Fig.1. (a) Radiolarian (*Eptingium manfredi*). (b) Sporomorph (*Echinitosporites iliacoides*). (c) Palynofacies (under blue light epifluorescence).

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Coniancian-Santonian OAE3, myth or reality? Example from Olazagutia, (Spain), Ten Mile Creek - Arbor Park, (USA) and Gabal Ekma (Egypt).

Brahimsamba BOMOU[1], Thierry ADATTE[1], Jorge SPANGENBERG[1], Eric de KAENEL[2] and Karl B. FÖLLMI[1]

[1] *Institut de Géologie et de Paléontologie, Université de Lausanne, Unil-Dorigny, Anthropole, 1015 Lausanne, Suisse, brahimsamba.bomou@unil.ch*
[2] *DRP, Matile 51, 2000 Neuchâtel, Switzerland.*

Several episodes of strong anoxia occur in worldwide ocean domain throughout the Cretaceous, and are characterized by accumulation of laminated organic carbon rich sediments, which coincide with a positive excursion in $\delta^{13}C$. The Cenomanian-Turonian OAE2 is the most studied and appears clearly global. In contrast, the Coniacian Santonian OAE3 is still poorly known and requires multiproxy investigations. This event appears to be more dependant on local conditions than OAE2. Black shales associated with OAE3 were restricted to areas located around the Atlantic Ocean, such as the east tropical Atlantic Ocean, Ghana and Ivory Coast, Venezuela, Brazil and and the Western Interior Seaway of North America. Moreover, black shales linked with OAE3 appear to be more restricted to shallow water settings and epicontinental seas. Specifically, our study focus on bulk and clay mineralogy, phosphorus, stable oxygen and carbon isotopes, and high-resolution quantitative micropaleontology to evaluate biotic effects of anoxia, changes in climate and primary productivity. Several sections from different paleogeographic areas at different paleodepths are currently studied.

We investigate in details Coniancian-Santonian (C-S) sections from two potential GSSP sites: Olazagutia (NW Spain) and Ten Mile Creek-Arbor park (Texas, USA) and an additional section located in Sinai, Egypt (Gabal Ekma) which exhibits several layers enriched in organic matter associated with extensive bonebeds. The Ten Mile Creek- Arbor Park composite section consists of interbedded limestones, marlstones and claystones of the Austin Chalk Formation. The occurrence of the inoceramid *Cladoceramus undulatoplicatus* marks the C-S boundary. Several bentonite layers have been recognized just above the proposed C-S boundary and may provide a more accurate age. The lower part of the Olazagutia section is characterized by a marly facies, quite poor in macrofauna, but slightly enriched in organic matter overlain by marly limestone beds with very abundant irregular and infaunal echinoids. Inoceramids are very abundant in only one level with *Cladoceramus undulatoplicatus*, the marker of the C-S boundary. Both sections sections show no black shale layers and no $\delta^{13}C$ positive excursion around the the C-S boundary and therefore reflect dysoxic-oxic conditions. The Gabal Ekma section exhibits a mixed siliciclastic/carbonate sediments at the C-S transition. These siliciclastic sediments (sandstone, calcareous quartz arenite) associated with cross-bedded and wave ripples alternate with silty shales and laminated black shales, indicative of dysoxic-anoxic conditions. Above, three bones bed are present and contain vertebrate bones, shark teeth in a phosphatic matrix reflecting period of reduced sedimentation.

Our preliminary data suggests that OAE3 is rarely expressed by truly anoxic conditions and seems to be more linked to local conditions rather than global paleoenvironmental changes.