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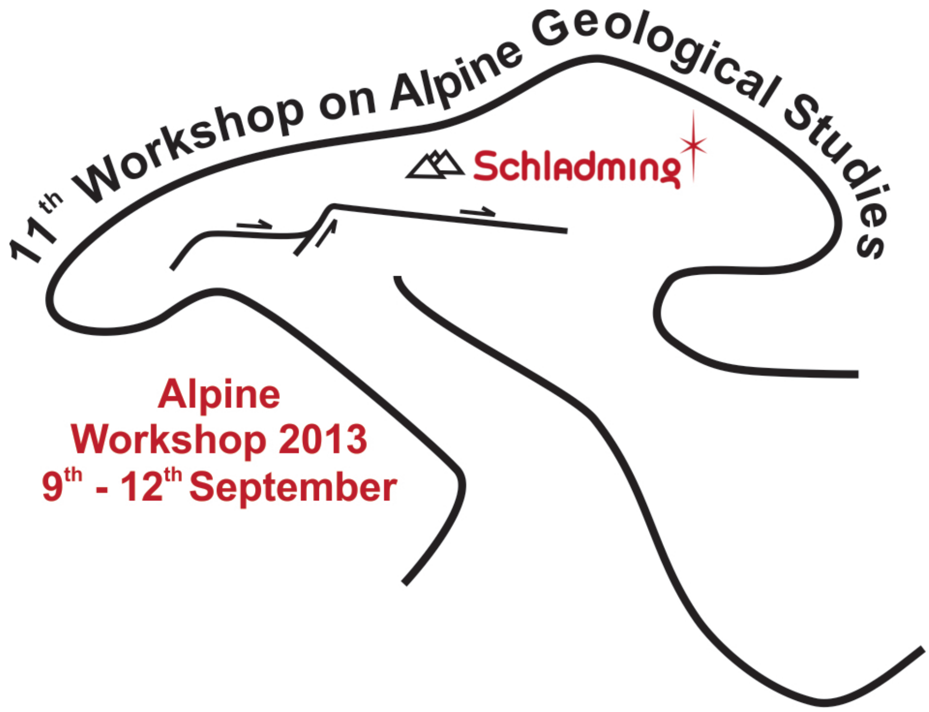

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Analysis of microseismicity in the Fribourg area (Western Swiss Molasse Basin)

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This study presents an analysis of microseismicity in the Fribourg area (Western Swiss Molasse Basin), a region that has recently displayed increased microseismicity (KASTRUP et al., 2007). Arrival time data of these earthquakes were used in a non-linear probabilistic earthquake relocation approach and to refine an existing three-dimensional (3-D) P-wave velocity model of the Fribourg area.

Two mini-arrays (seismic navigating systems/SNS) have been deployed since 2010 to enhance seismic monitoring of the Fribourg Lineament within the Fribourg area. A comprehensive local catalogue of microseismicity was build using recordings of the two SNS and of nine permanent stations of the Swiss Digital Seismic Network and the Swiss Strong Motion Network operated by the Swiss Seismological Service (SED). Events were detected on all traces by sonogram analysis, a non-linearly scaled and noise-adaptive spectrogram (SICK et al., 2012). It allows the detection of very low magnitude events, for which signal to noise ratio is minimal (JOSWIG, 2008).

Events were relocated using the non-linear probabilistic earthquake location software NonLinLoc (LOMAX et al., 2000). This approach requires consistent arrival time picking including uncertainties as well as a velocity model for the area. Initial arrival time picking was done using sonogram analysis. Arrival time picks were subsequently readjusted and its uncertainties were assigned according to New Manual of Seismological Observatory Practice (BORMANN, 2012). An initial 3-D P-wave velocity model was designed on the basis of controlled-source seismology data in the area (MEIER, 2009) and of a 3-D P-wave velocity model of Switzerland (HUSEN et al., 2003).

Since 2001, 314 were events detected in the Fribourg area, of which 112 events were detected routinely by the SED. In total 185 high-quality events were integrated in a local earthquake tomography analysis to refine the initial P-wave velocity model. Relocation of the events using the new tomographic model, yields on average smaller location errors as given by the volume of the 68 % confidence ellipsoid. Most of the events locate in the sedimentary cover, at depths shallower than 2500 m in the NNW and 4500 m in the SSE of our study region. The number of events located in the sedimentary cover is increasing by at least 3.5 % using our approach.

BORMANN, P. (2012): New Manual of Seismological Observatory Practice (NMSOP-2), IASPEI, GFZ German Research Centre for Geosciences, Potsdam.

HUSEN, S., KISSLING, E., DEICHMANN, N., WIEMER, S., GIARDINI, D. & BAER, M. (2003): Probabilistic earthquake location in complex three-dimensional velocity models: Application to Switzerland, J. Geophys. Res., 108.

JOSWIG, M. (2008): Nanoseismic monitoring fills the gap between microseimic networks and passive seismic, First Break, 26.

KASTRUP, U., DEICHMANN, N., FRÖHLICH, A. & GIARDINE, D. (2007): Evidence for an active fault below the northwestern Alpine foreland of Switzerland, Geophys. J. Int., 169, 1273-1288.

LOMAX, A., VIRIEUX, J., VOLANT, P. & BERGE, C. (2000): Probabilistic earthquake location in 3D and layered models. – In: THURBER, C.H. & RABINOWITZ, N. (eds.): Advances in seismic event location, Kluwer Acad., Norwell, Mass., 101-134.

MEIER, B. (2009): 2D Seismik Interpretation im Gebiet Fribourg und Berner Seeland, Report Interoil E&P Switzerland AG, for Resun AG, Zürich.

SICK, B., WALTER, M. & JOSWIG, M. (2012): Visual Event Screening of Continuous Seismic Data by Supersonograms, Pure Appl. Geophys.

Study of the thermal history of the Miocene Jarando basin (Southern Serbia)

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The Jarando basin is located in SSW part of Serbia and belongs to the internal Dinarides. It was formed during the Miocene extension affecting the whole Alpine-Carpathian-Dinaride system (SCHMID et al., 2008). In the study area Miocene extension led to the formation of a Studenica core-complex (SCHEFER et al., 2011) with the Jarando basin located in the hanging wall of the detachment fault.

The Jarando basin is characterized by the presence of bituminous coals, whereas in the other intramontane basins in Serbia coalification did not exceed the subbituminous stage within the same stratigraphic level. Furthermore, the basin hosts boron mineralization (borates and howlite) and hydrothermal-sedimentary magnesite, which indicate elevated temperatures.

Possible heat sources in the study area are magmatic activity, core-complex formation and burial of sediments. The intense Tertiary magmatic activity is represented by Oligocene I-type Kopaonik granodiorite, Miocene S-type Polumir granitoid, volcanics (SCHEFER et al., 2011) and subsequent hydrothermal fluid flow. The juxtaposition of warmer footwall units against cooler hanging wall units via rock uplift and exhumation of the Studenica core-complex could produce high heat flow in the Jarando basin.

This paper is aimed at providing new information about the thermal history of the Jarando basin. The vitrinite reflectance was measured for 11 core samples of shales from one borehole and 5 samples of coal from an underground mine. Fifteen core samples from three boreholes and 10 samples from the surrounding outcrops were processed for apatite and zircon fission-track analysis.

VR data reveal a strong post-depositional overprint. Values increase with the depth from 0.66-0.79% to 0.83-0.90%. Thus organic matter reached the bituminous stage and experienced temperatures of around 110-120°C (BARKER & PAWLEWICZ, 1986). All zircon grains from samples are older than the age of sedimentation. FT single grain ages for apatite scatter between 45 Ma to 10 Ma with a general trend towards younger ages with depth. The mean track length varies from 9.90±2.45µm to 12.32 ±2.23µm. Both the spread in single grain ages and the bimodal track lengths distribution clearly point to partial annealing of the detrital apatites. The temperatures given from the VR data and thermal modeling indicate short-lived thermal event around 15-12 Ma. The VR values and apatite FT modeling suggest two paleo-thermal events, heating and subsequent cooling. We correlate the thermal event with the extension and core-complex formation followed by the syn-extensional intrusion of the Polumir granite. Later cooling from 10 Ma onwards is related to basin inversion and erosion.

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BARKER, C.E. & PAWLEWICZ, M. J. (1986): The correlation of vitrinite reflectance with maximum temperature in humic organic matter. In: Lecture notes (eds. G. Buntebarth and L. Stegena), Earth Sciences, 5. Palaeogeothermics Springer-Verlag, Berlin, 79-93.

SCHEFER, S., CVETKOVIĆ, V., FÜGENSCHUH, B., KOUNOV, A., OVTCHAROVA, M., SCHALTEGGER, U., SCHMID, S.M. (2011): Cenozoic granitoids in the Dinarides of southern Serbia: age of intrusion, isotope geochemistry, exhumation history and significance for the geodynamic evolution of the Balkan Peninsula. - International Journal of Earth Sciences, 5: 1181-1206.

SCHMID, S., BERNOULLI, D., FÜGENSCHUH, B., MATENCO, L., SCHEFER, S., SCHUSTER, R., TISCHLER, M., USTASZEWSKI, K. (2008): The Alpine-Carpathian-Dinaridic orogenic system: correlation and evolution of tectonic units. - Swiss Journal of Geosciences, 101: 139-183.

Quartz vein formation during decompression and recrystallization in the Venediger Nappe Complex and Eclogite Zone of the southern Tauern Window (Eastern Alps): Fluid Inclusions linked with structures

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The Variscian Basement (Venediger Nappe Complex) and the Eclogite Zone are parts of the Subpenninic Units of the Tauern Window in the Eastern Alps. The investigated area, located in the southern Tauern Window along the Frosnitztal (Eastern Tyrol), shows asymmetric domino boudin structures with quartz-filled vein necks within the Venediger Nappe Complex. The amphibolite host rocks are surrounded by a layered penetrative foliation consisting of leucocratic melts (leucosomes) which can be linked with the Permian-Carboniferous intrusion of the Zentralgneis. Quartz samples are taken from the leucosomes and from the boudin neck structures.

In the Eclogite Zone concordant quartz layers occur beside carbonate-bearing micaschists and a penetrative foliation consisting of omphacite + garnet + epidote/zoesite + glaucophane. Three generations of fluid inclusions have been distinguished. On the basis of the textural occurrence and rheological characteristics, the chemistry of the metamorphic fluid during recrystallization of the leucosome layers and quartz-filled vein neck formation is reconstructed. It can be shown that during recrystallization and decompression the grade of salinity increases from about 6 to 15 mass% accompanied with a small change in the aqueous system H_2O-NaCl-$MgCl_2$±$CaCl_2$. This change occurred at estimated maximum P conditions around 850 MPa and temperatures of 500-550°C (fluid inclusion generation 1). Subsequent healing of micro-cracks postdates recrystallization in the range between 600 and 350 MPa (fluid inclusion generation 2). Restricted to the boudin necks a late fluid generation of primary character consisting of CO_2-H_2O-NaCl chemistry indicates entrapment conditions between 250-300 MPa which is linked with a late stage quartz vein precipitation in the boudin necks (fluid inclusion generation 3). These late veins are not recrystallized and contain conjugate microcracks that are different to earlier cracks which healed in recrystallized quartz aggregates (intragranular versus transgranular plane characteristics). In this late quartz vein generation fluid inclusion decrepitation features indicate isobaric cooling at the latest stage of the PT-evolution of the Venediger Nappe Complex.

Fluid Inclusions from a concordant folded quartz layer in the Eclogite Zone are compared to the fluids in the Venediger Nappe Complex but significantly different in their chemistry and densities. They are dominated by the N_2-CH_4-H_2O system and texturally arranged along intragranular planes within totally recrystallized quartz grains. The fluid chemistry of ca. 90 mol% N_2 can be related to the breakdown of K-bearing minerals like feldspar and mica during retrogression of the eclogitic host rock. Additionally a rare occurrence of pure aqueous inclusions is observed along cracks. Calculated low densities are indicative for reequilibration and leakage due to decompression and recrystallization.

Geometry, kinematics and P-T paths of the Money window (Western Alps): lower-pressure rocks overthrusted by higher-pressure ones?

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In the Western Alps, the polycyclic, eclogite-bearing units of the Gran Paradiso and Dora-Maira are thrusted over monocyclic, lower-grade units that contain as a diagnostic suite a sequence of graphite-rich sequences long ago thought to derive from Carboniferous sediments (Money and Pinerolo, respectively).

In detail, the Money window exposes in the Valnontey valley (Gran Paradiso massif, Western Alps) a sequence of clastic sediments and volcanics that are intruded by a granitoid body (Erfaulet metagranite). Two types of clastic sequences have been recognized. The first one essentially consists of greyish (i.e. graphite-rich) micaschists and polygenic metaconglomerates, reworking quartz veins, granitoids and some mud clasts. The second one is made of monogenic conglomerates (consisting essentially of quartz veins, with rare granitic pebbles), with a few interbedded graphite-rich micaschists. The two sequences are separated by fine-grained biotite-amphibole gneisses that display alkaline chemistry, and by albite-bearing gneisses and amphibolites. Although still uncertain, the few observed polarity criteria (graded bedding in the former conglomerate layers) are consistent with sequence 1 being older than sequence 2. In addition, this would be coherent with the transition from essentially polygenic to monogenic conglomerates (implying closer sources and /or higher relief for sequence 1 with respect to sequence 2) and a transition from graphite-rich to graphite-poor sediments (recording the climate change at the Carboniferous to Permian boundary). La-ICPMS U-Pb geochronology on detrital zircon grains and on the volcanics will be performed in order to test this hypothesis.

Detailed mapping and structural analysis has been made within the Money window, allowing recognizing four main stages of Alpine deformation. The first one is only identified as relic foliation (S1) in the cores of albite and garnet porphyroblasts, defined by the alignment of quartz, chloritoid and rutile. The second one is associated to a pervasive foliation (S2) that is parallel to the main lithological boundaries. This foliation is defined by garnet-chloritoid-white mica-rutile, and testifies to an early high-pressure event. The stretching lineation (L2) associated to this event has an E-W trend.

The third one is associated to a large-scale folding (F3) of the volcano-sedimentary sequence, and it is characterized by flat-lying axial plane with nearly E-W fold axes. The S2 schistosity is microfolded (crenulated) in the weaker lithologies, i.e. in the two clastic sequences, where a new mica-chlorite-ilmenite foliation develops. Because the F3 fold axes have a nearly E-W trend, they are almost parallel with the L2 stretching lineation. However, a minor angle is observed between the L2 stretching and the F3 fold axes, suggesting that the folds are non-cylindrical at a kilometer scale. 3D modeling of the geometry within the Money window will be displayed.

The thrust contact that separates the Money Unit from the overlying Gran Paradiso Unit predates this F3 folding event, because the mylonites at the base of the Gran Paradiso Unit are folded. Detailed petrological models will be performed in order to check the pressure difference between the hangingwall (Gran Paradiso Unit) with respect to its footwall (Money Unit). The consequences of these data with respect to existing models for the Alpine collision will be discussed.

A ductile shear zone terminating a brittle strike-slip fault: The gypsum-dominated Paluzza-Comeglians shear zone as western extension of the Fella-Save fault, Southern Alps

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Compressive and extensive horsetails are common structures on the lateral termination of brittle strike-slip faults, which forms within the shallow continental crust. Here we report another possibility, the lateral termination of a brittle strike-slip fault in a formation-parallel low-temperature ductile shear zone within sulphatic, gypsum-dominated evaporites. In the Southern Alps, over a distance of ca. 35 km, a steeply to gently S-dipping foliation, a subhorizontal stretching lineation and pure shear-dominated porphyroclast systems developed within the S-dipping Lower Bellerophon Formation of uppermost Permian age. Subordinate σ-clasts indicate dextral shear. The main-stage foliation is often overprinted by shear band structures, which also consistently indicate dextral shear along the shear zone. Open to tight faults form at several stages during shear zone development, and mainly refold the mylonitic foliation. Open folds are sometimes associated with reverse faults indicating final N-S shortening. Together, the structures within the Paluzza-Comeglians shear zone indicate transpression, which accommodated dextral displacement of the Fella-Save fault in the east.

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Analyzing hydrogeological properties of fault rocks and fracture networks in fault zones in carbonate rocks

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Around 60 % of the drinking water for Austria's capital Vienna comes from springs at the N and NE of the Hochschwab Massif. Hydrogeological flow properties in the Hochschwab Massif are essentially governed by karstified fault zones. We investigated sinistral strike-slip fault zones exposed in the Upper Triassic Wetterstein Fm., which formed at shallow crustal depth during the process of eastward lateral extrusion of the Eastern Alps in the Oligocene and Lower Miocene.

In detailed structural field-work we analyzed fault zone anatomy and distinguished zones of certain hydrogeological properties within the fault core and the damage zone. Fault rock classification, fracture network analysis and estimates over their spatial distribution in outcrop studies were supplemented by porosity and permeability measurements from representative samples. Additionally, thin-sections have been investigated with optical microscopy, cathodoluminescence and electron microscopy using backscattered electron imaging and focused ion-beam techniques.

The results show that by trend fault zones in dolomite lack a distinct, single fault core and masterfault but show multiple branching, minor fault cores that interlock in the 3D geometry of the outcrop. Fault zone formation in dolomite is accompanied and influenced largely by fluid interaction producing large volumes of cemented fault rock. In contrast fault zones in limestone have a definite fault core characterized by a distinct masterfault and delimited cataclastic fault rock associated. There is no evidence for spacious cementation processes.

Porosity values of fractured rocks show an exponential increase with increasing fracture densities, with an average effective porosity of 5 % for intensely fractured rocks. Fault rocks such as cataclasites show variable values of effective porosity (2% -6%) due to differences in their micro-structural fabric. The analytical methods provide an insight on deformation processes and features such as grain size reduction, cementation and recrystallization, and point out porosity and permeability differences due to deformation mechanisms and cementation events.

2D thermo-mechanical modeling of basement-cover deformation with application to the Western Alps

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The external crystalline massifs of Western Alps and the Helvetic sedimentary nappe stack result from the deformation of the European passive margin during the Alpine collision. This area has been studied extensively for the past hundred years. However although the geometry and tectonic structures are well documented, the mechanical behavior of the rocks during nappe stacking and basin inversion is still highly debated. The aim of this study is to reproduce the first order tectonic structures of the Western external Alps. We use a 2-D thermo-mechanical finite element model with visco-elasto-plastic rheology formulation to simulate the deformation of half-graben structures during collision. We systematically investigate the control of (1) the rheology, i.e. ductile vs brittle; linear vs power-law viscous rheology, and (2) the boundary condition, i.e. pure shear vs simple shear. Geometry and finite deformation patterns in both basement and sediments are then compared to cross-sections, finite strain ellipses and cleavage orientation from published field data. Orientation and distribution of plastic shear bands in the model are compared to fault distribution from field data and sand box analogue models.

Alpine evolution of the central Aar-massif (Grimsel section)

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The Aar-massif represents a polycyclic basement window representing a part of the inverted former European continental margin. The exhumation and cooling history of the Aar-massif have been already intensively discussed in the literature using fission track and U-Th/He data. However, the thermal and structural situations in the Aar massif in its adjacent tectonic units (e.g., Gotthard unit in the south, Helvetic nappes in the north) during Alpine peak metamorphic conditions (Tmax) are less clear. The maximal temperatures in the Aar massif are similar in age and level as in direct south oriented Gotthard unit and the trend can be followed towards the South into the Lepontine dome (i.e. in Oligocene-Miocene Barrovian metamorphism), a situation which is fundamentally different to other external massifs of the Western Alps (e.g., Aiguille Rouge-, Mont Blanc-, Pelvoux-massifs).

Several problems exist for the reconstruction of Tmax in such basement units: (1) the lithologies (mainly granitoids) are not ideal for P-T estimates based on conventional mineral assemblages, and (2) the timing of mineral equilibration is not clear (mixing of pre-Alpine and

Alpine temperatures). These problems in mind, we compiled metamorphic and isotope age data of the Aar massif in a central cross-section. We add own data using different geothermometers solely collected in Alpine shear zones (e.g., Ti-in-biotite, calcite-dolomite thermometry).

The available P-T conditions in the Grimsel area indicate conditions of ~450°C and 6.5 kbar, which is similar or only slightly lower as in the adjacent southern units (Gotthard units). Such elevated temperatures are found up to the central region of the Aar-massif and therefore no substantial change in temperatures from the southern to the central part is indicated. In contrast, the northern part of the massif shows fundamental lower Tmax (~250°C). These Tmax data suggest a change in the temperature field gradient from south (more constant) to north (relative steep).

The Grimsel area requires exhumation from depths of ~18 km since the Miocene, which is consistent with age and metamorphic conditions in the units further south (the thick skinned units of the Lepontine dome). The northern area shows much less vertical transport and is related to the physical emplacement conditions of the Helvetic meta-sedimentary units (thin skinned, fold and thrust belt). This variation and the related difference in vertical transport from south to north have to be connected to an array of numerous vertical shear zones inside the Aar-massif. Several of these shear zones show a steep transport direction, but also strike slip shear zones exist.

Despite the localized deformation in the individual shear zones, their large number and spatially homogeneous distribution is capable to accommodate uplift and exhumation on the scale of the entire Aar massif in a distributed manner. In other words, temperature offsets between individual shear zones are too small to be detected but in light of the whole Aar massif the shear zone arrays bring different former mid crustal levels to today’s exposed position at the surface.

The lithosphere-asthenosphere boundary below the Eastern Alps and the effect of eastward extrusion

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The Eastern Alps (EA) are the result of the European and Adriatic plates convergence. The architecture of this portion of the Alpine collision has been furthermore affected by a lateral (east directed) tectonic extrusion caused by the retreating subduction of the nearby Carpathians. Analysis of Ps and Sp receiver functions from datasets collected by permanent and temporary seismic stations, located in the EA, show the presence of a low velocity layer (LVL) at depth. This LVL might indicate the velocity drop that the seismic waves undergo passing through the asthenosphere, and it testifies a sudden lateral thickness change of the lithosphere. The detected thinner lithosphere is bounded by the Bohemian Massif to the north, and by the Lavanttal fault to the South-west. The detected asthenosphere is deeper (100-130 km) below the North Calcareous Alps, and shallower (70-80 km) below the Vienna Basin and Styria Basin. Unraveling the depth extent of the coherent rigid lithosphere moving over a weak asthenosphere helps deciphering the decoupling determining plate motions and tectonics of the EA. For the first time in the area the Lithosphere-Asthenosphere Boundary is imaged with such a clear depth variation, reflecting the depth extent of the dextral extrusion of the EA towards the Pannonian Basin.

Landscape evolution north of the Sonnblick (Salzburg) during the Alpine Lateglacial

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The area north of the Hoher Sonnblick, in the Austrian province of Salzburg, offers unique opportunities to study landscape forming events (glacial advances, glacial retreats and mass movements) since the Last Glacial Maximum (LGM). The field work revealed unique relationships of cross-cutting landscape elements.

These include multiple moraines and a till cover of a dominant glacial stadial overlying a giant landslide (0.4 km^3, largest in the province of Salzburg), which is then topped by a younger landslide of smaller dimension. The landslide events (13ka BP and 10ka BP), as well as the glacial advance (12.5ka BP) and retreat (11ka BP) were dated using the 10Be method. To establish an extensive chronology, six 10Be samples from the landslides, twelve 10Be boulder samples and two ^{10}Be polished bedrock samples related to glacier history were processed. Furthermore, ^{14}C samples were taken at suitable sites to augment the ages gained by exposure dating. The combination of the evidence found in the field and a detailed geological map, concentrating on Quaternary features, with ^{14}C dating and ^{10}Be dating made it possible to reconstruct the glacial chronology and the landscape evolution of the study area between 21ka BP and 1850 AD with special focus on the time between 14ka and 10ka BP.

Based on mapping and dating, we modeled the glacial dynamics of the Younger Dryas (Egesen stadial) glacier system and its relation to the prominent landslides (old: Allerød interstadial; young: Preboreal) from the onset of the ice advance to the retreat phase.
Detailed sedimentary evidence allows us to constrain the starting position of glaciers before the Younger Dryas advance, as well as reconstructing a confluence situation of the two local glaciers (Goldbergkees and Pilatuskees), producing a glacier system with a maximum surface area of 10 km^2. Furthermore, distinctive shaped moraine ridges allow us to shed some light on the glacier conditions during stabilization phases during the retreat phases of the Egesen. In addition, surface models revealed a reconstituted glacier geometry for the Egesen-age Goldbergkees.

We employed various methods for calculating Equilibrium-Line-Altitudes (Maximum Elevation of Lateral Moraines, Toe-to-Headwall-Altitude Ratio, Area x Altitude, Area x Altitude Balance Ratio, and Accumulation Area Ratio) and compared them to already available data from western Austria and Switzerland. With this data, we are able to reconstruct temperature and precipitation change of the local climate and glacier dynamics during the maximum of the Younger Dryas in the central part of the European Eastern Alps.

With our multiple-dated Egesen (Younger Dryas) glacier system as a solid basis, we critically discuss the correlation of Lateglacial to Holocene stratigraphy with our study area and other inner-alpine areas, based on high resolution climate archives in the North Atlantic region, which have been targets of palaeoclimate research.

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Thresholds in karst catchments: the example of the Lurbach karst system

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Threshold behavior in hydrological systems generally involves a qualitative change of either a single process (process threshold), the response of the system (response threshold), or the functioning of the system (functional threshold) (ZEHE & SIVAPALAN, 2009). The transition from laminar to turbulent flow provides an example of threshold behavior at the process level, which occurs when the ratio of inertial forces to viscous forces (represented by the Reynolds number) exceeds an empirical threshold value. This transition, for instance, occurs in karst aquifers where water flows rapidly through solution conduits, and it is known that it may strongly influence the hydrological response of the springs draining these aquifers. Assessing if and under which conditions this leads to threshold behavior at the response level, however, is not straightforward, as the spring response is governed by the interaction of several processes and flow components. One example of a response threshold is provided by the Lurbach System (Austria) where the sinking stream Lurbach, which under low-flow conditions only resurges at the Hammerbach spring, additionally supplies a second spring, the Schmelzbach outlet, once a given threshold discharge is exceeded. Interestingly, this threshold appears to have changed after a flood event in 2005, presumably because of the plugging of flow paths with sediments or collapse material. Flow duration curves, master recession curves, and the thermal response of the Hammerbach spring have markedly changed since then, suggesting that a sudden qualitative change in the hydrological functioning was triggered by this flood event (functional threshold). This example demonstrates that thresholds in karst catchments are closely connected to geomorphologic processes, such as sediment transport, and climatic factors, such as the occurrence of extreme events.

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ZEHE, E. & SIVAPALAN, M. (2009): Threshold Behaviour in Hydrological Systems as (Human) Geo-Ecosystems: Manifestations, Controls, Implications. Hydrology and Earth System Sciences 13 (7): 1273–1297.

Serpentinite slices within a tectonic zone at the base of the Juvavic nappe systems (Eastern Alps, Austria): petrography and geochemistry

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Near to Unterhöflein (Lower Austria/Austria) at the eastern margin of the Eastern Alps several tectonic slices of serpentinites occur within a highly tectonised zone composed of schist of the Werfen Formation and different Triassic limestones and dolomites. The tectonic zone is situated at the base of the Juvavic nappe system of the Austroalpine unit. In a similar position basic magmatic rocks are known from several other localities, mostly occuring within evaporitic sediments of the Permian Haselgebirge (GRUBER et al., 1992; SCHORN et al., 2013). Further between the Juvavic nappe system and the underlying Tirolic nappe system tectonic slices of the Meliata unit occur, which represents remnants of the Neotethys oceanic domain (MANDL & ONDREJIKOVA, 1993).

The largest serpentinite body, 400 to 100 meters in size, was investigated by petrological (X-ray diffraction) and geochemical (X-ray fluorescence) methods. The primary mineral composition was olivine + orthopyroxene + clinopyroxene + chromite. Olivine is completely replaced by chrysotile which shows the typical mesh-structures. Some grains of clinopyroxene are preserved, whereas the main part and the orthopyroxene were transformed into lizardite. Within some pseudomorphs after orthopyroxene the former cleavage and twin lamella are visible. Chrome spinel is mostly transformed into magnetite. Further Mg-rich chlorite, talc and hydrogrossular appear.

The mineral compositions of the former peridotites were recalculated by an interative method using a dataset of typical chemical compositions for fresh harzburgite and lherzolite and geochemical analyses of the serpentinites. The results indicate harzburgites as precursor rocks of the serpentinites.

According to SCHORN et al. (2013) the basic rocks from the Haselgebirge represent remnants of the Permian to Lower Triassic rift of the Meliata ocean. However, it is difficult to exhume mantle rocks to the surface with the proposed mechanism without creating a deep marine basin. However, the latter is not indicated by the evaprites and the overlying Triassic shelf sediments of the Juvavic nappes. In any case a relation of the harzburgites to westward propagation of initial rifting of the Neotethys ocean seems to be the most convenient explanation for the investigated rocks.

GRUBER, P., FAUPL, P. & KOLLER, F. (1992): Zur Kenntnis basischer Vulkanitgerölle aus Gosaukonglomeraten der östlichen Kalkalpen - ein Vergleich mit Vulkaniten aus dem Haselgebirge. - Mitt. Österr. Geol. Ges., 84: 77-100.

MANDL, G.W. & ONDREJIKOVA, A. (1993): Radiolarien und Conodonten aus dem Meliatikum im Ostabschnitt der Nördlichen Kalkalpen (Österreich), Jahrbuch der Geologischen Bundesanstalt, Wien, Band 136/ 4, 1993: 841-871.

SCHORN, A., NEUBAUER, F., GENSER, J. & BERNROIDER, M. (2013): The Haselgebirge evaporitic mélange in central Northern Calcareous Alps (Austria): Part of the Permian to Lower Triassic rift of the Meliata ocean? - Tectonophysics, 583: 28–48.

Large-Scale Deformation of the Eastern Alps from Seismic Anisotropy

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Internal deformation in the Eastern Alps is documented by seismic anisotropy, and we report here observations from SKS shear-wave splitting. Together with earlier observations from the Western Alps, these observations present one of the clearest examples yet of “mountain chain parallel fast orientations” worldwide, with a stunningly simple pattern of fast orientations, nearly parallel to the trend of the mountain chain. This simple pattern (of deformation) appears to be in contrast with the complex surface geology of the Alps. Regarding the pattern, we make a number of important observations: there are rapid spatial variations of fast orientation in certain parts of the Alps while there is little variation in others. Where fast orientations vary (Western Alps and the Tauern-Window region), they do so with nearly constant spatial rotation rate. In the Eastern Alps, the fast orientations do not “connect” with neighboring mountain chains, neither the present-day Carpathians, nor the present-day Dinarides, but rather with an intermediate orientation.

There is a clear jump of fast orientations across the Tauern Window, by about 45 degrees, somewhat similar to the geometry of the Adriatic indenter. In the very east, where lithosphere is thin, and where we most likely observe asthenospheric anisotropy, the anisotropy is consistent with eastward extrusion toward the Pannonian basin, if we assume that the anisotropy recorded relative motion of the surface with respect to the deeper Earth moving coherently with the Central Alps. An eastward extrusion has been suggested before, based on the pattern of seismicity, surface geology, and more recently geodesy. It appears that much of the deformation associated with the eastward extrusion is accommodated within the asthenosphere. This suggests that the entire lithosphere is escaping to the east, not only the crust.

The origin and age of the metamorphic sole from the Rogozna Mts., Western Vardar Belt: New support for the one-ocean model for the Balkan ophiolites

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This study reports new geochronological and petrochemical data from the metamorphic sole beneath the Rogozna Mts., Western Vardar ophiolite belt. The Rogozna metamorphic sole is located at the base of an Ibar serpentinite nappe and consists of (i) high-grade andalusite–garnet–sillimanite gneisses and cordierite-bearing hornfels (mostly listwanitized), (ii) medium-grade pyroxene amphibolites and hornfels, amphibolites, amphibolite schists and metagabbros and (iii) low-grade micaschists and talc-chlorite schists. Selected samples of the Rogozna amphibolites and talc-chlorite schists were subjected to the electron microprobe, SEM-EDS, $^{40}Ar/^{39}Ar$ analysis and whole-rock geochemistry. The Rogozna amphibolites are medium- to fine-grained rocks with nematoblastic texture and pronounced foliation. They consist of green amphibole (~70 vol.%) with variable silica contents (6.4 to 7.8 Si a.p.f.u.), as well as Mg# (molMg/[Mg+Fe_{tot}]; 0.53 to 0.77) and variably albitized plagioclase (~30 vol.%; Ab_{24}–Ab_{98}). Amphibolites are overprinted by a retrograde assemblage containing actinolite, epidote, clinochlore, sericite, chlorite and magnetite. The amphibolites formed due to metamorphism of two basaltic suites: subalkaline/tholeiitic and alkaline. Subalkaline/tholeiitic amphibolites possess low Zr, Nb, Y, Th, Hf, TiO_2 and P_2O_5 values and a LREE-depleted patterns typical for the N-MORB to BAB (back-arc basalt) origin. Alkaline amphibolites show elevated concentrations of Zr, Nb, Y, Th, Hf, TiO_2 and P_2O_5 with a LREE-enriched patterns typically displayed by ocean island basalt (OIB). Amphibolites crystallized during intra-oceanic thrusting at temperatures between 685 ºC–765 ºC and at a depth of 12–17 km. $^{40}Ar/^{39}Ar$ cooling ages of amphibole range from 165–170 Ma and slightly postdate the sole formation. The Rogozna talc-chlorite schists are related to retrograde greenschist-facies metamorphism after amphibolite facies conditions. They consist of talc (Mg-rich minnesotaite), chlorite (diabantite), serpentine and white mica pseudomorphs after amphibole and MORB-type Cr-Al spinel, surrounded by Al- and Mg- poor ferrit-chromite. The occurrence of ferrit-chromite is related to earlier, amphibolite facies metamorphism. Chlorite pseudomorphs after amphibole were formed at ~415 °C, whereas low-K white mica from the assemblage cooled below the argon retention temperature in a time period of ~95–105±25 Ma. The studied metamorphic rocks of the Rogozna Mts. underlying the Ibar serpentinite massive represent, therefore, typical products of metamorphic sole. The amphibolites are of igneous origin, displaying subakaline/tholeiitic and alkaline geochemical affinities. The protoliths of subakaline/tholeiitic amphibolites originated in a N-MORB or BAB setting. The alkaline group of amphibolites are analogous to E-MORB or OIB and their protolith derived from fragments of seamounts or islands from the lower oceanic plate. Maximum P-T conditions of the formation of the Rogozna Mts. metamorphic sole were 685–765 ºC and 4–6 kbar (corresponding to a 12–17 km thick overburden). The Rogozna Mts. metamorphic sole experienced rapid cooling below the closure temperature of hornblende and actinolite between 164.9±1.3 and 170.0±1.4 Ma. Intra-oceanic thrusting must have started maximum 5 m.y. earlier, between 170 Ma and 175 Ma. The greenschist-type retrograde assemblage was formed after medium-grade metamorphic conditions at ~415 °C. A weakly constrained Cretaceous age (95 and 105±25 Ma) obtained from white mica within talc-chlorite schists is related to the westward obduction of the Vardar ophiolites over the Adria continental margin. Data reported in this study clearly suggest that there is no essential difference in the emplacement age of the Dinaric and West Vardar ophiolite belts, supporting the interpretation involving a single Mesozoic ocean in the Balkan sector.

Tectonometamorphic record in the cover sequences of the western Tauern Window, Eastern Alps

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The Tauern Window in the Eastern Alps represent a tectonic window within Austroalpine crystalline nappes. The window is formed by the Venediger (Zentralgneiss) nappe system forming large scale antiformal dome structure with preserved Mesozoic cover sequences. This system is overlain by the Subpenninic nappes (namely Modereck and Wolfendorn nappe and Eclogite zone) distinguished from the rest of the nappes by discrete deformation record. The Subpenninic nappes are overlain by the Penninic nappes represented by the Glockner nappe, Reckner Ophiolitic Complex and Matrei zone.

In the studied area, the Venediger duplex is composed of nappes of late Variscan/Permian Tux Gneiss and Zillertal Gneiss with its post-Variscan (Permo-Carboniferous and Mesozoic) cover sequences (VESELÁ et al., 2011). The Subpenninic nappes in the hanging wall are represented by the Modereck and Wolfendorn nappes which are overlain by the Glockner nappe being part of the Penninic units (SCHMID et al., 2013). The nappes alltogether were previously named as Lower Schieferhülle, Upper Schieferhülle and their P-T conditions of up to blueschist facies were described by SELVERSTONE (1988, 1993).

Our detailed structural and petrological study focused mainly on the cover sequences represented by the post-Variscan cover and Subpenninic nappes and their tectono-metamorphic evolution with respect to the Central gneiss complexes.

The cover sequences consist mainly of schists, amphibolites and quartzites and they show dominant NW-dipping fabric in the northern and central parts of studied area and S-dipping fabric in the western part. The observed stretching lineation plunge to the W-SW. This dominant fabric is subsequently folded by open to tight folds with steep E-W trending axial planes and axes gently plunging to the W. The rocks were later affected by cleavage showing dip-slip kinematics with lineations perpendicular to fold axes.

The overlying Glockner nappe (former Upper Schieferhülle) is composed of deformed greenschists and marbles, which are together folded by large-scale open folds with NW trending fold axes and lineations and steep NW dipping cleavage in fold planes.

The metamorphic overprint observed in the cover sequences is characterized by occurence of garnet. These garnets show decrease in spessartine and sometimes also grossular component, while almandine and pyrope increase towards the rim. The core to rim increase in XMg documents the overall prograde growth of these garnets. An attempt is made to characterize this prograde evolution of a garnet by means of thermodynamic modelling.

VESELÁ, P., SÖLLNER, F., FINGER, F. & GERDES, A. (2011). Magmato-sedimentary Carboniferous to Jurassic evolution of the western Tauern Window, Eastern Alps (constraints from U-Pb zircon dating and geochemistry). - International Journal of Earth Sciences, 100: 993–1027.

SELVERSTONE, J. (1988): Evidence for east-west crustal extension in the Eastern Alps: implications for the unroofing history of the Tauern Window. – Tectonics, 7:87–105.

SELVERSTONE, J. (1993): Micro- to macroscale interactions between deformational and metamorphic processes, Tauern Window, Eastern Alps. - Schweizerische Mineralogische und Petrographische Mitteilungen, 73: 229-239.

SCHMID, S.M., SCHARF, A., HANDY, M.R. & ROSENBERG, C.L. (2013): The Tauern Window (Eastern Alps, Austria) – A new tectonic map, cross-sections and tectonometamorphic synthesis. - Swiss Journal of Geosciences, 106: 1–32.

Mobility Within the Subduction Channel: Correlation of P-T-D-t Stages Amongst Tectonic Fragments

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Numerical models of subduction channels indicate that tectonic mixing may be an important process. Opinions diverge with regards to possible origins of fragments, amplitudes of internal mobility, and temporal scales of such mixing processes. Recent work in the Sesia Zone of the Western Alps shows that the HP-evolution was substantially more long-lived and complex than previ¬ously established (e.g. RUBATTO et al., 2011). Significantly different HP-stages have been identified in different slices of the Eclogitic Micaschists Complex (EMC; REGIS, 2012), providing evidence of differential movements of HP-fragments, with subduction- and exhumation-related stages being recorded. The size, geometry, and ultimate provenance of fragments are in the focus of our present research.

We report on methods refined to relate petrochronology to structural data. Detailed analysis of local phase equilibria using X-ray images (XMapTools software) yields local P-T equilibrium conditions; these are combined with in situ U-Th-Pb dating for growth zones in allanite and zircon. Careful microstructural details (e.g. on deformation fabrics, mineral inclusions) and REE-distribution data are used to document an integrated HP-record for single samples. Provided that corresponding time intervals were recorded in several tectonic units, it appears thus possible to correlate HP-stages and deformation.

Results are shown for HP-fragments from several tectonic units in the internal Western Alps, with examples ranging from the eastern parts of the Sesia Zone right across to the Austroalpine klippen units now resting atop Piemonte-Liguria oceanic units:

- In eastern parts of the EMC (Mombarone area) HP-micaschist equilibrated at 1.9-2.0 GPa and 540-550 °C contains allanite dated at 85.8±1.0 Ma; zircon shows rims at ~75 Ma and 70-60 Ma, these reflect growth during decompression, but still at pressures >1.4 GPa.
- Further west (Val de Lys), micaschists from the EMC show a HP foliation (ECL-BLS facies) and weak (GRS facies) retrogression. Several generations of phengite, garnet, glaucophane (±early omphactie) and allanite are distinguished, plus quartz, epidote, chlorite, and titanite (rimming rutile). Growth zones in garnet and allanite correspond to distinct HP stages. Preliminary Th-Pb age data for allanite from in situ LA-ICP-MS analysis show 80-74 Ma for cores and 68-62 Ma for rims. These ages compare well with the two HP stages (HP1: ~75 Ma; HP2: ~65 Ma) REGIS et al. (subm.) found in several samples of the Fondo slice of the Sesia Zone, from which pressure cycling was inferred.
- Leucocratic gneiss from the Glacier-Rafray klippe shows assemblages with amphibole-phengite-epidote-plagioclase-titanite-quartz. Complex growth zoning in phengite allows us to establish a relative, but detailed P-T path. Replacement of phengite by chlorite adds late-stage information. When combined with published P-T data an absolute P-T path can be constructed. Dating of the HP-stage(s) is underway.

The analysis of the fossil continental margin between the Sesia Zone, the Piemonte Zone and the external klippen may have significant implications. Several stages and scenarios for the evolution of this margin need to be reconsidered, from pre-collisional rifting, formation of an OCT zone, through polyphase subductive processes to the juxtaposition of fragments during collision or exhumation.

REGIS, D. (2012): High-pressure evolution in the Sesia terrane (Italian Western Alps) – PhD thesis, University of Bern, 161 p, Switzerland.

REGIS, D., RUBATTO, D., DARLING, J., CENCI-TOK, B., ZUCALI, M. & ENGI, M. (subm.): Multiple metamorphic stages within an eclogite-facies terrane (Sesia Zone, Western Alps) revealed by U/Th-Pb petrochronology. – Journal of Petrology (submitted 2013).

RUBATTO, D., REGIS, D., HERMANN, J., BOSTON, K., ENGI, M., BELTRANDO, M. & MCALPINE, S.R.B. (2011): Yo-yo subduction recorded by accessory minerals in the Italian Western Alps. – Nature Geoscience. 4, 338–342.

Geodynamic and structural controls on the exhumation of Cenozoic metamorphic core complexes: Application to the Alpine-Carpathian-Hellenic orogenic belt

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Metamorphic core complexes (MCCs), particularly Cordilleran-type MCCs, represent typical the thick ductile/viscous material within the middle to lower crust and the mechanically strong upper crust within highly extensional tectonic setting. In the extensional setting, the rheological stratification is particularly the presence of a thick layer of highly ductile material, which results in an upward motion of the viscous material during progressive exhumation. Extensive studies of metamorphic core complexes have highlighted a fundamental problem that the relationship between the mylonitic rocks in the footwall of the ductile low-angle detachment fault at its top, and the brittle-deformed to undeformed hangingwall unit. The exhumed metamorphic rocks typically record a progressive change from ductile to brittle behaviors during decompression. As such, MCCs also reflect highly localized extensional strain on the scale.

As exemplified in the Alpine-Carpathian-Hellenic (ACH) orogenic belt, the exhumations of such MCCs are controlled by several processes including: (1) the retreat of the subduction zone, (2) extensional gravitational collapse of previously shortened lithosphere, (3) continental strike-slip component of tectonic plate movement, and (4) rheological stratification of the extending crust in post-orogenic settings. Our examples mainly include the Naxos MCC in the Aegean Sea, and Rechnitz and Tauern MCCs in the Eastern Alps, which represent Cordilleran-type MCCs. Cordilleran-type MCCs are exhumed virtually parallel to the regional extension direction. Such cases are common in post-collisional settings with extension of previously over-thickened lithosphere, or as in the case of the Aegean Sea, in a back-arc basin setting, which formed due to the retreat of a subduction zone.

Here, we propose a scheme between several possible end-member type cases of exhumation mechanisms of MCCs, e.g., classification of different detachment modes (e.g., rolling hinges, initial low-angle detachment) and contribution of pure-shear vs. simple-shear modes of exhumation. In these cases, upward motion along a detachment (ductile low-angle normal fault) and internal ductile thinning imply gradual exhumation with the youngest exhumation along a rolling hinge at the trailing edge of the MCCs.

Deformational styles at all scales are dominated by extensional structures similar to those documented in numerous MCCs. In all cases investigated by us, the level of the ductile low-angle normal fault is controlled by the presence of thick successions of calcite-dominated lithologies (e.g., calcite marble, calcareous phyllite), which are rheologically weak at low temperatures. These lithologies are overlain by quartz- and feldspar-rich lithologies in the upper hangingwall unit, which remains brittle during deformation. One of the most important meanings to occur in these low grade metamorphism rocks is the new recrystallized assemblage formed the lower the strength of the rock, active representing a matrix-controlled interconnected weak layer rheology. Strain partitioning results in preservation of high-temperature microfabrics, minerals and textures with low-grade mylonitic shear zones. As a result, grain size reduction associated by fluids circulating within shear zones leads to rock softening, which results in strain localization, weak rock rheology and the overall thermal structure of the crust.

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Differential compaction and early rock fracturing in the Triassic Esino Limestone high-relief carbonate platform (Central Southern Alps): field evidence and numerical modeling

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Syndepositional fractures are important features in high-relief, steep-slope carbonate systems as they control the occurrence of platform-margin collapse events, drive the generation of early diagenetic fluid flow systems and development of karst networks and may enhance permeability. Studies on modern and fossil carbonate systems recognized the importance of early (syndepositional) fractures, which can be generated by different processes (gravitationally controlled fractures, antecedent-topography controlled fractures, and tectonically controlled fractures).

In this study we focus on the generation of margin-parallel, gravitationally-induced early fractures driven by compaction of basinal sediments prograded by early-cemented high-relief carbonate platforms with steep slopes. Compaction is most effective when brittle early-lithified sediments prograde over unconsolidated basinal deposits.

Numerical models were used to investigate the effects of differential compaction on strain development and early fracturing in early-cemented high-relief carbonate platform, prograding onto basinal sediments, whose thickness increases basinward. Results show that basinal sediment compaction induces stretching of internal platform and slope strata in prograding platforms. When sediments are early cemented, such extensional strain is accommodated by the generation of syndepositional fractures. The amount of stretching is predicted to increase from the oldest to the youngest layers, due to the thickening of the compactable basinal sequences towards the external parts of the platform. Stretching is also controlled by the characteristics of the basin: the thicker and the more compactable the basinal sediments, the larger will be the stretching.

To test this model on a real case, ad hoc computations were dedicated to the Ladinian-Early Carnian carbonate platform of the Esino Limestone (Central Southern Alps, Italy), up to 800 m thick and with a top to basin relief of more than 500 m. This platform, after a prevailing initial aggradational stage, rapidly progrades on thinly-bedded fine-grained resedimented limestones. This case study is favorable for numerical modelling, as it is well exposed and both its internal geometry (inner platform, reef and prograding steep clinostratified slope deposits, consisting of reef-derived breccias) and the relationship with the adjacent basin can be fully reconstructed, as the Alpine tectonic overprint is weak in the study area. Furthermore, rapid early cementation processes affect the carbonate platform facies, so that conditions for creation and preservation of early fractures occurred. Evidence for early fracturing (fractures filled by fibrous cements coeval with the platform development) is described and the location, orientation and width of the fractures measured. The fractures are mainly steeply dipping and oriented perpendicularly to the direction of progradation of the platform, mimicking local platform margin trends.

The integration of numerical models with field data gives the opportunity to quantify the extension triggered by differential compaction and predict the possible distribution of early fractures in carbonate platforms of known geometry and thickness, whereas the interpretation of early fractures as the effects of differential compaction can be supported or rejected by the comparison with the results of ad hoc numerical modelling. The obtained models on generic platforms further indicate that strain induced by differential compaction is strongly geometry- and lithology-dependent.

Subduction flip in the Mediterranean and the asymmetry of Alps and Apennines

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Geological (magmatological and tectonic) observations and numerical models are used to constrain and describe the last 50 Myr evolution of the Central-Western Mediterranean. Both oceanic and continental lithospheric plates were diachronously consumed along plate boundaries with different styles of evolution and polarity of subduction. The hinge of subducting slabs converged toward the upper plate in the double-vergent thick-skinned Alps-Betics and Dinarides. The hinge diverged from the upper plate in the single-vergent thin-skinned Apennines-Maghrebides and Carpathians orogens. The mass deficit caused by the lithosphere retreat was compensated by passive asthenosphere upwelling and by the opening of several back-arc basins. The magmatic evolution of the Mediterranean area cannot be easily reconciled with simple magmatological models proposed for the Pacific subductions. This is due to synchronous occurrence of several subduction zones that strongly perturbed the chemical composition of the upper mantle in the Mediterranean region and, above all, to the presence of ancient modifications related to past orogeneses.

In our reconstruction, the W-directed Apennines-Maghrebides nucleated along the retro-belt of the Alps, following a subduction flip. The origin this process is investigated with 2D thermo-mechanical models. In particular we focus on the influence of mantle flow relative to the overlying lithosphere on subduction dynamics. We obtain that, for mantle flow supporting the slab, as occurred in the Alps, an initial stage of slab steepening is followed by a stage of continuous decrease in slab dip. This slab shallowing eventually leads to mantle wedge closure, subduction cessation and slab break-off, possibly driving to subduction flips.

As a result of the described geodynamic evolution, Alps and Apennines developed highly asymmetric. The Alps have higher morphological and structural elevation, two shallow, slow subsiding foreland basins. The Apennines have rather low morphological and structural elevation, one deep and fast subsiding foreland basin. While the Alps sandwiched the whole crust of both upper and lower plates, the Apennines rather developed by the accretion of the upper crust of the lower plate alone. Alpine relics are boudinated in the hangingwall of the Apennines, stretched by the Tyrrhenian back-arc rifting. Relative to the upper plate, the subduction hinge moved toward it in the Alps from Cretaceous to present, whereas it migrated away in the Apennines from late Eocene to Present, apart in Sicily where since Pleistocene(?) it reversed.

We investigated the origin of part of these asymmetries using 2D and 3D viscoelastic models. In particular we analyzed the dependency of the stress field of slabs and overriding plates on geometry (dip of the slab) and kinematics (velocity of convergence between upper and lower plates and their absolute velocity with respect to the underlying mantle) of subduction zones. We obtain that, although the state of stress in slabs and overriding plates is controlled also by other processes, down-dip compression in the subducting slab and extension in the overriding plate are enhanced by mantle flow opposing the direction of the dip of the slab, whereas down-dip extension in the slab and contraction in the overriding plate are favoured by mantle flow in the same direction of the slab dip (i.e., sustaining it). We conclude that the asymmetry of Alps and Apennines is primarily controlled by the slab polarity with respect to the westward drift of the lithosphere.

Structure and kinematics of the northern Adula nappe (Central Alps, Switzerland) and its emplacement in the Lower Penninic nappe stack

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The Adula nappe belongs to the Lower Penninic domain of the Central Alps. It consists mostly of pre-Triassic basement rocks containing also numerous eclogites. The Adula nappe has the peculiarity to comprise several cover occurrences within the basement. The nature of the deformation experienced by the nappe reveals a complex history with several deformation phases.

The purpose of our study is a better understanding of the Alpine kinematics of the northern Adula nappe with a special focus on the early deformation phases responsible for the nappe emplacement. This study is mainly based on a detailed geologic mapping of several representative key-areas in the Northern Adula nappe. It has been also extended to a multi-scale structural analysis of the nappe at a broader scale.

We recognized that the nappe emplacement is associated with two phases of deformation. The early Ursprung ductile deformation phase is characterized by folds that are compatible with a top-to-the-south shearing. The Zapport phase is partially contemporaneous with the Ursprung phase. It produces the main structural features of the nappe by ductile north directed shear and forms two generations of isoclinal nappe-scale folds. These folds are revealed by a detailed mapping in areas preserved by later deformation. The Zapport phase folds are complex synclines cored by the sedimentary cover at the front of the nappe.

In the Eastern transect of the Central Alps, the Adula nappe and the nappes derived from paleogeographic domains located south of the Adula domain (hyper-extended margin) are mostly emplaced by detachment and basal accretion in the Alpine accretionnary prism. In contrast, the Adula nappe and the other nappes located northward in the paleogeography are derived from a coherent European slab and form fold-nappes. The specific paleogeographic position of the Adula domain at the leading edge of a coherent European slab explains why this unit was subducted to depth sufficient to form eclogites. This leads the Adula nappe to act as a major shear zone during the nappe emplacement.

Two later deformation phases postdate mainly the nappe emplacement. The Leis and the Carassino deformation phases are principally characterized by NW-vergent folds. These deformations affect the nappe front formed during the previous nappe emplacement phases.

Two separated Lower Cretaceous basins in the Transdanubian Range, Hungary and their relation to the Eastern and Southern Alps

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The Transdanubian Range is the only tectonic unit where the original connection between the North- and the South-Alpine facies connection is preserved. The first signal for the stop of the more or less uniform development of the Transdanubian Range occured at the end of the Triassic. In the Bakony Mts continued the deposition of the platform carbonates in the Hettangian while the Gerecse (Eastern part of the Range) has been raised above the sea level at the end of the Triassic, the sedimentation started there in the Late Hettangian. Further on in the Jurassic the successions of the Bakony and the Gerecse Mts are similar. The basin is fragmented by submarine highs in the Early Jurassic. The sedimentation is more or less continuous in the basins while on the highs highly lacunose and condensed. Thanks to the rifting process of the Penninic ocean the tendency in both areas is the deepening till the end of the Middle Jurassic but the subsidence in the Bakony area was quicker than in the Gerecse. The result is that the first area became deep bathyal while the other one only shallow bathial.

Based on the Jurassic and Cretaceous formations in the axial (synclinal) part of the Transdanubian Range the Gerecse Basin is separated completely from the Bakony one in the Early Berriasian albeit the process started in the Late Tithonian already. In the South Bakony the pelagic Tithonian Szentivánhegy Limestone is replaced upward by the Maiolica or Biancone facies (Mogyorósdomb Limestone Fm) typical for the Southern Alps, while in the Gerecse the change is more complicated. In the Eastern Gerecse the Szentivánhegy Limestone is substituted by the Bersek Marl in the Early Berriasian while it lasted in the Western Gerecse until the Valanginian. As a consequence the formation of the Felsővadács Breccia as a product of an event at the boundary of the Berriasian/Valanginian it is found in the Bersek Marl in the Eastern Gerecse and in the Szentivánhegy Limestone in the Western Gerecse.

The result of the Eastward shallowing tendency is that the Berriasian-Hauterivian Mogyorósdomb Limestone is replaced by a crinoideal, ammonite and bivalve-bearing, highly condensed Borzavár Limestone restricted only for the Zirc Basin. The Biancone facies in the Southern Bakony turns into grey marl facies such as in the Karawanken.

The Lower Cretaceous in the Gerecse Mts is dominated by a coarsening upwards flysh type siliciclastic succession similar to the Rossfeld one and in part to the Inner Dinarides.

The two basins must have been united temporalily for the fist time in the Late Aptian when the crinoidal Tata Limestone covered the entire Bakony Mts and the Vértes Foreland and in part the Vértes Mts as well. This limestone is proved to be in the Tatabánya Basin and intercalated in the Lábatlan Sandstone as well.

The two basin separated again in the Early Albian (Austrian tectonic phase) when the whole Bakony Mts and is western continuation has been raised, strongly eroded, katsified and bauxite accumulated, as far as the sedimentation is continued in the Gerecse and in part of the Vértes Foreland. On the Western margin of the Gerecse and partly on the Vértes area restricted basinal facies developed which interfinger with the lower rudisted Urgonian limestone restricted for a few km broad zone only.

The large part of the Albian bauxite is covered by fluvial, lacustrine and later brackish-water – predominantly pelitic and marly sediments (Tés Clay Fm) in the Bakony Mts. The marine invasion came from the Gerecse the northern foreland of which platform carbonate existed since the Berriasian. The Tés Clay is overlain by the beds of the 2nd Urgonian limestone succession which was deepening step by step. In the Late Albian - Cenomanian time the entire Transdanubia Range but at least ist synclinal part has been flooded again thanks to the global sea level rise. After a long period when the fundamental differences between the two part of the Transdanubian Range North-Alpine and the South-Alpine origin ceased.

Late Cretaceous bimodal igneous association of the northern Kozara Mts. revisited: New geochemical data serving for refined geodynamic interpretations

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The recent interpretations suggest that the Sava-Vardar (SVZ) is a relic of the youngest Tethyan realm in the present-day Balkan area, which left behind after Upper Jurassic closure of the West and East Vardar domains. The SVZ supposedly represents the last suture between the Tisza/Dacia and Dinarides acting as upper and lower plate, respectively. One of the best exposed SVZ segments is found on the Kozara Mts. (northern Bosnia and Herzegovina). We here report and discuss new geochemical data on igneous rocks of the northern Kozara Mts. in order to further constrain their geotectonic setting and with special emphasis on the petrogenetical link between the basic and acid rock suite.

The northern Kozara Mts. bimodal igneous association is thrust onto the West Vardar ophiolites of the southern Kozara Mts. and is unconformably overlain by Late Cretaceous-Paleogene fluvial siliciclastic sediments. It consists of isotropic to layered gabbro, diabase dykes and basaltic pillow lavas and hyaloclastites, as well as of relicts of rhyodacite-rhyolite lava flows and extrusions and subordinate small-scale granitoid intrusions representing basic (BS) and acid suite (AS), respectively. We analyzed 13 samples of the BS and 11 samples of the AS on major and trace element concentrations (including rare earth elements – REE) in the ACME Laboratories Ltd. Vancouver (Canada). A vast majority of the studied rocks show silica contents <53 wt % or >64 wt % SiO_2. The BS and AS rocks show different trends on Harker's diagrams with SiO_2 as index of differentiation. Thus, Al_2O_3, P_2O_5 and TiO_2 contents in the BS rocks mostly increase with increasing silica concentrations, while in the AS rocks the opposite trend is observed. On the chondrite- and primitive mantle-normalized diagrams for REE and incompatible trace elements, respectively, the BS rocks show relatively flat to moderately light-REE enriched patterns with no or weak negative Eu-anomaly. The AS rocks exhibit steeper patterns and have distinctively more pronounced Eu- and Sr- negative anomalies. Compared to the known intra-ophiolitic granitoids from the Eastern Vardar Zone, the AS rocks show geochemical similarities to oceanic plagiogranites.

These new geochemical data confirm earlier opinions that the BS rocks of the northern Kozara Mts. neither derived from pure mid-ocean ridge basalts (MORB) nor from volcanic arc basaltic magmas. This conclusion appears to be robust even taking into consideration that most BS rocks crystallized from evolved magmas. Moreover, it is suggested that the BS primary magmas probably correspond more to enriched MORB (or to MORB+EMORB) than to typical ocean island basalts. On the other hand, geochemical characteristics of the AS rocks indicate that their primary magmas most probably originated via partial melting of the altered gabbros from the lower oceanic crust. Main geodynamic implications of our study are, first, that it confirms the oceanic nature of the northern Kozara Mts. rock assemblage, and second, that it could have formed within an anomalous ridge setting similar to present-day Iceland. We therefore challenge previous interpretations that the northern Kozara Mts. ophiolites are relicts of an oceanic plateaux from a wide oceanic area.

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The Meliata and Piemont-Ligurian rifted margins: stratigraphic record and tectonic evolution of polyphase rift systems

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The Late Permian to Late Jurassic paleogeographic evolution of the Alpine domain was strongly controlled by the formation of polyphase rift systems. If these rift systems are the result of a single, long lasting rifting event or if they are generated by two distinct rift pulses is still a matter of debate. Recent studies seem to agree on the second hypothesis, supporting two distinct rift events: one Early-Middle Triassic (Meliata s.l.) and one Early to Middle Jurassic (Piedmont-Liguria s.l.). Nevertheless major incertitude arises on the interpretations of the evolution of the former rifting, which leads to either multiple or one single, continuous ocean branch. This uncertainty is mainly due to the successive orogenic overprint related to the formation of the Alpine belt and of the Western Mediterranean domain. The aim of this work is to explore how rifting events are recorded by the stratigraphic and structural evolution using both the vast existing literature and own observations. Selected areas belonging to different paleogeographic domains in the Alpine realm (Southalpine, Briançonnais s.l. and Austroalpine) will be studied in order to define relevant time-marker levels to map and correlate the temporal and spatial evolution of rift events. With this “basinal” approach we point to major tectonic events, filtering smaller-scale tectonics and minor environmental controlling factors on sedimentation. Our final goal is to identify the “fingerprints” for major rifting events that may enable to map the location and timing of hyper-extended domains. The evaporitic successions, the onset of thick carbonate platforms, their demise or drowning, the iron-manganese hardgrounds sedimentation (that may represent a response of hydrothermal circulation associated with hyper-extension) may correspond to correlable and mappable residues of large-scale rift events. These observations, together with data of the subsidence history, exhumation of basement rocks and magmatic evolution may provide a major, well-constrained framework that can be used to compare the evolution of the Alpine domain with that of present-day rifted margins.

Stratigraphic architecture and correlation of rifting-related deposits of potential conjugate distal margins: the Ligurian Prepiedmont-Piedmont (I) and the Lower Austroalpine (CH)

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Major rifting within the Alpine domain was active since the Late Triassic and led to the exhumation of subcontinental mantle and the formation of an embryonic oceanic domain during Late Middle Jurassic time (~165Ma). The rift history is recorded in several sectors of the Alpine belt, where complete pre- to postrift successions are preserved. These successions record the evolution of different sedimentary basins, showing different architectures and sedimentary evolutions. Today they are preserved in different Alpine domains and at different structural levels in the Alpine nappe pile as a result of the Alpine collision. In this work, we focus on the sedimentary successions of different domains of the former distal rifted margins: those belonging to the Ligurian Prepiedmont and Piedmont domains, outcropping in the Ligurian Alps in Italy (European margin) and those belonging to the Lower Austroalpine exposed in the Central Alps in SE Switzerland (Err, Bernina units; Adria margin). We chose these domains because of the completeness and the correlatability of the sedimentary successions. We aim to test if, with a certain degree of approximation, these areas can be considered as part of a former "conjugate" rift system and if sedimentation shows evidence of continuity along composite sections across these domains. The two margins are characterized by sudden drowning of a Late Triassic to Early Jurassic shallow-water carbonate platform into a Lower Jurassic carbonate ramp. In the Ligurian Prepiedmont the drowning event is dated as Lower Hettangian to Lower-Middle Sinemurian and it is characterized by the deposition of discontinuous condensed deposits (Fe-Mn hardgrounds). This level has a good correlation potential through both the sections. The following external-platform to ramp carbonates deposited in different basins, more or less subsident (e.g. Arnasco-Castelbianco). Locally, they are followed by huge amounts of coarse breccias, fed by the progressive activation of fault-scarps during the ongoing deformation in highly subsiding troughs. At the same time, ramps with moderate gravity flows formed in the areas directly facing the future exhumation zone (i.e. Lencisa, Bardella sections) testifying its progressively deepening trend. The sedimentation was interrupted by successive episodes of condensation, in the Upper Sinemurian and in the Pliensbachian. At the scale of the basin, these events show quite a good correlation considering selected areas. Successively, accommodation space was created especially above the major exhumation fault(s). The portion of the margin closely-facing the exhumation area was dismembered in blocks, (extensional allochthons; e.g. Piz Alv, Piz Bardella) while just above the main exhumation area, a depression formed (outer trough) hosting a composite sedimentation made up of deep water deposits (calcschists) and slices of exhumed serpentinite (Montaldo Unit). Thus, despite of all the complications that may be introduced considering local basin subdivision, the general stratigraphic framework in the two study areas is pretty well comparable and shows a first-order similar evolution of the sedimentation during the initial stage of rifting, beginning to clearly differentiate only after the exhumation stage. In addition, we recognize some new elements for a more accurate stratigraphic correlation of synrift deposits. These data lead us to consider that the studied sections can be approached as "conjugate" domains within an evolving rift system, with a good degree of continuity in stratigraphy and in sedimentological features.

Geochronology of Alpine shear zones in the Mont Blanc region using $^{40}Ar/^{39}Ar$ step-heating and Rb-Sr microsampling techniques

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Timing of deformation in the Mont Blanc massif in the western Alps and the understanding of its structural evolution, especially with regard to its recent exhumation, remains a matter of debate. Ductile deformation in the Mont Blanc region lasted from Oligocene to Late Miocene times, resulting in the development of the Helvetic nappe stack, with the Mont Blanc massif forming a crustal-scale fold-nappe. Generally NW-directed thrusting interacts with dextral transcurrent movements related to the Rhône-Simplon fault along the Chamonix valley and the Val Ferret on the internal side of the Mont Blanc massif. This case study presents geochronological data from 11 sample locations collected at 6 key areas in the Mont Blanc-Aiguilles Rouges region, which represent different stages in the tectonic evolution of the area. The $^{40}Ar/^{39}Ar$ step-heating method on white mica and the Rb-Sr microsampling method on texturally-controlled, µg-sized white mica - calcite pairs in textural equilibrium were applied to samples collected from individual low-grade shear zones with the aim of obtaining direct constraints on ages of deformation from synkinematically grown or recrystallized minerals. The results are critically assessed with respect to cooling versus neocrystallization ages and their assignment to distinct periods of tectonic activity in the Mont Blanc area is discussed. The sampled shear zones are low-grade mylonites and phyllonites and because of their deformation temperatures most of the ages obtained are interpreted to reflect neo-/recrystallization of synkinematic minerals, therefore giving deformation ages. Steep and often conjugate shear-zones in the Chamonix zone between the eastern margin of the Aiguilles Rouges massif and the western margin of the Mont Blanc massif overprint the main Alpine fabric related to NW-directed shear. Ages from such shear zones indicate a change from intensive NW-directed shearing between Mont Blanc and Aiguilles Rouges massifs to more coaxial deformation between the two massifs around 14.5-15 Ma. This is interpreted to be related to a collective updoming of the two massifs from Middle Miocene times. 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. Rb-Sr microsampling ages of 27-30 Ma from the Mont Chétif reflect early stages of deformation in the study area in the footwall of the Penninic thrust in Oligocene times, whereas Early Miocene $^{40}Ar/^{39}Ar$ ages (18-20 Ma) from the same sample are interpreted to reflect cooling below the closure temperature of the $^{40}Ar/^{39}Ar$ system of white mica. However, the youngest sample from the Mont Chétif basement yielded a Late Miocene age, suggesting that subsequent folding that overprints the shear zone must have taken place after 9.5 Ma. One age spectrum from Col de la Seigne of 28-35 Ma fits well with Oligocene activity along the Penninic thrust. A NW-verging shear zone between the Mont Blanc granite and Mont Blanc paragneiss, close to Champex-Lac and coinciding with the Faille du Midi, yields ages between 15-20 Ma. The age results provide key time constraints for our new model for the structural and temporal evolution of the Mont Blanc area during the Neogene.

Development of nappe stacking in the eastern Tauern Window with special attention to new Rb/Sr biotite and ^{40}Ar/^{39}Ar white mica ages, and peak-temperature data

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The Tauern Window (Eastern Alps) exposes a Paleogene nappe stack comprising European derived units (Subpenninic units) and Penninic units (Glockner, Matrei nappes) below the Austroalpine units. The Subpenninic units form the cores of two domes at the eastern and western ends of the Tauern Window. Our work focuses on the Eastern Tauern Dome where a peak-temperature of c. 612° C was recorded in the core of Subpenninic units and c. 500°C was measured at its rim in contact with the Penninic nappes. Peak temperatures at the contact of the Penninic units with the Austroalpine nappes are ≤ 450°C. Grt-st, grt-bt and bt-wm thermometers yield temperatures in the range of 596 to 630°C, calculated for a mean pressure of 9.2 kbar obtained with the chl-bt-ms geobarometer. These temperatures lasted at least until 25.4 ± 2.5 Ma according to a $^{147}Sm/^{144}Nd$ formational age on garnet that overgrew the main foliation related to nappe stacking but that predates doming.

The Eastern Tauern Dome is itself divided in two smaller domes (Sonnblick, Hochalm) and the intervening tight Mallnitz synform. Reddy et al. (1993) proposed that the Sonnblick Dome cooled earlier than the Hochalm Dome based on distinct clusters of Rb/Sr biotite ages in the cores of the Sonnblick and Hochalm domes. However, when combined with this existing dataset, our new $^{87}Rb/^{86}Sr$ biotite ages point to simultaneous cooling of the domes to below the closure temperature of this isotopic system (300°C). $^{87}Rb/^{86}Sr$ biotite ages decrease from 23-20 Ma in the northwest to 19-16 Ma in the southeast and do not vary in a transect across the Mallnitz Synform. Also, $^{87}Rb/^{86}Sr$ white mica ages range from 30-26 Ma to 25-20 Ma and apatite fission track data young in the same direction. A SE-ward increase in the intensity of mylonitic shearing along strike of the Mallnitz Synform is interpreted to be a manifestation of stretch faulting that was kinematically linked to top-E to–SE directed normal faulting along the central part of the Katschberg Shear Zone System (KSZS, SCHARF et al., 2013). We attribute the SE-ward decrease of the $^{87}Rb/^{86}Sr$ biotite cooling ages to an increased component of tectonic unroofing towards the eastern and southern margins of the Tauern Window. Moreover, new $^{40}Ar/^{39}Ar$ laser ablation data on individual mica grains in a transect oriented perpendicular to the central part of the KSZS yields ages between 31 and 13 Ma in the footwall. Nine samples were analyzed and their microstructural setting brackets the ending of rapid exhumation. The ages lead to the conclusion that ductile shear along the KSZS started sometime before 20 Ma at a temperature of more than 470°C and ended no later than 17 Ma at the contact of the KSZS with the Austroalpine unit above.

The consideration of structures in the Tauern Window combined with our new garnet age constrains duplex formation to have occurred before 25 Ma. Moreover, there is no difference in the cooling histories of the Hochalm and Sonnblick domes, indicating that the Eastern Tauern Dome was exhumed as a single unit during doing and coeval extensional exhumation in the footwall of the KSZS. Shearing along the KSZS started no later than 20 Ma and ended at about 17 Ma. The onset of rapid cooling related to fast exhumation is still poorly constrained, but probably began no earlier than 21 Ma according to stratigraphic criteria in the Giudicarie Belt of the Southern Alps (SCHMID et al., 2013).

REDDY, S.M., CLIFF, R.A. & EAST, R. (1993): Thermal history of the Sonnblick Dome, south-east Tauern Window, Austria: Implications for Heterogeneous Uplift within the Pennine basement. - Geologische Rundschau, 82: 667-675, Stuttgart.

SCHARF, A., HANDY, M.R., FAVARO, S., SCHMID, S.M. & BERTRAND, A. (2013): Modes of orogen-parallel stretching and extensional exhumation in re-sponse to microplate indentation and roll-back subduction (Tauern Window, Eastern Alps). - Int. J. Earth Sci. (Geol. Rundschau) DOI 10.1007/s00531-013-0894-4.

SCHMID, S.M., SCHARF, A., HANDY, M.R. & ROSENBERG, C.L. (2013): The Tauern Window (Eastern Alps, Austria) – A new tectonic map, cross-sections and tectonometamorphic synthesis. Swiss Journal of Geosciences, 106: 1–32.

Jurassic to Early Cretaceous basin evolution of the northern Transdanubian Range: structural influences of two oceans

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The northern Transdanubian Range (TR), Hungary occupied a paleogeographical position between the Neotethys and Alpine Tethys during the late Jurassic and early Cretaceous. Structural events in the two oceanic domains strongly controlled the basin evolution.

We used field structural measurements, mapping, sedimentological and stratigraphical analysis to date the succession, reconstruct the basin geometry and structural evolution. To place structural data in Alpine frame, an 80–50 counterclockwise Cenozoic rotation should be considered.

Jurassic basin evolution started with differentiation of the Triassic carbonate platform in the Sinemurian. Syn-sedimentary dykes and faults prove extensional deformation related to early rifting events of the Alpine Tethys. The direction of extension was NNE–SSW at present position. Different Jurassic successions indicate map-scale faults: WNW–ESE trending normal, and N–S striking transfer faults with oblique-slip. As the revival of Early Jurassic faulting, nodular "Ammonitico rosso" and Bositra limestones deposited in syn-sedimentary half-grabens.

In geodynamic models, late Middle to Late Jurassic times were marked by the subduction of the Neotethys Ocean. For the TR, such models would mean N–S to NE–SW directed compression. However, direct structural observations indicate extensional or transtensional deformation. Observations can be consistent with a model that Late Jurassic extension could form on the bended part of the slab subducting to N or NE. The obducting Neotethyan oceanic crust and related nappes thrust over this downbended slab.

Long-lasting carbonate sedimentation stopped in the late Berriasian. The following Valanginian to Aptian basin evolution was dominated by clastic input from the approaching Alpine–Carpathian–Dinaridic nappe pile containing Neotethyan ophiolite and accreted passive margin rocks. The subsidence of the basin was caused by the increasing load of the emerging orogenic wedge. The TR remained on the southern side of this flexural basin during the Valanginian-Hautrivian. The instable slope was deformed by large slides with northern or north-eastern vergency. The more southerly located forebulge was marked by strongly reduced carbonate sequence.

In the Barremian to Aptian coarse clastics dominated over the marl deposition. Sedimentation took place in form of submarine fans. The orogenic wedge approached but still did not reach the TR clastic basin. After sedimentation ceased, the northern TR was gently folded and faulted by N–S or NE–SW compression in the earliest Albian.

As a major change, the whole TR was deformed by NW–SE compression. Large-scale NE-trending folds and thrust faults were completed from Albian to Coniacian (113–86 Ma). As part of this phase, the TR thrust over different Alpine nappe units and integrated to the Austroalpine system.

This structural evolution suggests that the TR changed completely its structural position: it was on the lower plate in the Jurassic–early Cretaceous and became the highest unit in the "Mid-Cretaceous" phase. This needs a major reorganisation of the subducting and overriding plates. We follow earlier suggestions that a major strike-slip fault operated during this time. The large shift placed the TR and its Neotethys-related foreland-type Early Cretaceous basin in the rear of the subduction, in the highest position.

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Late Miocene depositional units and syn-sedimentary deformation in the western Pannonian basin, Hungary

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The Pannonian Basin system is due to late Early to Mid-Miocene lithospheric extension and related crustal faulting between 19 and 11.6 Ma. The faults bounded more or less isolated sub-basins with few hundred meters of marine sediments while the intermittent basin highs were marked by a reduced sedimentation or erosion.

At the beginning of the Late Miocene, the sedimentation has been changed and the brackish Lake Pannon developed. Between 11.6 and 9.7 Ma the former basin highs were progressively inundated and the surface and volume of the lake increased. Since 9.7 Ma onwards clastic input via extensive fluvial networks progressively filled the lake, large scale normal regression took place.

Late Miocene deposition pattern, facies relationship and coeval structural geometry and kinematics, as well as their influence on sedimentation was studied by the help of surface structural, sedimentological and palaeontological observations, by 2D and 3D seismic reflection data sets. Our research extended into the Transdanubian Range (TR), the largest high in the Miocene, and sub-basins W, S and SE of it.

The transgressive phase resulted in in a spatially variable facies pattern. Deep lacustrine marls of large thickness accumulated in the deep sub-basins and condensed marls in the less than 100 m deep waters covering the basement highs. This lithofacies is characteristic along the western margin of the TR during 9.5–9 Ma. The clastic input reached the western Pannonian basin from the NW and N. As rivers entered the lake deltas of ca. 20–50 m thick coarsening upwards successions were formed. These shelf deltas prograded towards basin-margin-slopes of several hundred meters high in the deep sub-basins, and also towards flooded basement highs where slopes were missing. Deltas were prograding across both type of areas, but above deep basins deltaic successions has a large thickness, while on highs a reduced sequences.

Systemathic mapping of shelf-to-basin clinoforms clearly indicate the influence of basement highs which deflected slope progradation into a direction sub-parallel to highs. These basement highs were partly inherited from the syn-rift deformation, however, seismic sections clearly demonstrate active syn-sedimentary faulting during the transgressive phase and partly during slope progradation, ca. between 11.6 and 8.5 Ma. Fault-controlled abrasional gravels and fault breccias are found along the margins of TR, were most likely coeval with the flooding of highs and and might have occurred between 9.5 and 8.8 Ma. Surface measurements suggest an E–W to ESE–WNW extensional (transtensional) stress field in agreement with seismic fault mapping. South from the TR, thickness of basinal marls decreased above E–W trending active transpressional ridges between ca. 12 and 9 Ma. After the ceasion of deformation during slope progradation between 9 and 8 Ma, growing of E–W trending anticlines started from 8 Ma. However, regional subsidence counterbalanced anticlinal growth and deltas overstepped folds.

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Garnet systematics of a polymetamorphic basement unit: Evidence for coherent exhumation of the Adula Nappe (Central Alps) from eclogite-facies conditions

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The Adula Nappe in the Central Alps is derived from the former continental margin of the European Plate that was subducted beneath the Adriatic Plate during the Alpine orogenic cycle. It consists of pre-Mesozoic basement (various gneisses with layers of garnet-micaschist, and bodies of mafic and locally of ultramafic rocks) and few Mesozoic cover rocks. High-pressure and ultra-high-pressure conditions are preserved in eclogite and ultramafic rocks but are apparently not recorded in the gneisses that build up the bulk of the nappe. It is unclear whether the unit constitutes a tectonic mélange that is compiled of rocks with different Alpine PT histories or wether it represents a coherent unit that was subjected to eclogite facies conditions as a whole. Within the nappe, eclogite-facies conditions and post-peak pressure amphibolite-granulite-facies conditions display increasing peak temperatures between 500 °C and >750 °C from north to south.

We present Lu-Hf garnet ages and detailed garnet chemistry of eclogite samples from several locations throughout the Adula Nappe. Samples from the central Adula Nappe are characterised by the presence of two populations of garnet. A first generation yields a Variscan Lu-Hf age and a second one an Alpine (Late Eocene) age, a result already established at the locality Trescolmen and here shown for more locations. In eclogites from the southern Adula Nappe, Alpine metamorphic conditions completely reequilibrated Variscan assemblages and garnet reveals exclusively Eocene Lu-Hf ages. In contrast, garnet is almost unaffected by Alpine metamorphism and is consistently of Variscan age in the northern Adula Nappe. Hence, the degree of Alpine metamorphic overprint and an associated re-equilibration of the Lu-Hf system is maximal in the southern part of the unit and decreases towards the north. Isotopic ages are in line with microstructural observations and major-element maps of garnet. Element maps display fully equilibrated garnet in the southern Adula Nappe, i.e. garnet with a homogeneous composition due to diffusive reequilibration during Alpine metamorphism. In the central nappe, relicts of an older, partly reequilibrated Variscan garnet generation are overgrown by a second Alpine generation with perfectly preserved prograde zoning and no diffusive overprint at all. Towards the north, the Alpine generation becomes less abundant and is absent in the northermost eclogite sample.

Eocene garnet ages are about the same through the entire nappe, 35-38 Ma. This and the continuous gradient of Alpine metamorphic overprint in high-pressure assemblages strongly suggest that the Adula Nappe essentially remained coherent during Eocene high-pressure metamorphism and exhumation despite very intense deformation. The gneissic host rocks of eclogites very likely experienced the same high-pressure metamorphic conditions but did not completely equilibrate, and later re-equilibrated during exhumation (see also abstract by KURZAWSKI et al., same volume).

A review of magmatic zircon ages from the Rhodope Metamorphic Complex: tectonic implications

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The Rhodope Metamorphic Complex is a stack of thrust sheets assembled during a protracted history of tectonic deformation during the Mesozoic and Cenozoic. Most studies on the geology of the Rhodope Metamorphic Complex (including the Rhodope Massif and the Serbo-Macedonian Massif) are regional investigations and address local problems. As a result the number of local nominations and tectonic subdivisions made large scale tectonic interpretations difficult. JANAK et al. (2011) proposed a simplified tectonic subdivision, merging all the known units of the Rhodope Metamorphic Complex into four super units (allochthons), namely the Lower (LA), Middle (MA), Upper (UA), and Uppermost Allochthon (UMA).

Due to the scarcity of distinctive lithologies, geochronological characterization is particularly important and the amount of data is rapidly increasing. The majority of zircon U/Pb ages obtained by conventional ID-TIMS, SHRIMP or LA-ICP-MS from orthogneisses, amphibolites, and metagabbros rather date protolith formation than metamorphism. Another important group of zircon ages comes from syn- to posttectonic plutons that crosscut the metamorphic section and thus can also be used as reliable markers for the restoration of the geodynamic evolution of the Complex.

We review the available zircon age data in the framework of the allochthon subdivision scheme. In the LA, alpine granitoids are less than 34 Ma old and postdate stacking of the nappe pile. The MA additionally contains Late Cretaceous (70 - 65 Ma), Late Paleocene-Early Eocene (57 – 53 Ma) and Middle-Late Eocene (46 - 37 Ma) granitoids. Tertiary and Late Cretaceous granitoids are also found in the UA. Orthogneiss protoliths in the LA are mostly Variscan/Late Variscan (319 to 270 Ma) with a few older samples. In the MA, this age group occurs as well but most are 164 to 136 magmatic arc granitoids. In the western part of the UA (Vertiskos, Ograzhden), 460 to 432 orthogneiss protoliths occur. In the eastern Rhodopes both Variscan and Jurassic protoliths occur in units presently attributed to the UA (Kimi, Kardzhali units) but these series may also contain parts of the MA. Protoliths of mafic rocks are around 570 Ma (UA), 470 to 430 (UA and MA), 312 - 253 Ma (UA and MA), and ca. 160 Ma (MA, UMA).

The age distribution provides constraints for the paleogeographic reconstruction. It is compatible with a model where the units were stacked by Late Cretaceous to Palaeogene southwestward thrusting, the UA representing Europe, the LA Apulia, and the MA comprising elements of the Vardar Ocean (160 Ma ophiolite), adjacent magmatic arcs (Late Jurassic granitoids), and possibly Pelagonian continental and Pindos-Cyclades oceanic crust. The UMA comes from the Vardar Ocean and associated arcs as well but was thrust towards north onto Europe already in the Late Jurassic to Early Cretaceous.

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JANAK, M., FROITZHEIM, N., GEORGIEV, N., NAGEL, S. & SAROV, S. (2011): P-T evolution of kyanite eclogite from the Pirin Mountains (SW Bulgaria): implications for the Rhodope UHP Metamorphic Complex. - Journal of Metamorphic Geology. 29/3: 317-332, DOI:10.1111/j.1525-1314.2010.00920.x.

Distinguishing different generations of deformation structures by structural and magnetic fabric analyses: examples from the Central gneiss (Tauern window) and Tschigotgranodiorite (Eastern Alps)

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The classical methods of structural geology prove the polyphase tectonometamorphic history of rocks mostly relying on relationships between different generations of foliations, lineations and folds. In schists and paragneisses due to their varied and finer grained composition, the relationships between different generations of foliations and lineations are easier to define. In contrary, the monotonous and coarse-grained orthogneisses make this task more complicate and it is often difficult to distinguish between different generations of structures.

The anisotropy of magnetic susceptibility (AMS) is a standard method for structural investigations of undeformed and deformed igneous, sedimentary and metamorphic rocks. In deformed rocks and shear zones AMS can reveal the position of the finite-strain axes. In such cases the principal axes of the magnetic ellipsoid ($K_{max} \geq K_{int} \geq K_{min}$) are in agreement with the X, Y and Z strain axes (i.e. with the stretching lineation and mylonitic foliation). On the other hand the magnetic lineation (K_{max}) can parallel the intersection of two different planar fabrics. In these cases the pole to the magnetic foliation (K_{min}) coincides with the mylonitic foliation pole (Z axes) but the other two axes of the magnetic ellipsoid K_{max} and K_{int} can differ from X and Y strain axes.

We have studied two different orthogneiss bodies, the Central Gneiss of the Tauern Window and the Tschigot Granodiorite, hosted by the Texel Unit. Both orthogneisses belong to units which underwent a polyphase tectonometamorphic evolution. On outcrop and sample scale the studied rocks show strain partitioning and intensive deformation being localized in cm to decametre wide shear zones. While the sheared parts are characterized by a strong and coherent mylonitic foliation, intensity of deformation varies significantly in the surrounding rock. Within the shear zones there is perfect agreement between the AMS and structural data. There Kmax and the measured stretching lineation are parallel and the pole of Kmin fits the pole of the mylonitic foliation. The less deformed parts are more complicated due to the presence of different generations of competing foliations and lineations. By combining structural and AMS data we distinguish between different foliations and lineations some of which are not observable at outcrop scale. Thus, some lineations which due to the field observations were assumed as stretching lineations, after the interpretation of AMS data are reinterpreted as intersection lineations. The latter is the intersection of either two macroscopically defined foliations or a macroscopically defined foliation and an optically invisible but magnetically defined foliation.

The parallelism between magnetic and field structures in the shear zones shows that the intensive shearing fully overprints and reorients the preexisting structural and magnetic features. In less deformed orthogneisses combination of structural and AMS data can be used to decipher macroscopically undetected penetrative features and thus to detect different generations of deformation.

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Early exhumation of the Aiguilles Rouges and Mont Blanc massifs, European Alps

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Although the exhumation history of the external crystalline massifs of the European Alps has been studied in detail, little is known about the timing and kinematic of the initiation of exhumation. Here we present new zircon fission track, apatite fission track and apatite (U-Th-Sm)/He data from the central Aiguilles Rouges massif, collected from the NW prolongation of the densely sampled Mont Blanc tunnel transect. This profile together with another densely sampled profile through the NW Aiguilles Rouges and Mont Blanc massif along the Rhône valley are used to investigate the (early) exhumation history of the Mont Blanc and Aiguilles Rouges external crystalline massifs. We use a variety of methods with increasing complexity and parameterisation to infer the exhumation history: (i) the age-elevation approach, (ii) transdimensional inverse thermal modelling, (iii) 1D thermal-kinematic modelling, and (iv) state-of-the-art 3D numerical-kinematic modelling (Pecube).

Age-elevation relationships yield apparent exhumation rates of ≤0.05 km/Myr between 230 and 23 Ma, increasing to ≥0.4 km/Myr since 15 Ma. The low slope of >23 Ma old zircon fission track ages is interpreted to be the result of prolonged stay within the partial annealing zone during burial due to nappe emplacement. The timing of initiation of exhumation most likely happened between 23 and 15 Ma. Transdimensional inverse thermal modelling results further suggest that burial due to nappe emplacement must have occurred rapidly during less than 10 Myrs. According to 1D thermal modelling exhumation of the external crystalline massifs initiated before 20 Ma at rapid rates (~1 km/Myr) and decreased before 10 Ma to moderate rates (~0.4 km/Myr). 3D thermal kinematic-modelling reveals that the thermochronological data are best fitted with a burial/exhumation scenario with rapid burial (~0.6 km/Myr) from ~33 Ma to ~20 Ma followed by rapid exhumation at ~1.3 km/Myr until 10 Ma and final exhumation at ~0.6 km/Myr up to present. Modelling further reveals a strong gradient in burial and early exhumation normal to the orogen, whereas burial/exhumation rates are lowest in the external Aiguilles Rouges massif and approximately half as much as in the Mont Blanc massif.

Deciphering the driving forces of short-term erosion in glacially impacted landscapes, an example from the Western Alps

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Tectonic uplift is the main driver of long-term erosion, but climate changes can markedly affect the link between tectonics and erosion, causing transient variations in short-term erosion rate. Here we study the driving forces of short-term erosion rates in the French Western Alps as estimated from in-situ produced cosmogenic 10Be and detrital apatite fission-track thermochronology analysis of stream sediments. Short-term erosion rates from 10Be analyses vary between ~0.27 and ~1.33 mm/yr, similar to rates measured in adjacent areas of the Alps. Part of the data scales positively with elevation, while the full dataset shows a significant positive correlation with steepness index of streams and normalized geophysical relief. Mean long-term exhumation and short-term erosion rates are comparable in areas that are exhuming rapidly (>0.4 km/Myr), but short-term rates are on average two-three (and up to six) times higher than long-term rates in areas where the latter are slow (<0.4 km/Myr). These findings are supported by detrital apatite fission-track age distributions that appear to require similar variations in erosion rates. Major glaciations strongly impacted the external part of the Alps, increasing both long-term exhumation rates as well as relief. Based on our data, it seems that glacial impact in the more slowly eroding internal part is mainly restricted to relief, which is reflected in high transient short-term erosion rates. The data further reveal that normalized steepness index and ridgeline geophysical relief are well correlated with (and could be used as proxies for) short-term erosion, in contrast to slope, corroborating studies in purely fluvial landscapes. Our study demonstrates that climate change, e.g. through occurrence of major glaciations, can markedly perturb landscapes short-term erosion patterns in regions of tectonically controlled long-term exhumation.

Dating Alpine brittle deformation with hydrothermal monazite

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Alpine clefts (open fissures) are tectonically formed cm- to meter-sized voids that become filled with hydrothermal fluid. Interaction of cleft-filling fluid with wall rock results in mineral dissolution/precipitation, alteration of the wall rock, and repetitive crystallization of minerals on the cleft walls. Dating monazite from such clefts thus provides a possibility to attribute an age to an exhumation-related brittle structure. Moreover, unlike thermochronometers, the ^{232}Th-^{208}Pb system of monazite is not affected by diffusion and yields a crystallization age.
Two cleft monazites and minerals from the cleft wall have been studied using an electron microprobe at the University of Copenhagen. U-Th-Pb isotope analyses of monazite were subsequently performed on a Cameca IMS1280 SIMS instrument at the Swedish Museum of Natural History (Nordsims facility).

Deformation in the study area located in the Baltschieder Valley, Aar Massif, Switzerland, has been subdivided into three main events: (D1) main thrusting including formation of a new schistosity; (D2) dextral transpression; and (D3) local crenulation including a new schistosity. The two younger deformational structures are related to a subvertically oriented intermediate stress axis, which is characteristic for strike slip deformation. The inferred stress situation is consistent with observed kinematics and the opening of such clefts. Therefore, the investigated monazite-bearing cleft formed at the end of D2 and/or D3, and dextral movements along NNW dipping planes.

The two investigated, millimetre-sized hydrothermal monazites from a late D2 cleft are characterised by high Th/U ratios typical of other hydrothermal monazites. Despite mineralogical changes in the cleft wall, the bulk chemistry of the system remains constant at the decimetre scale. Thus the mineralogical changes require redistribution of elements via a fluid over distances of a few centimetres. ^{232}Th/^{208}Pb monazite ages are not affected by excess Pb and yield growth domain ages between 8.03 ± 0.22 Ma and 6.25 ± 0.60 Ma. These crystallization ages are younger than ^{40}Ar/^{39}Ar ages obtained on white mica from ductile shear zones of the Aar Massif in the Grimsel area and younger than ^{40}Ar/^{39}Ar-dated 13.7 ± 0.1 Ma to 11.0 ± 0.1 Ma old phyllonites (mylonites) outcropping near Baltschieder. Monazite crystallization in brittle structures is in this case coeval or younger than 8 Ma old zircon fission track data, and hence occurred at temperatures below 280°C.

Mesozoic stratigraphy and general structure of the Julian Alps (eastern Southern Alps, NW Slovenia)

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The study area is part of the zone of overlap between the Southern Alps and the Dinarides. This zone is to the north bounded by the Periadriatic Fault and extends south to the South Alpine front, where the Southern Alps are in a direct thrust contact with the

External Dinarides. The Sava Fault, a branch of the Periadriatic fault system, separates the Julian Alps from the South Karavanke Mountains and the Kamnik-Savinja Alps.

The Julian Alps have classically been subdivided into the Tolmin nappes and the overlying Julian nappes. The Tolmin nappes consist of three superposed E-W trending south-vergent nappes. The sediments are typically deeper marine (shale, chert, pelagic limestone, calcareous turbidites) from the Middle Triassic volcano-sedimentary succession up to the Campanian-Maastrichtian flysch. These Mesozoic rocks exhibit a considerable thermal overprint.

The Julian nappes originated from various paleotopographic units that started to differentiate in the Late Carnian. Small scale half-grabens did exist in the Middle Triassic but the entire area was then uniformly covered by the Schlern Formation. From bottom to top (and from NW to SE) we distinguish three major tectonic units. (1) The Tamar Nappe is characterized by Upper Carnian to Rhaetian carbonates rich in organic matter and chert nodules. (2) The Krn Nappe has the largest areal extent and mainly consists of the Dachstein limestone. Middle Jurassic deposits are cherts and calcareous turbidites or condensed Rosso Ammonitico limestone. (3) The Pokljuka Nappe is composed of deep-water Upper Triassic to Lower Cretaceous deposits. The most distinguishing stratigraphic unit is the Valanginian-Hauterivian flysch-type deposits that suggest a correlation with relatively internal tectonic units of the Northern Calcareous Alps and Dinarides. The Zlatna Klippe in the central part of the Julian Alps is structurally well differentiated but stratigraphically less distinctive, because it is composed only of the Schlern Formation and older rocks. Its position on top of the Krn Nappe suggests that the Zlatna Klippe is part of the Pokljuka Nappe.

The Julian nappes are dissected by parallel reverse faults oblique to the Sava Fault. Fault-propagation folds are the most commonly observed structures along these faults. The NE-SW striking faults east of the Vrata-Trenta line are characterized by SE vergent folds, whereas the folds and the steepened beds west of this line have the same orientation but the opposite vergence. South of Bohinj, i.e. closer to the Tolmin nappes, the faults are NW-SE trending and the associated folds are S to SW vergent. This pattern suggests an overall pop-up structure and CW rotation of internal smaller-scale fault blocks. A number of later normal faults have been observed, with down throw ranging from a few meters to several hundred meters.

The three-stage Paleogene to early Neogene deformation history, generally postulated for the eastern Southern Alps, is well recognized in the Julian Alps. The Dinaric phase was characterized by nappe emplacement, presumably towards west, perpendicularly to the orogen. During the Insubric transpressional phase, doubly-vergent reverse faults and CW rotation of fault blocks characterized the rheologically stiffer Julian nappes. At the same time the entire stack of the Julian nappes may have been transported southward on top of the Tolmin nappes and individual slices of the Tolmin nappes were imbricated. The subsequent short-lasting extensional phase near the end of the Early Miocene caused subsidence along steep normal faults in the Julian nappes and exhumation of the deeply-buried Tolmin nappes.

Magnetic susceptibility and spectral gamma ray stratigraphy of the Tithonian – Berriasian limestones in the Carpathians of Poland and Hungary – paleoenvironmental implications

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Magnetic susceptibility (MS) reflects para- and ferromagnetic mineral content in sedimentary rocks and is often applied as a correlation tool and, integrated with geochemical methods, as a useful palaeoenvironmental proxy. Field gamma ray spectrometric measurements determine the content of radionuclides: ^{40}K, ^{238}U and ^{232}Th. Integrated MS and spectral gamma ray (SGR) logs are presented from several marine pelagic sections of Tithonian – Berriasian age from the Carpathian area of Poland (Tatra Mts, Pieniny Klippen Belt) and the Pannonian Basin (Transdanubian Range, Mecsek Mts). All sections are reliably dated by calpionellid stratigraphy. Sections in the Tatra Mts, and the Transdanubian Range are additionally calibrated with magnetostratigraphy. MS in the Polish sections correlate well with K, Th, Al, Ti and other lithogenic elements and therefore might be used as a measure of lithogenic influx into basins. MS low that occurs in the lower to middle Berriasian (magnetozones M18r to M17r) correlates with high sea level, while MS highs in the upper Tithonian/lowermost Berriasian (M20r to M19n2n) and upper Berriasian (M16n) match the low sea level. High sea level coincides with a slight oxygene deficiency evidenced by elevated U/Th ratio. Some second order changes might be interpreted as climatic events; for example subtle MS increase within M17n which might represent humidity increase. The same interpretation might be applied for the section studied in the Mecsek Mts (Tisza unit) which encompasses most of the Berriasian. Sections in the Transdanubian Range reveal a different MS pattern without significant MS contrasts around the Jurassic/Cretaceous boundary. These results suggest that instead of the eustasy, the climatic conditions might have been the main factors controlling MS and SGR signal in the studied sections.

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3D Modeling of the Fribourg Area - Western Swiss Molasse Basin

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This study focuses on the structural style of the western Swiss Molasse Basin near Fribourg (west of Bern, Switzerland). We are elaborating a 3D geological model with Move Software (Midland Valley) covering an area of 1700 km2 around the city of Fribourg. Based on 2D seismic line interpretations and deep borehole data (SOMMARUGA et al., 2012) three dimensional seismic horizons are built. Horizons correspond to the following stratigraphic boundaries: Near Base Tertiary, near Top Late Malm, near Top Early Malm, near Top Dogger, near Top Lias, near Top Trias, near Top Muschelkalk and near Base Mesozoic. Surface bed dip data from the Geological Atlas 1:25'000 (swisstopo) are included so as to improve orientations of geological strata. Fault surfaces in Tertiary and Mesozoic cover as well as in Pre-Mesozoic basement rocks are constructed based on seismic interpretations (SOMMARUGA et al., 2012), geological cross-sections (Geological Atlas 1:25:000, swisstopo) and hypocenter positions (VOUILLAMOZ & ABEDNEGO, in prep.). Due to the lack of continuous seismic reflectors in Tertiary Molasse sediments, an appropriate mapping of fault structures in the latter is difficult. As a consequence Mesozoic fault surfaces are extrapolated through Tertiary Molasse sediments based on mapped surface fault structures (Geological Atlas 1:25'000, swisstopo; IBELE, 2011). 3D seismic horizons are depth converted based on a 3D heterogeneous P-velocity model of the Fribourg area (ABEDNEGO, in prep.).

The model shows a kinematic decoupling of Tertiary and Mesozoic units along a detachment horizon in Triassic evaporites. A second decoupling can be observed along the base Tertiary horizon in the south of the study area, probably linked to the thrust front of Subalpine Molasse. East of the city of Fribourg, several N-S-striking, en echelon type normal faults in Mesozoic and Tertiary units can be observed. Faults form a zone of 20 km length from N to S. The zone is called the "Fribourg zone". Faults root in listric bends within middle Triassic evaporites forming a graben or half-graben structure. Triassic evaporites show an important thickening beneath the Fribourg zone. Mapping of fault structures at surface give evidence for left-lateral reactivation of the Fribourg zone under the NW-SE compressional stress field in Neogene times. Correlation of mapped structures does not indicate the presence of large scale fault surfaces exceeding a length of 1 – 3 km (IBELE, 2011). The location of fault traces between 2D seismic lines is speculative in the central part of the Fribourg zone due to a gap of seismic data. Recent studies on present earthquake activity show an enhanced recurrence of low magnitude earthquakes (ML 0 to 4.3) along the Fribourg zone (VOUILLAMOZ & ABEDNEGO, in prep.; KASTRUP et al., 2007). It is therefore proposed, that the Fribourg zone is formed by an assemblage of multiple small scale fault surfaces rather than a few large scale faults. The Fribourg zone forms the eastern border of a N-S striking, low amplitude syncline, called the "Fribourg structure". The N-S-alignment of the Fribourg structure deviates from the overall NE-SW trend of fold axis in the region. Triassic evaporites show a thinning beneath the Fribourg structure.

IBELE, T. (2011):Tectonics of the Western Swiss Molasse Basin during Cenozoic Time, PhD Thesis, University of Fribourg, 166 p.

SOMMARUGA, A., EICHENBERGER, U. & MARILLIER, F. (2012): Seismic Atlas ofthe Swiss Molasse Basin, Edited by the Swiss Geophysical Commission. Matér.Géol. Suisse, Géophys. 44 p.

KASTRUP, U., DEICHMANN, N., FRÖHLICH, A. & GIARDINE, D. (2007): Evidence for an active fault below the northwestern Alpine foreland of Switzerland, Geophys. J. Int., 169: 1273–1288.

The Gran Paradiso massif: an upside down lower crust?

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At the structural top of the Gran Paradiso (GP) orthogneiss dome, on its W- and NW-margins, seemingly layered or, at any rate, strongly flattened formations comprise greenstones, quartzites, as well as Al-rich whiteschist seams (BERTRAND, 1968). From their peculiar mineral assemblage, including margarite and magnesiochloritoid, CHOPIN (1977) inferred a premonitory estimation of ~1 GPa peak-pressure for the Alpine metamorphism of a part of the Internal Crystalline Massifs (ICM), i.e. Monte Rosa and GP. Soon after (CHOPIN, 1984), his seminal discovery of >3 GPa coesite in Dora Maira (DM, next ICM massif to the S) was from a chemically similar rock, again associated to metagranites, alike the GP whiteschist layers. In both cases, from the Al,Mg-rich chemistry those authors invoked a sedimentary origin, either as a bauxite or as an evaporite level. However this hypothesis of an upper crustal origin has been questioned. SCHERTL & SCHREYER (2008), based on geochemical investigations, have proposed instead that those whiteschists would have been leucophyllite shear zones inside the granites, secondarily metasomatized at depth.

Underlying DM coesite-units to the E, the conglomeratic Pinerolo unit is analogous by its position and by its rock-types to the conglomeratic Money unit that underlies the GP orthogneiss dome. Both metaconglomerate units were unaffected by eclogitization. Overlying DM as well as GP, eclogitized metamafic units (VZSFO = Mt.Viso and Zermatt-Saas-Fee Ophiolite) comprise subordinate calcschists. VZSFO are in their turn tectonically overlain by Combin-type units composed of dominant calcschists and subordinate ultramafic rocks. All those ultramafic-bearing units were classically supposed to be of oceanic origin, representing the Jurassic Piemont Ocean.

Protolith age data comprise mostly Permian to Late Upper Carboniferous ages (310 to 265 Ma) for the orthogneiss (BERTRAND et al. 2005). This is also the radiometric age range for the Ivrea mafic body, a verticalized, Permian, lower crust wedge. The Gneiss du Charbonnel Formation, consisting of interlayered felsic levels of unknown origin in the VZSFO, nearby GP massif, also yielded zircons of Permian age, as is also the case for the Lanzo peridotites. Gabbros of the latter Lanzo zone yielded Jurassic ages (KACZMAREK et al. 2008), correlated to the radiolarite ages at the base of the calcschists, and representing the age of the oceanization (MOHN et al., 2010).

A suggested vision of the ICM would hence them to be an upside down Permian crust of S-Alpine origin representing a lateral equivalent to the Ivrea body. More speculatively, parts of the presently overlying eclogitized mafic units of the VZSFO might represent parts of their related upper mantle. Thin marble levels previously considered as Triassic deposits, between GP and VZSFO, might instead represent layered lower crust remnants.

Abundant zircon crystals found in the Al,Mg-rich whiteschist of western GP margin are presently being investigated, regarding their age(s) of crystallization as well as their mineral inclusions. Field data might also help better defining the relationships of the GP whiteschist with its host-rocks.

BERTRAND, J.-M. (1968): Étude structurale du versant occidental du Massif du Grand paradis (Alpes Graies). - *Géologie Alpine*, 44: 55-87.

BERTRAND, J.-M., PAQUETTE, J.-L. & GUILLOT, F. (2005): Permian zircon U-Pb ages in the Gran Paradiso massif: revisiting post-Variscan events in the Western Alps - Schweizerische Mineralogische und Petrographische Mitteilungen, 85: 15-29.

CHOPIN, C. (1977): *Comptes Rendus de l'Académie des Sciences*, 285, p.1383)

CHOPIN, C. (1984): Coesite and pure pyrope in high-grade pelitic blueschists of the Western Alps: a first record and some consequences. - Contribution to Mineralogy and Petrology 86:107–118.

MOHN, G., MANATSCHAL, G., MÜNTENER, O., BELTRANDO, M. & MASINI, E. (2010): Unravelling the interaction between tectonic and sedimentary processes during lithospheric thinning in the Alpine Tethys marginsInternational Journal of Earth Sciences, 99/Suppl 1, 75-101.

KACZMAREK, M.-A., MÜNTENER, O. & RUBATTO, D. (2008): Trace element chemistry and U-Pb dating of zircons from oceanic gabbros and their relationship with whole rock composition (Lanzo, Italian Alps) - Contributions to Mineralogy and Petrology, 155:295-312.

SCHERTL, H.-P. & SCHREYER, W (2008): Geochemistry of coesite-bearing “pyrope quartzite” and related rocks from the Dora-Maira Massif, Western Alps. - European Journal of Mineralogy, 20, p.791-809.

Evolution and reactivation of basement highs at hyper-extended rifted margins: the example of the Briançonnais domain in the Alps and comparisons with modern analogues

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The development of new reflection and refraction seismic techniques enabled to image the crustal architecture of deep-water rifted margins. The new data show that in addition to the classical tilted blocks rifted margins are formed by a large variety of different types of crustal blocks/structures, including micro-continents, continental ribbons, H-blocks and extensional allochthons. This large variety of structures suggest a complex rheological, thermal, and subsidence history of rift systems that is recorded by the tectonic, magmatic and sedimentary processes occurring during rifting. Since rifted margins may eventually be reactivated and become part of an orogenic system, understanding their rift architecture may also be a key to understand the final structure of internal parts of collisional orogens. Distal parts of rifted margins are often at deep-water and sealed by thick post-rift sediments, which makes that these highs are difficult to drill. That's why we combine the study of seismic sections with that of field analogues exposed in the Briançonnais domain in the Alps. Mapping the pre-Alpine and Alpine structures of this domain and properly define their stratigraphic and tectonic evolutions provide important insights into the tectonic evolution of distal rifted margins during their formation and subsequent reactivation.

The Briançonnais domain forms the most distal part of the European margin. In contrast to the Adriatic margin that was the focus of many studies investigating the architecture and evolution of the Jurassic margin, much less is known about the structure and evolution of the conjugate Pre-Piemontais/Briançonnais domains. To better understand their evolution during rifting, we reviewed the existing structural, stratigraphic and age data of these domains from Liguria/Italy, across the French Alps to Grisons in Switzerland. We propose new constructed sections across the Briançonnais domain that forms the basis to discuss the rift-related tectono-stratigraphic and subsidence evolution of this domain. This study will enable to compare the along and across strike stratigraphic architecture of the Pre-Piemontais/Briançonnais domains and to compare them with those made at seismic sections imaging deep-water rifted margins (e.g. Campos (S-Atlantic), Newfoundland (N-Atlantic) and eastern Indian margin).

The first results show that the principal Alpine structures in the Briançonnais domain reactivated mainly pre-Alpine structures. The structural evolution and the change in vergence across the Briançonnais domain are likely controlled by the crustal architecture of the former rifted margin. The stratigraphic architecture and its relation to basement structures within the Pre-Piemontais/Briançonnais domains suggest the abrupt juxtaposition of crustal domains of different crustal thickness with strong lateral changes of the top basement architecture. These relations are very similar to that observed along present-day rifted margins. This complex, 3D architecture of the European margin may have played an important role for the distribution of post-rift sedimentary systems as well as for the reactivation of the European margin during the Alpine convergence.

Internal structure of cataclastic faults along the SEMP fault system (Eastern Alps, Austria)

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In this study three different sites along the ENE-trending, sinistral Salzach-Ennstal-Mariazell-Puchberg [SEMP] fault zone were investigated with respect to brittle fault zone evolution and fault re-activation. All sites crop out in Triassic carbonates (Ladinian Wetterstein limestone/ -dolomite). Simultaneously (re-) activated faults were investigated with focus on fault-slip data and structural inventory of each individual fault zone.

Configuration of (internal) structural elements, fault core thickness, strike direction and slip sense in addition to particle analysis of fault core cataclasites add up to three different fault types (Fault type I, II and III).

Fault type I is classified by a complex internal fault core structure with thicknesses up to several 10s of meters and generally evolve in a strike direction of maximum shear stress (τmax). Type II faults, characterized by cataclastic fault cores with thicknesses up to 1m, as well as type III faults (thin solitary cataclastic layers) evolve sub-parallel to the main fault direction and in orientation according to R, R' or X shear fractures with variable (σn / τ) ratio.

Progressive development from type III to type II and type I faults is consistent with increasing displacement and increasing fault core width.

Fault type classification and related paleostress analysis provides evidence from field observation compared to theoretical and analogue models of Mohr-Coulomb fracture evolution.

Changing fluid chemistry during continuous shearing in cataclastic fault zones along the SEMP fault system

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Brittle fault rock samples from carbonate shear zones along the Salzach-Ennstal-Mariazell-Puchberg fault system (SEMP) have been analysed using cathodoluminescence microscopy (CL), microprobe analysis and stable isotope composition. The combination of these analytical methods provides an insight into comminution processes and fluid chemistry. The reconstruction of the evolution of fluid chemistry leads to a chronological classification of five fluid phases with respect to fluid chemistry, CL behavior and related structural processes. Initial cataclasis is accompanied by dedolomitization processes along crystal borders and intragranular fractures derived by Ca-rich fluids (Phase P1). Subsequent fluid phases (P2-P5) are characterized by variable Fe- (and Si-content) and therefore variable CL behavior.

Microprobe element mappings support the discrimination of Fe-enriched, non luminescent phases and Ca- and Mn-enriched fluids with bright luminescent calcite precipitations. Fe-enriched carbonates and Fe-hydroxide precipitation indicates fluid circulation in deeper parts of the stratigraphic sequence. These fluids are assumed to be derived from underlying clastic sequences of the Werfen Formation. Stable isotope signatures (δ13C and δ18O) indicate mainly meteoric origin of penetrating fluids and variable amounts of fluids in the fault zone.

Oligocene and Neogene tectonic processes in the southeastern Alps and northwestern Dinarides: constraints from new (U-Th-Sm)/He apatite ages

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The AlDi-Adria project aims at deciphering the late-stage orogenic evolution for the northern edge of the Adriatic microplate, i.e. the Friuli orocline and its surrounding regions by a combination of structural studies, subsidence analysis and low-temperature thermochronology. Results will form the base for studying the large-scale surface response to deep-seated lithospheric processes, a number of which have been debated for the study area, e.g. slab break-off, slab delamination, orogenic shortening and lateral extrusion. First results from apatite (U-Th-Sm)/He dating (AHe) in combination with existing apatite fission track age constraints allow us to derive some regional patterns of deformation and exhumation in the Southalpine units/Dinarides and phases of fault movement along the PAF. Here, we discuss those constraints on tectonic processes from old to young events.

Only very limited low-temperature thermochronological data are available south of the Periadriatric Fault (PAF). Oligocene AHe ages were derived for samples from the inner portions of the External Dinarides (Fužine). Similar ages were found even in the southernmost Austroalpine units (e.g. the Reifnitz tonalite). Together, these ages are interpreted as belonging to a regional scale deformation event, which caused large-scale low-amplitude folding due to shortening mainly directed to the stiff interior of Adria. The PAF was also initially activated during this stage. Tonalites intruded into the eastern PAF during Early Oligocene (ca. 34 to 32 Ma; GENSER & LIU, 2010) forming a zone of weakness immediately activated as fault zone.

A major phase of dextral shear along the PAF is indicated by cooling ages of ca. 16 to 20 Ma, attributed to lateral extrusion of the Eastern Alps (e.g., RATSCHBACHER et al., 1991). A new Ar-Ar biotite age of 19 Ma from a mylonitic gneiss from the PAF near Kupitsch with a similar age corroborate this phase of exhumation and deformation.

We find latest Miocene/Pliocene AHe ages of ca. 7 – 5 Ma Ma for an Oligocene tonalite just north of the easternmost Periadriatic Fault. Similar ages were recently reported from the Lavanttal fault by WÖLFLER et al. (2010) and ascribed to fault activity and hydrothermal fluid circulation causing rejuvenation. Since our samples do not show any alteration fabrics we interpret them to indicate final uplift, which is supported by the young relief in this area: To the north, the Klagenfurt basin has been overridden by the Karawanken Mountains during Pliocene-Quaternary times. Formation of the Sava fold belt in the south is also of similar age. A denser network of low-temperature data is needed to refine these preliminary patterns and more results from ongoing apatite fission track and AHe work will be presented.

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GENSER, J. & LIU, X. (2010): On the age of the Eisenkappel granites. - Journal of Alpine Geology, 52: 121–122.

RATSCHBACHER, L., FRISCH, W., LINZER, G. & MERLE, O. (1991): Lateral extrusion in the Eastern Alps, part 2: Structural analysis. – Tectonics, 10: 257–271.

WÖLFLER, A., KURZ, W., DANISIK, M. & RABITSCH, R. (2010): Dating of fault zone activity by apatite fission track and apatite (U-Th)/He thermochronometry: a case study from the Lavanttal fault system (Eastern Alps). - Terra Nova, 22: 274-282.

Mapping the transition between the eo-Alpine HP-nappe system and the Ötztal-Bundschuh Nappe system using garnet zoning types and geothermobarometry

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The investigated area is situated west of the Penninic Tauern Window directly at the already proposed transition between the Ötztal Nappe as part of the Ötztal-Bundschuh Nappe System and the Schneebergzug as part of the Koralpe-Wölz high pressure Nappe System. Aim of this study is to compare garnet major element zoning linked with pseudo-sections from different types of metapelites to be able to distinguish between polymetamorphic and monometamorphic units. Polymetamorphism means combinations of Variscan, Permian and eo-Alpine events which are related to the Ötztal Nappe (Variscan and Eo-Alpine) and the Texel Complex (Varsican, Permian and Eo-Alpine). Monometamorphism means eo-Alpine and is related to the Schneeberzug. Texel Komplex is together with the Schneebergzug part of the Koralpe-Wölz high pressure Nappe System.

Two main types of pre-Alpine garnet zoning patterns in the cores, type-1 and type-2 and two main types of eo-Alpine garnet zoning in the rims, type-3 and type-4 have been observed. Type-1 shows typical prograde zoning with decreasing XGrs (Grs30 to Grs8) and bell-shaped XSps patterns, as well as increasing XAlm (Alm60 to Alm70) and XPyp (Prp5 to Prp12) from the inner core close to the rim. Type-2 is characterized by homogeneous contents of XGrs (Grs8-10), XAlm (Alm70-75), XPyp(Prp10-15) from the inner core close to the rim. The rims of the porphyroblasts show two different garnet zoning types with significantly higher XGrs and can be distinguished into: type-3 with a small jump in XGrs (from Grs10 to Grs25), in XAlm (Alm75 to Alm60) and in XPrp (Prp15 to Prp10) and type-4 with a higher jump in XGrs (from Grs10 to Grs30), in XAlm (from Alm75 to Alm55) and in XPrp (from Prp15 to Prp5). Type-4 comprises a large garnet volume with a continuous decrease in XGrs (Grs30 to Grs20) and a continuous increase in XAlm (Alm55 to Alm65), and in XPrp (Prp5 to Prp10) towards the outermost rims.

To estimate the P-T conditions of pre-Alpine and eo-Alpine garnet growth, grossular-, almandine- and pyrope isopleths were calculated with the program Theriak Domino. The intersections of the isopleths yielded 0.7-0.9 GPa and 550-650°C for the pre-Alpine type-1 and type-2 garnets and also 0.8-0.9 GPa and temperatures from 550 up to 600°C for the eo-Alpine type-3 and type-4 garnets.

First approaches of this study support Variscan followed by an eo-Alpine metamorphic imprint and exclude a Permian HT/LP event.

Strain localization history of the Simplon Fault Zone: How far can we look back?

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Large-scale shear zones localize deformation, where with progressive exhumation old initial deformation fabrics are continuously overprinted under changing physico-chemical conditions. The study of such meso- to micro-scale structures provides the key for unraveling the retrograde geological evolution. When looking at these structures in the high strain parts, the question arises, up to which former stage these features still can be preserved, i.e. how far back in time can we look? To answer this question, we combine quantitative microstructural analyses in mylonitic quartz veins, with Ti in quartz geochemistry and thermochronological modeling on samples collected along vertical profiles across the Simplon Fault Zone(SFZ, SW-Switzerland).The SFZ is a major mid- to upper crustal shear zone accommodating substantial amounts of orogen parallel extension.

With increasing proximity to the fault plane (FP), dynamically recrystallized quartz grain sizes in the footwall decrease from a few mm (2-4 km away from FP) to sizes as small as 10-20 micrometers (a few meters away from FP). Along with this grain size reduction, dynamic recrystallization processes change from grain boundary migration, over subgrain rotation to bulging recrystallization. These variations indicate continuous strain localization, with decreasing temperature conditions and increasing flow stresses. Despite these trends, in close vicinity to the FP recrystallized grain sizes in different quartz veins show a considerable spread and all three recrystallization processes are found in different veins. When measuring Ti contents in these quartz veins, they are always high in the more distant parts but decrease the closer the sample is located to the FP. Similar to the quartz microstructures, the Ti concentration also shows a considerable spread near the FP, covering the entire range from highest to lowest Ti values. Ti in quartz geothermometry yields temperatures from 530°C down to 350°C. How is it possible that ‘high-T’ and ‘low-T’ microstructural and geochemical signatures can occur in samples just a few millimeters apart from each other, but all located in the most intensely deformed parts of the SFZ?

The answer to this question is synkinematic quartz veining combined with selective strain partitioning. All mylonitic quartz represents former, synkinematic quartz veins that formed during different episodes of the long lasting deformation history of the SFZ. At the time of their formation, their Ti uptake is in equilibrium with the fluid, reflecting the geochemical conditions of vein formation. Due to the inefficient resetting of the Ti concentrations under retrograde deformation conditions, the formation temperatures are largely preserved. In terms of the quartz microstructures, the timing and amount of overprinting of initial structures by subsequent deformation stages depends on the amount of strain accommodated in the gneissic matrix and its variation in space and time. In this sense, some of the early-formed quartz veins preserve an old stage of dynamic recrystallization, while others are completely overprinted by younger low temperature deformation (e.g. small grain sizes, bulging recrystallization). Whether the veins are old or young can be inferred from the Ti in quartz signature. It follows that even in the very high strain part of major shear zones, a careful combination of microstructural and geochemical analysis allows us to look far back into the temporal evolution of such a shear zone, with the potential to thereby obtain improved, high-resolution information on the spatial and temporal evolution of retrograde shear zones.

New geochemical data of Badenian volcanic rocks from south Pannonian Basin in Baranja, Eastern Croatia

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Investigated area is situated in the south part of the Pannonian Basin in Baranja province (Eastern Croatia). This abstract presents new geochemical results of volcanic and pyroclastic rocks, collected during the investigations in Baranja through preparing of Basic geological map of Republic Croatia (scale 1:50 000).

Investigated volcanic rocks (lavas) and pyroclastic rocks that include tuffaceous breccias and crystallovitrophyric tuffs are collected from three localities: Popovac, Vračevo and abandoned Batina quarry. Field evidence suggest polyphase magmatism which is evidenced by Badenian sediments that overlie lavas and by dykes cutting Badenian limestones (Begovac quarry). In Batina quarry volcanic and tuffaceous breccia are overlain by sub-horizontal beds of Quaternary loess. K-Ar measurements on volcanic rocks gave 13.8 and 14.5 Ma.

Volcanic rocks and magmatic fragments of volcanic and tuffaceous breccias (Batina quarry) are composed of plagioclase, olivine and clinopyroxene phenocrysts set in the groundmass of glass, microlites of phenocrystic population and accessory apatite, ilmenite and magnetite. Clinopyroxene and olivine microlites may be pseudomorphosed by chlorite and serpentine, respectively. Amygdules are filled by calcite and chlorite.

Volcanic rocks have SiO_2 ranging from 52.58 wt.% to 57.64 wt.% and Na_2O+K_2O content of 4.97-5.83 wt.%. They are dominantly sodium rich (Na_2O/K_2O = 2.1-5.5). In the TAS diagram they show subalkalic affinity and plot in the field of basaltic andesites and andesites. In the diagram K_2O – SiO_2 they show calc-alkaline to high-K calc-alkaline affinity. The lavas are moderately fractioned in the term of Mg# and Cr content (50.1-61.3 and ~ 110 ppm, respectively) but are very depleted by Ni (< 20 ppm) suggesting olivine + spinel fractionation. Rounded fragments of basaltic andesites from the volcanic breccias are characterized by lower K_2O, HFSE and REE, and higher Cr and Ni contect with regard to the basaltic andesite and andesite lavas.

All lavas show moderate enrichment of LREE over HREE [(La/Lu)cn = 5.41-8.38] at ~ 86 times chondrite relative concentrations. Negative Eu anomaly (Eu/Eu* = 0.77–0.95) indicates early feldspar fractionation at low pressure. The spider diagram normalized to N-MORB values shows an inconsistent secondary LILE enrichment. Negative anomaly of Nb-Ta relative to La is well pronounced [(Nb/La)n = 0.41-0.48] as well of other HFSE which is typical of subduction zone magmas.

However, although the chemistry of Badenian calc-alkaline basalt-andesite rocks in Baranja is similar to those of the recent orogenic and subduction related areas, the origin of their primary magma should be linked to post-orogenic geotectonic environment typical for continental margin (back-arc) rift-basin. Thus, the geotectonic setting of Baranja volcanic rocks harmoniously complements initial extension phase of Neogene geodynamic evolution of Pannonian Basin proposed by many authors. The Pannonian Basin is interpreted as post-colision continental back-arc basin which extended during the Miocene due to uplift the upper mantle diapirs that caused strong trancurent faulting. This allows the differentiation of the Basin in several small pull apart rhomboidal depression. Calc-alkaline basaltic to basaltic andesite magmas, which may fractionated to andesitic and/or dacite and rhyolite extrusives, erupted along weakened tectonic zones of the basinal depressions.

Middle and Upper Triassic slope and basin carbonates along the Neo-Tethyan (Meliata) margin (NE Hungary): facies and paleoenvironmental interpretation

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The studied area, the Aggtelek-Rudabánya Hills (NE Hungary) is part of the Silicic nappe system of the Inner Western Carpathians. In the Triassic pre-rift stage (from ?Middle–Late Permian to Middle Anisian) the evolution of the area was uniform, however, during the Neotethyan synrift stage in the Early-Middle Anisian the Steinalm carbonate ramp broke up, creating three different tectonostratigraphic units: the pelagic Bódva Unit, the Szőlősardó Unit representing slope sedimentation and the Aggtelek Unit where the carbonate platform building continued until the Late Norian. During the time period between the Middle Anisian and Rhaetian different types of carbonate rocks were deposited on the slopes and in the basins of these units: 1) greyish pink bedded limestone that suffered multiple phases of brecciation, 2) red, nodular, cherty limestone with purple-red shale intercalations, 3) grey to red bedded limestone with stromatactis structures, 4) the Massiger Hellkalk and Hangendrotkalk Members of the Hallstatt Formation and 5) grey, cherty beds of the Pötschen Formation.

Within the framework of the current study sedimentary and microfacies analyses were conducted regarding the Middle and Upper Triassic slope and basin carbonates of the three units, including resampling and revision of important drilling cores, detailed geological mapping of the surface outcrops and thin-section analysis. The next step in the near future will be the Conodont-biostratigraphical revision of important, yet not dated cores and profiles as well as stable isotope and other instrumental analyses.

The aim of the work is to create a modern and comprehensive facies model for the different rock types thus to gather additional data related to their paleoenvironment and paleogeographical position, clarify the similarities and differences between the different formations and try to correlate the Hungarian examples to the Austrian ones. A future goal is to use these newly acquired data and interpretations to help understand the otherwise very complex structural system and tectonic movements of the Aggtelek-Rudabánya Hills by determining the original relative position of the tectonostratigraphic units.

Inside the Gurktal nappes – A modified tectonic and lithostratigraphic concept

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The Gurktal nappes represent a part of the Austro-Alpine superunit. They extend over the geographic region of the Gurktal Alps, located in the southern part of Austria (Styria, Carinthia) and form an area of around 4000 sqkm. Historically the Gurktal nappes are a key area in understanding of Alpine tectonics where nappe-stacking has been early mentioned (HOLDHAUS, 1921). Studies of several authors followed during the 1920s to 1950´s (e.g. SCHWINNER, THURNER, STOWASSER, TOLLMANN, BECK-MANNAGETTA) giving base-descriptions of rock types and lithological units. During the 1970´s to 1990´s (e.g. PISTOTNIK, VAN GOSEN, NEUBAUER, FRIMMEL, LÖSCHKE, KRAINER) the view on the Gurktal nappes was expanded by works on lithostratigraphy, tectonics (NEUBAUER & PISTOTNIK, 1984), petrology, geochronology and structural geology. Hitherto a synthesis is missing.

Tectonically the Gurktal nappes are part of the Drauzug-Gurktal nappe system (Thesaurus-Redaktionsteam/GBA, 2013) and represent the uppermost/top tectonic unit of the Upper Austro-Alpine nappes, underlain by the Ötztal-Bundschuh nappe system to the W and by the Koralpe-Wölz nappe system to the N, E and SW. The lithologies are composed of Palaeozoic metavulcanites and metasediments as well as mica-schists and gneisses, transgressively overlain by Carbono-Permo-Mesozoic (meta-) sediments. Based on new comments on the Lithostratigraphic Chart of Austria (Volume 1 – Palaeozoic Era (them) – HUBMANN et al., 2013) a lithostratigraphic model for the Gurktal nappes can be shown. In this context we discuss the conceptional idea of a classification in lithodems and complexes (lithodemic units). Comments on the Geological Map of Salzburg 1:200.000 (PESTAL et al., 2009) and the succession of tectonic units in the Gurktal nappes (Thesaurus-Redaktionsteam/GBA, 2013) give evidences for a modified tectonic model. From substratum to top, indicated by metamorphic grade, age and rock characteristics six nappes can be divided: a group of basal mica-schist nappes, the Murau nappe, the Phyllonite zone, the Pfannock nappe, the Stolzalpe nappe and on top the Ackerl nappe. The geologic/tectonic evolution can be divided in two main events: A Variscan event during Carboniferous indicated by white mica Ar/Ar-cooling ages, followed by an Eoalpine event during Cretaceous times. Several data in the Gurktal nappes and surrounding areas show that this part of the Alpine orogen formed the upper plate during nappe-stacking in an orogenic wedge during Eoalpine subduction with a normal metamorphic gradient and maximum conditions at (upper-)greenschist-facies.

HOLDHAUS, K. (1921): Über den geologischen Bau des Königstuhlgebietes in Kärnten. - Mitteilungen der Geologischen Gesellschaft in Wien, 14: 85-103.

NEUBAUER, F. & PISTOTNIK, J. (1984): Das Altpaläozoikum und Unterkarbon des Gurktaler Deckensystems (Ostalpen) und ihre paläogeographischen Beziehungen. - Geologische Rundschau, 73 (1): 149-174.

PESTAL, G, HEJL, E., BRAUNSTINGL, R. & SCHUSTER, R. (2009): Geologische Karte von Salzburg 1:200000: Erläuterungen. Geologie der Österreichischen Bundesländer. - Geologische Bundesanstalt, Wien.

HUBMANN, B., EBNER, F., FERRETTI, A., HISTON, K., KIDO, E., KRAINER, K., NEUBAUER, F., SCHÖNLAUB, H.-P. & SUTTNER, T.J. (2013): The Paleozoic Era(them). – In: PILLER, W.E. [Ed.]: The lithostratigraphic units of the Austrian Stratigraphic Chart 2004 (sedimentary successions) – Vol. I – Abhandlungen der Geologischen Bundesanstalt, 66: 9–133..

Thesaurus-Redaktionsteam/GBA, "Drauzug-Gurktal nappe system, Basal mica-schist nappe, Murau nappe, Phyllonite zone, Pfannock nappe, Stolzalpe nappe, Ackerl nappe" – http://resource.geolba.ac.at/tectonicunit/126, 127, 136, 138, 137, 143, 128, aufgerufen am 25. April 2013.

Viscous overthrusting versus folding: 2D numerical modeling and application to the Helvetic and Jura fold-and-thrust belts

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The geometry of the Helvetic and Jura fold-and-thrust belts has been studied in detail since more than 100 years. However, the dynamics of the combined folding and thrusting are still incompletely understood. Two types of nappes have been described in the Alps: fold nappes and thrust nappes. While fold nappes are characterized by continuous sedimentary layers that can be traced back to their root (parautocthonous), thrust nappes exhibit a basal thrust (allochtonous). Detailed mapping in the Alps has shown that the tectonic style can vary laterally from fold to thrust type. Moreover thrust planes in the Helvetic nappe system and in the Jura are often folded and thrust nappes often exhibit considerable internal ductile deformation. It has been proposed that the pre-Alpine stratigraphy, especially the alternation between shales (weak) and limestone (strong), control the tectonic style of the nappes in the Helvetic and Jura fold-and-thrust belts.

We use 2-D numerical simulations of viscous flow to simulate the layer-parallel shortening of a strong viscous layer embedded in a weak viscous matrix, and above a flat detachment plane. A thin weak zone exists initially in the layer representing an initial discontinuity (e.g. thrust plane). We investigate systematically the control of (1) the ratio of the layer thickness to the matrix thickness (between the layer and basal detachment), (2) power-law versus linear viscous rheology and (3) the viscosity ratio between layer and matrix, on the deformation style. When the matrix is linear viscous, only thickening or folding of the layer occurs. When the matrix is power-law viscous (n=5), deformation occurs mainly by folding when the thickness ratio is >~1 and the viscosity ratio is >~10. Overthrusting of the layer occurs when the viscosity ratio is >~100 and the thickness ratio is <~1. Both overthrusting and folding can occur simultaneously for thickness ratios >~1 and viscosity ratios >~50.

Our simulations show that overthrusting is mechanically possible during dominantly viscous flow. The results support the interpretation that many structures in the Helvetic and Jura fold-and-thrust belt resulted from an effectively and dominantly ductile deformation. The results further show that for the same rheology but varying thickness ratio the deformation style can vary from folding-dominated to overthrusting-dominated, which is in agreement with observations in the Helvetic and Jura fold-and-thrust belts.

Orogen-parallel exhumation and topographic gradients east of the Tauern window: a possible clue for shear strength at depth and intra-orogenic raft tectonics

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The interplay of indentation by the Southalpine indenter, surface uplift and exhumation of the Tauern window characterizes the post-collisional Late Oligocene to recent evolution of the central sectors of the Eastern Alps. Strong Miocene E-W extension, basement subsidence in the Pannonian realm and surface uplift in the Tauern window area created an E-W topographic and exhumation gradient allowing the brittle upper crust to move along the mid-crustal ductile decollément level towards the east. The purpose of this study is to estimate the critical topographic angle of the brittle upper crust to move along the basal viscous layer. Subject of research is the area between the viscously behaving Penninic zone of the eastern Tauern Window and the brittle-behaving Austroalpine basement units with its Neogene basins on top. We use published apatite fission track (AFT) and (U-Th)/He data from two sections of the Hohe Tauern to the east to constrain the E-W exhumation gradient. We also consider partitioning of translation of the Austroalpine crust by ca. ENE-trending orogen-parallel Oligocene faults separating the Hohe Tauern from the Northern Calcareous Alps, respectively the combined Hohe Tauern/Niedere Tauern block from the Nock/Gurktal/Murau Mts. domains. For comparison, we include an E-W section along the southern Northern Calcareous Alps and sections along the SEMP and Mur fault zones. Assuming a thermal gradient of 30 ºC/km, we find a similar gradient of ca. 0.04 for both basement sections. This low gradient is close to a gradient typical for viscous material with low shear strength. These relationships imply that gravitational collapse alone might be sufficient to explain the eastward motion of the brittle Austroalpine crust over a thick viscous layer. Flow above a low-friction viscous layer also explains the eastward tilting of blocks like the Saualpe and Koralpe blocks along antithetic high-angle normal faults. Together, the area east of the Tauern window could be explained by intra-orogenic raft tectonics.

Deformation within a subduction channel at eclogite facies conditions and consecutive exhumation: The Eclogite Zone of the Tauern Window, Austria

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Many recent models for the exhumation of subducted oceanic crust assume corner flow in a subduction channel and exhumation of the very dense metabasites, i.e. eclogites, within a buoyant melange of serpentinites or metasediments. The Eclogite Zone of the Tauern Window represents a paleo-subduction channel in the Eastern Alps, which formed during the subduction of the Penninic ocean beneath the Adriatic continent in the Tertiary. It comprises metasediments as well as large metabasite lenses. Since serpentinites are very rare and occur only in small patches in the western Tauern Window, the metasediments are likely to be the buoyant medium for the exhumation of the eclogites. The Eclogite Zone was exposed to P/T-conditions of 20 - 25 kbar and 600±30°C and exhumed in a very short time span of 1 - 2 Ma. Most of the deformation of this rapid exhumation was presumably concentrated in the metasediments almost exclusively displaying the retrograde mylonitization. This is due to the rheological weakness of gneisses, schists, and marbles in comparison to the metabasites. In addition, the large strains required for exhumation caused a penetrative amphibolite to greenschist facies overprinting. Although only weakly deformed, the metabasites show almost the complete deformation history comprising localized eclogite facies shear zones and the whole amphibolite to greenschist facies deformation sequence during exhumation. The foliation consistently dips to the SSE with 70-85° demonstrating the long-standing operation of this shear plane orientation. However, the omphacite stretching lineation plunges SW, while the hornblende stretching lineation is WSW-plunging to sub-horizontally W-trending.

The structural field mapping is completed by microstructural analyses and crystallographic preferred orientation (CPO) measurements. The variable foliation intensity corresponds to a wide range of CPO intensities. In eclogites indicative of dynamic recrystallization of omphacite and garnet, omphacite exhibits a pronounced CPO. Weaker CPOs of other eclogite samples reveal strain gradients and localized deformation. Occasionally, the hornblende CPO mimics the omphacite CPO arguing for a static overprint. In contrast, differing omphacite and hornblende CPOs indicate ongoing deformation during exhumation. The metasedimentary rocks show a strong mica foliation with a pronounced muscovite CPO. The quartz CPO in the metasediments indicates simple shear deformation with top to the NE sense of shear.

From the mineral CPOs and particular elastic moduli and volume fractions, the CPO-related contribution to bulk rock elastic anisotropy was estimated. P-wave velocity distributions of the eclogite samples exhibit rather low anisotropies of 1-2 %, which are mainly caused by the omphacite CPO. The growth of retrogressed mineral assemblages, specifically hornblende, causes a slight anisotropy increase up to 3 %. P-wave anisotropy of the paragneisses approximates 7 %. It is mainly caused by the muscovite CPO, because the minimum velocity parallels the foliation normal. In metasediments containing only very small amounts of muscovite the elastic anisotropy is around 5 % and mainly caused by the quartz CPO.

From the compilation of all these data comprehensive information on the internal architecture, elastic anisotropy, accumulated bulk strain and strain partitioning within the Tauern Window subduction channel is expected. A more detailed model of subduction channel deformation may result, which could be compared to already existing models.

Alpine metamorphism in the continental Etirol-Levaz slice (Western Alps, Italy) – Insights from petrological, thermodynamic and geochronological investigations

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The Etirol-Levaz slice in the western Valtournenche of Italy is a continental fragment trapped between two oceanic units, the eclogite-facies Zermatt-Saas Zone in the footwall and the greenschist-facies Combin Zone in the hanging wall. It has been interpreted as an extensional allochthon derived from the Adriatic continental margin and stranded inside the Piemont-Ligurian oceanic domain during Jurassic rifting. The slice consists of pre-Mesozoic high-grade gneisses, micaschists and metabasics which have been overprinted under eclogite-facies conditions during Early Tertiary Alpine subduction. We analyse metabasic and metasedimentary rocks in terms of their chemical and mineral compositions and focus on mafic eclogites of which two samples are dated with the Lu-Hf geochronometer. Distribution maps of major bivalent cations in garnets are used to identify zonation patterns and to distinguish between different garnet generations.

Eclogites generally consist of the assemblage garnet + omphacite ± epidote ± amphibole ± phengite ± quartz. In one sample, garnets have compositions of Alm52-61 Grs18-41 Prp5-22 Sps0.5-2 and display typical growth zoning. Some garnet grains are brittlely fractured, strongly corroded and overgrown by epidote. Amphibole occurs as a major phase in the matrix and shows a progressive evolution from glaucophane in the core to pargasitic hornblende towards the rim. Amphibole grains are often truncated by epidote veins. Another sample shows a particular Ca-rich bulk composition (18.3 wt% Ca) and displays two distinct garnet generations. Perfectly euhedral cores show compositions of Grs42-45 Alm47-51 Prp3-6 Sps2-7 and typical prograde growth zoning. These cores are overgrown by irregularly shaped rims characterised by an initial rise in Mn and the Fe-Mg ratio. Omphacite in this sample with jadeite-contents of 19-28 mol% apparently has been fractured and annealed by jadeite-poor (7-12 mol%) omphacite suggesting brittle behaviour at eclogite-facies conditions or brittle deformation between two high-pressure stages.

We constrain pressure and temperature conditions for prograde, peak and retrograde mineral assemblages using equilibrium phase diagrams. Preliminary results suggest that high-pressure rocks of the Etirol-Levaz slice record equilibration at different metamorphic stages along a single Alpine metamorphic cycle. We also use thermodynamic modelling of mineral growth during prescribed PT paths to unravel the significance of observed garnet zonation patterns. Application of Lu-Hf geochronometry is used to further constrain the timing of Alpine high-pressure metamorphism in the Etirol-Levaz slice.

New constrains to the Mesozoic structural evolution of the Inner Western Carpathians achieved by metamorphic, structural and age data

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A complex thin-skinned nappe pile of the Inner Western Carpathians was studied in the central part of the Rudabánya Hills, NE Hungary. A new structural model and evolution were suggested on the basis of structural, metamorphic petrological, geochronological and paleontological data.

The investigated nappes derive from the Neotethys Ocean and its attenuated continental margins and built up by Triassic and/or Jurassic sedimentary rocks. The flysch-type, fine to coarse-grained sedimentary sequence of the Telekesoldal nappe (Meliata nappe system) has evidenced for Bajocian-Callovian sedimentary age (~160 – 170 Ma) and low-grade metamorphism (1.5-2.5 kbar and 300-350°C). The Torna nappe system built up by Triassic sedimentary cover rocks of an attenuated continental crust suffered low-grade overprint with 3-4.5 kbar and 300-350°C, corresponding to 10-15 km of burial. This tectonic burial resulted in S0-1 foliation in both tectonic units. Because of their very similar early deformational history (D1 foliation, D2 folding, D3 kink-type folding) and metamorphic degree, it is supposed that their tectonic contact is a pre-metamorphic nappe contact. Newly obtained K-Ar ages put a time constraint of 142 – 113 Ma for D1 phase.

The metamorphosed, deformed and exhumed Meliata and Torna rocks were emplaced onto non-metamorphic Triassic to Jurassic series (D4 phase). Outcrop- and map-scale structures refer to NW-SE shortening and southeast-vergent nappe emplacement.

Later, the metamorphosed over non-metamorphosed tectonic couplet was thrust again onto the metamorphic Meliata nappe system along E-W striking thrusts (D5 phase). Thrusting associated with reworking of the previous nappe contacts and map-scale F5 folding. Fold vergency indicates southward tectonic transport.

Research on the basal cataclastic breccias of the overthrusting units permits to establish a relative chronology of D4 and D5 thrust contacts and the p-T data of the movements. Trapped fluids in synkinematic minerals indicated temperature up to 200-320°C and pressure up to 3.6 kbar during the D4 nappe movements. Fluid inclusions from the D5 contact resulted in significantly lower p-T values (200-260°C, 0.3-1.0 kbar), indicating thrusts in shallower crustal level.

Migrating high temperature fluids along the nappe contacts caused partial or total reset of the K-Ar isotope system, thus the measured 87–94 Ma is suggested to be connected to nappe movements.

Geodynamic implication: 150-160 Ma southern directed subduction of the West Carpathian margin (marked by the blueschist-facies Bôrka nappe slice) continued at 140 Ma, when the uppermost, Mesozoic part of the thinned and already imbricated crust entered the subduction zone, indicated by the medium-pressure metamorphism of the Torna unit. Part of the Jurassic Meliata sediments submerged into the subduction zone, too. This is the time (D1) when the Torna structural unit underplates the tectonically buried Meliata sedimentary melange. Meanwhile, part of the already HP metamorphosed oceanic and continental crustal fragments (Bôrka nappe) exhumed to the foot of the buried Meliata sedimentary melange. Ongoing compression pushed tectonic slices of the HP unit into the Meliata unit as a tectonic matrix. Low-grade prograde metamorphism of the Torna and Meliata tectonic units and retrograde metamorphism of the Bôrka HP nappe were coeval, indicated by K-Ar data (140-120 Ma).

The mid-Cretaceous Eoalpine phase resulted in thick- and thin-skinned nappe movements (southeast- and south-vergent) in the Western Carpathians, dominating the present tectonic scene and being responsible for the former contradictory views on the structural setting.

Plagioclase metastability during HP-metamorphism? Observations and models from the Adula Nappe

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The Adula Nappe in the Central Alps consists of pre-Mesozoic basement with some Mesozoic cover rocks. Its rock assemblage is assumed to be derived from the distal Mesozoic European continental margin towards the North Penninic ocean. In Eocene times, at least parts of the Adula Nappe experienced extensive alpine metamorphic overprint at eclogite-facies conditions and subsequent rapid exhumation to mid-crustal depths. The Adula Nappe displays a stunning lithological heterogeneity and has been referred to as a lithospheric high-pressure/ultra-high-pressure (HP/UHP) mélange though it is not clear whether (1) the heterogeneity results from intense mixing in the alpine subduction channel or (2) is partly inherited from the pre-Mesozoic history while the Adula Nappe remained coherent during alpine history.

Here, we describe the metamorphic record in orthogneisses from the central portion of the nappe (Alp de Ganan). In the study area, thin layers of orthogneiss are intercalated with HP garnet-mica-schists, which enclose eclogite-cored metabasic boudins. In contrast, the orthogneisses display the commonplace assemblage Qtz + Kfs + Pl + Wm + Bt ± Grt ± Czo/Aln ± accessory minerals (Ap, Zrn, ore minerals). Equilibration under eclogite-facies conditions, however, is expected to produce plagioclase-free jadeite-gneisses. Several explanations exist for the absence of high-pressure relicts in the metagranitoids: (1) The orthogneisses never experienced HP conditions, (2) the orthogneisses did experience HP conditions, were transformed to jadeite-gneisses and completely re-equilibrated to plagioclase-gneisses during retrograde metamorphism, and (3) orthogneisses experienced HP conditions but plagioclase remained metastably through the metamorphic history.

We present petrographic descriptions, whole rock chemical data and extensive microprobe data including chemical maps from orthogneisses sampled at Alp de Ganan. The only clear hint to high-pressure conditions is phengitic white mica preserved in cores of matrix grains and as inclusions in K-feldspar porphyroclasts. In the foliated matrix, white mica coexists with biotite. These matrix grains show pronounced chemical zoning with high silica contents up to ca. 3.4 Si p.f.u. in cores. The increase of Al towards the rim is secondary and controlled by diffusion, probably during biotite growth or deformation. Biotite is only weakly zoned and displays phlogopite components between 50 and 54 %. K-feldspar porphyroclasts consistently contain high-Si phengite as inclusions. Equilibrium assemblage diagrams calculated for the bulk compositions of our samples predict the observed matrix evolution during nearly isothermal decompression from 16 kbar at 700 – 750 °C. This trajectory exactly matches the lower pressure part of published P-T data concerning the nearby-located Trescolmen eclogites. Si-contents as high as observed, however, are predicted only at considerably higher pressures in assemblages with clinopyroxen. The entire sequence of assemblages including observed high-Si contents in phengite can be reproduced in equilibrium phase diagrams if clinopyroxen is removed from the database and a PT-Path as recorded in the adjacent eclogites is assumed. We therefore favor a scenario in which plagioclase remained in the rock metastably through the P-T evolution of a coherent basement unit. Similar metastable survival of plagioclase is described from other HP/UHP terranes.

P-T-t estimates in low-grade metamorphic terrains, a key to reconstruct the geodynamic evolution of the Alpine continental subduction (Briançonnais zone, Western Alps)

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The study of the geodynamic evolution involving continental subduction and exhumation processes requires knowledge of detailed Pressure-Temperature-time paths as recorded in different units across mountain belts. Such P-T-t estimates can be obtained from well equilibrated high-grade metamorphic rocks; usually several methods are available. By contrast, in low-grade metapelites P-T-t estimation using such an approach is challenging, especially if no index minerals occur. Metapelites at greenschist facies metamorphic conditions show a poor spectrum of metamorphic minerals, such as quartz, chlorite and K-white mica; commonly detrital metamorphic relics inherited from a prior metamorphic history remain. Therefore, to acquire reliable P-T estimates a multi-method approach is required, involving qualitative and quantitative Raman study of Carbonaceous Material (RSCM), chemical analysis from standardized X-ray maps and multi-equilibrium inverse thermodynamic modelling of chlorite and white mica. This thermobarometry study may be coupled with $^{40}Ar/^{39}Ar$ dating on newly crystallized phengite in order to constrain the age of crystallization.

In the French Western Alps, the Briançonnais zone is a remnant of the continental subduction wedge. Several studies conducted over the last ten years have aimed at constraining the P-T-t conditions and evolution of the internal parts of the continental wedge (e.g. the Vanoise and Ambin massifs) during the Alpine orogeny. By contrast, the metamorphic evolution of the external part of the Briançonnais Zone, (i.e. the Briançonnais cover and the Briançonnais Zone houillère) remains largely unconstrained. The present study focused on these units; P-T and P-T-t paths were estimated using a multi-method approach advertised above. Examples will be shown, notably for a sandstone sample in the Briançonnais Zone houillère. The study allows distinguishing Hercynian peak metamorphic conditions of 371 ± 26°C and 3.5 ± 1.4 kbar (recorded by detrital minerals) and Alpine peak metamorphic conditions of 275 ± 23°C and 5.9 ± 1.7 kbar. Another sample, taken further south, from the Plan-de-Phasy unit, allows to estimate phengite crystallization conditions at 270 ± 50°C and 8.1 ± 2 kbar at an age of 45.9 ± 1.1 Ma. According to these and previous results in more internal parts of the Briançonnais zone, an adjusted geodynamic model is proposed for the evolution of the Alpine continental subduction. The results are consistent with a diachronous evolution of the Briançonnais zone involved in the Alpine continental subduction.

Gabbro olistoliths from the Mts. Kalnik and Ivanščica ophiolite mélanges in the NW Dinaric-Vardar ophiolite zone (Croatia)

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Mts. Kalnik and Ivanščica ophiolite mélanges vestige for the Repno oceanic domain (ROD), a discrete domain of Neo-Tethys that connects Meliata with Dinaric-Vardar oceanic systems. The domain exposes ophiolitic rocks in four mélange sectors: Mts. Ivanščica, Kalnik, Medvednica and Samoborska Gora. The large gabbro blocks are relatively more abundant in the Kalnik and Ivanščica Mts. mélange sectors, mostly exposed as fault-bounded tectonic inclusions incorporated during ophiolite/mélange emplacement. The preliminary results on petrography, mineral chemistry and bulk rock chemical composition of the gabbro olistoliths are presented and interpreted.

Three mineralogical and geochemical gabbro groups could be distinguished (A, B and C). The gabbros of group A and B show isotropic texture whilst those of group C are coarse grained intergranular. The gabbros of group A are bimineral, composed of plagioclase and augite, the gabbros of group B additionally contain significant but variable amount of edenitic amphibole, whilst edenite represents an additional minor phase in group C. The clinopyroxene from the gabbros is augite (Wo36.5-44.7En29.8-47.7Fs11.0-29.7). Magmatic plagioclase preserved in the rocks of groups B and C shows continuous normal zoning patterns with maximum core to rim compositional range of An41.5-33.7. Edenite textural position and the high content of TiO_2, Al_2O_3 and Na_2O (up to 2.5, 8.3 and 2.7wt.%, respectively) suggest its igneous origin (cotectic with augite). Ilmenite and apatite occur as accessory minerals in all three groups. The C group gabbros contain discrete domains of parallel oriented ilmenite plates (up to 35μm wide) exsolved from a completely decomposed ferromagnesian mineral. A significant chemical difference with respect to the Mn-content of ilmenite was measured between rocks of group B and C (7.82-7.96wt.% vs. 3.28-4.67wt.% MnO). The representative gabbro from group A contains low-Mn ilmenite (< 1.5wt.% MnO) typical of ocean ridge gabbros.

All gabbros are in part altered. The most prominent alteration is transformation of plagioclase to albite and/or peristerite. Less intensive are alterations of augite and edenite to ferro-anthophyllite and/or magnesiohornblende, ferrohornblende, ferroactinolite, actinolite. Other secondary minerals are sericite, calcite, prehnite, diabantite-brunsvigitic chlorite, epidote, leucoxene, high-Al and -Fe titanite, low-Mg stilpnomelane (Mg#=0.20-0.22; K=0.21-0.72 a.p.f.u.) and high-Al pumpellyite, typical of greenschist facies hydrothermal alteration.
Analysed gabbros discriminated into three geochemical groups: (A) N-MORB-type gabbros with slight subduction signatures [(Th/Nb)n=1.80-2.07; (Nb/La)n=0.85-0.90], (B) IAT-type edenite gabbros with clear supra-subduction characteristics [(Th/Nb)n=4.41-5.10; (Nb/La)n=0.41-0.53], and (C) BABB-type gabbros [(Th/Nb)n=2.86-4.04; (Nb/La)n=0.57-0.75]. The representative rocks of the groups A, B and C dated to Early Jurassic, Late Jurassic and to the Cretaceous era, respectively. Early Jurassic gabbros reflect a peculiar stage of Palaeo-Tethyan slab break-off, Late Jurassic gabbros vestige a nascent intra-oceanic arc, and Cretaceous gabbros indicate the existence of magmatism in the back-arc marginal basin. The analyzed gabbroic rocks enable a refinement and completion of the geodynamic evolution of the ROD.

Biostratigraphy, isotope stratigraphy (δ18O, δ13C) and geochemical characteristics (XRF) of Upper Tithonian to Lower Cretaceous deeper-water sedimentary rocks (Northern Calcareous Alps, Salzburg) as a tool to prospect raw material for the cement industry

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We investigated the Uppermost Jurassic to Lower Cretaceous deeper-water calcareous to siliciclastic and siliceous sedimentary rocks (Oberalm, Schrambach and Rossfeld formations) of the Leube quarry in the central Northern Calcareous Alps of Salzburg. Based on an already existing detailed biostratigraphy supported by Calpionellids and Ammonoids, we measured the geochemical characteristics (XRF) and the isotope stratigraphy (δ18O, δ13C) of the more than 450m thick sedimentary succession. Aim is to establish besides the existing classical prospecting methods a new method based on geochemical data to recognise similar successions in the partly deeply weathered and highly deformed Late Jurassic to Early Cretaceous successions of the Northern Calcareous Alps. Beside the limestones of the Oberalm Formation, characteristic sedimentary rocks in the Upper Tithonian to Lowermost Cretaceous are reef slope breccias of the Barmstein Limestone and the oligomictic breccias of the late Upper Tithonian so called “Tonflatschenbreccia”. This succession is characterized by a general deepening- and fining-upward trend getting upsection more and more homogeneous. Generally the content of clay increases and the amount of carbonate decreases. Reason is the back-stepping of the Plassen Carbonate Platform in the Late Tithonian to Middle Berriasian. This trend also becomes apparent in the analysis of major elements with XRF showing a more and more homogeneous chemical composition of the samples. The δ18O and δ13C curves constitute more or less a similar trend.

The drowning of the Plassen Carbonate Platform around the Middle/Late Berriasian boundary resulted in the deposition of a condensed section with red and green limestones and marls of the Gutratberg beds in the uppermost part of the Oberalm Formation. This event can also be seen in the geochemical data and the isotope curves and represents the upper boundary of the Oberalm Formation. The Late Berriasian to Valanginian Schrambach Formation is characterized by the deposition of a relatively homogenous marly and well-bedded limestone marl sequence followed by the Rossfeld Formation (Late Valanginian to Early Aptian). The deposited rocks change to coarse grained siliciclastic breccias and conglomerates followed by a fining upward trend with finegrained arenites, siliceous limestones and marls. The abrupt change at the Schrambach/Rossfeld boundary is also clearly visible in the geochemical data.

We present the first correlation of isotope and geochemical data in connection with high resolution biostratigraphy. Using a standard profile of a more or less complete sedimentary succession of the considered period in the deeper part of the basin, these resulting data can provide the basis to correlate sections from different outcrops. It will be also able to distinguish different depositional areas within the basin. This combination of different methods should help to recognise the completeness of successions occurring usually in weathered outcrop conditions. Besides classical prospecting methods this approach can act as a new tool in the prospection of raw materials for the cement industry.

Alternative models to explain the evolution of Alpine-type collisional orogens: the importance of rift inheritance

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Many plate kinematic and tectonic models proposed for the evolution of the Alps in Western Europe are deeply inspired by present-day SW Pacific-type subduction systems. However, key features characterizing the upper plate of Pacific-type margins, such as high temperature-low pressure metamorphic overprint associated with volcanic arcs and back arc basins are not found in the Alpine domain, despite the fact that the upper plate (Adriatic plate) is very well exposed. This significant difference questions the validity of the supposed similarity between the Alpine Tethys and Pacific-type systems, especially with respect to the nature of the subducted lithosphere and the original basin width.

In our presentation we will first explore the most recent insights on rifted margins architecture and dynamics from the southern North Atlantic, Pyrenean and Alpine domains and discuss how these results may impact the plate kinematic reconstruction and geodynamic evolution of the Alpine system. Based on these observations we will propose an alternative scenario for the pre-Alpine rift evolution. Furthermore, we will show that the rift architecture exerted a major control on the structural and sedimentary evolution of the Alpine system during plate convergence (tectono-sedimentary evolution of Flysch and Molasse sequences) as well as on the final architecture of the orogen (evolution of the external massifs and along strike variations of the Alpine orogenic structure). A key result of our studies is that rift inheritance strongly controlled the final architecture of the interal parts of the orogen. The intimate link between ophiolites and remnants of thinned continental crust and the strong segmentation and diachronous evolution of the mountain belt are largely a result of rift-related tectonics and do not need to be explained by “ad hoc” models. The observation that the Alps in Western Europe developed from a complex paleogeographic domain and represent a collage of different orogenic belts and accretionary prisms that were formed diachronously along different parts of the convergent African-European system questions the comparison with classical steady-state Pacific-type subduction systems.

The structure and P-T evolution of the Dent Blanche Tectonic System (Austroalpine Domain, Western Alps): from the Permian lithospheric thinning to the Alpine subduction and collision

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The Dent Blanche Tectonic System (DBTS) is a composite thrust sheet consisting of superimposed units of polycyclic basement, i.e. Arolla and Valpelline Series, both derived from the Adriatic continental margin. These units preserve a polyphase structural and metamorphic history, comprising both pre-Alpine and Alpine cycles.

The Pre-Alpine history is characterised by a polyphased Permian (from 290 to 265 Ma) granulite-facies event (peak at 860°C, 8 kbar) in the Valpelline Series, and by Permian (~290 Ma) granitoids that intruded at 750°C, 4-5 kbar in the Arolla Series. It is therefore concluded that the Valpelline and Arolla Series are representatives of the lower and upper crust, respectively, of the Adriatic continent.

The Alpine history is heterogeneously preserved in both the Valpelline and the Arolla Series. In the Valpelline Series, previous authors described rare relics of chloritoid-mica in cordierite pseudomorphs and kyanite replacing silllimanite. The lack of extensive blueschist-facies overprint could be due to the low a(H_2O) activity and/or the lack of Alpine ductile deformation. In the Arolla Series, highly strained granitoids display glaucophane-phengite (10-14 kbar, 400-500°C) overprinted by actinolite-chlorite (2-4 kbar, 220-330°C). This transition from blueschist-facies to greenschist-facies parageneses is also seen in some metacherts.

Two main tectonic boundaries are observed within the DBTS. Firstly, the contact between the Arolla and Valpelline Series is marked by a thick (10 m) zone of mylonites that locally display blueschist-facies minerals (blue amphibole, garnet, phengite, aegirine-augite), overprinted by greenschist-facies assemblages. The dominant foliation in the Arolla-Valpelline mylonites shows a prominent NW-SE stretching lineation, and both these structures are overprinted by NE-SW trending folds.

Secondly, the Roisan-Cignana-Shear-Zone (RCSZ) is a NW-dipping shear zone, which cuts through the Arolla-Valpelline contact and separates the DBTS in two subunits, the Dent Blanche nappe to the NW and the Mont Mary nappe to the SW. It results from several deformation phases developed at blueschist (13±2 kbar, 480±50°C) then greenschist (2-4 kbar, 200-300°C) facies conditions. Within this shear zone, tectonic slices of Mesozoic and pre-Alpine metasediments are amalgamated with continental basement rocks. The occurrence of blueschist-facies assemblages along the contact between these tectonic slices indicates that the amalgamation occurred prior to or during the subduction process, at an early stage of the Alpine orogenic cycle.

The structural, petrological and geochronological data provided in this study and those available in the previous works enable us to propose a possible kinematic evolution for the current geometry of the Austroalpine domain. We will discuss the contributions of (i) the Permian lithospheric thinning, (ii) the Jurassic rifting and (iii) the subduction-collision processes in controlling the final geometry of the Austroalpine domain.

Tectonic models for Adria and the External Dinarides in the context of Jurassic-Cretaceous paleomagnetic results

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Adria is a crustal block playing an important role in the geodynamic history of the Central Mediterranean s.l. Recently, a reliable Late Jurassic – Eocene APW path was obtained for its "autochthonous" core. This can serve as a reference frame for describing displacements in its more tectonized margins, like the External Dinarides, where we also carried out systematic paleomagnetic investigation, involving Gorski Kotar and the Velebit Mts from the mainland, several islands of the Northern Adriatic basin, and further in the south, Dugi otok and Vis islands.

The External Dinarides have a complicated internal structure. That is why the tectonic models published for the area are diverse. When the different models are inspected in the context of the above mentioned paleomagnetic data, we can conclude that. 1. the Adriatic islands from the Northern Adriatic basin down to Vis island must have moved in close coordination from the Albian on, although some tectonic models place them to different tectonic units. 2. coeval paleomagnetic directions for the Adriatic islands and for "autochthonous" Adria are co-incident from the late Albian on, thus the paleomagnetic results support the models which regard the former as the imbricated margin of the latter. 3. the Northern Adriatic mainland rotated about 30° CW with respect to Adria, which may be regarded as "inherited" (two carbonate platforms) or may signify relative rotation during Late Eocene between the thrust sheets of the mainland and Adria.

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Identification of tectonically active areas in the Panonnain basin: a combination of DEM based morphotectonic and structural analysis of Bilogora Mt. area (NE Croatia)

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Bilogora Mt., which is predominantly composed of highly deformed Pliocene-Quaternary clastic sediments, represents more than 90 km long and 10 km wide young transpressional structure related to the NW-striking Drava basin boundary fault (DBBF). DBBF was reactivated from originally normal into dextral fault accommodating c. 10 km displacement during Pliocene-Quaternary transpression in the southern part of the Pannonian Basin. On-going tectonic activity is documented by historical seismicity reporting several moderate earthquakes of intensity VI°-VIII° MCS in vicinity of larger towns. It is characterized by NE-SW orientation of the greatest horizontal stress direction determined from fault plane solutions of instrumentally recorded earthquakes (3,5≤ML≤5,6), indicating steeply NE-dipping, and S-SW dipping seismogenic structures with predominantly strike-slip and reverse motions.

Landscape features has been analyzed by DEM raster with 10 m cell resolution. It was modeled and analyzed using ESRI ArcMap 9.x.x. software package with CalHypso, Spatial Analyst, ArcHydro 1.1 and StPro extensions as well as Matlab software. Study area was divided into 130 drainage units. For each unit relative elevation and slope distribution values, drainage unit area-altitude relations (hypsometric integral values) as well as unit absolute asymmetry ratios were calculated. In addition, we analyzed main drainage longitudinal trunk channel statistical values extrapolating parameters of maximum concavity (Cmax), position of maximum concavity (Δl/L), concavity factor (Cf), steepness index (ksn) and concavity index (θ). All calculated geomorphic parameters have been combined and overlayed as rasters, which enable a separation of drainage units characterized by geomorphic parameters that could possibly indicate an on-going tectonic deformation. These units are located between towns of Koprivnica and Pitomača on northeastern slopes and in the vicinity of Daruvar on southwestern slopes, in the northwestern and southeastern part of Bilogora Mt., respectively.

To verify about a possible relationship between geomorphic indices and tectonic deformation a set of 72 reflection seismic sections was analyzed using Schlumberger Petrel Seismic to Simulation software. This software enabled construction of structural depth model comprising 6 stratigraphic horizons and more than 50 faults active during the Neogene-

Quaternary times. Spatial correlation between geomorphic and structural data proved that calculated geomorphic indices in the northwestern part of Bilogora Mt. correlate well with subsurface fault-related folds of Late Pontian-Quaternary age. These folds are formed in hangingwalls of either normal-inverted or younger reverse faults that cut across the base Pliocene-Quaternary horizon and propagate towards the surface. Vertical offset along these faults is in range between 20-480 m, thus indicating a slip rate of ≤ 0.1mm/year during the Pliocene-Quaternary times. Using the published empirical geometrical fault-scaling relationships, we estimate that at least some of these faults are capable to generate earthquakes with magnitudes up to 6.86 which are significantly greater than historically reported in Croatian Earthquake Catalogue.

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Single event time-series analysis in a karst catchment evaluated using a groundwater model

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The Lurbach-Tanneben karst system (Styria, Austria) is drained by two major springs and replenished by both autogenic recharge from the karst massive itself and a sinking stream that originates in low permeable schists (allogenic recharge). Detailed data from two events recorded during a tracer experiment in 2008 demonstrates that an overflow from one of the sub-catchment to the other is activated if the discharge of the main spring exceeds a certain threshold. This data was used to examine how far the time-series analysis (auto-correlation, cross-correlation) supports the identification of the transient inter-catchment flow observed in this karst system. As inter-catchment flow is found to be intermittent, the analysis was focused on single events. In order to support the interpretation of the results from the time-series analysis a simplified conceptual model of the karst system was implemented in the numerical groundwater flow model MODFLOW. In particular, the overflow inferred from the tracer experiment was represented using the wetting capability package of MODFLOW. Thus, the groundwater model represents a synthetic karst aquifer for which all aquifer properties are known in detail. Different types of recharge events were employed to generate synthetic discharge data, which was then used for the time-series analysis. In addition, the geometric and hydraulic properties of the karst system were varied in several model scenarios to distinguish in the results from the time-series analysis the effects of recharge from those of aquifer properties. Comparing the results from the time-series analysis of the observed data with those of the synthetic data a good general agreement was found. For instance, the cross-correlograms show similar patterns with respect to time lags and maximum cross-correlation coefficients if appropriate hydraulic parameters are assigned to the groundwater model. Thus, the heterogeneity of aquifer parameters appears to be a controlling factor. Moreover, the location of the overflow connecting the sub-catchments of the two springs is found to be of primary importance, regarding the occurrence of inter-catchment flow, and further support our current understanding of an overflow zone located near the sinkhole. Thus, time-series analysis of single events can potentially be used to characterize transient inter-catchment flow behaviour of karst systems.

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Rockfall occurrence at the southern border of the Tauern Window – structural, lithological and geomorphologic aspects

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The southern part of the central Tauern Window with the main tectonic units Sub-Penninic and Penninic nappes are overthrusted by Austroalpine nappes (SCHMID et al., 2004; PESTAL et al., 2009). Therefore the tectonic and lithological heterogeneity in this region results in a variety of areas with different lithological and structural anisotropies and consequently geotechnical-lithological properties (MELZNER et al., 2012). This fact has fundamentally influenced the landscape evolution: The area is characterized by two main strike slip fault systems. These tectonically predefined weak zones have been subject to glacial and glacio-fluvial erosion processes. Nowadays the valleys follow the main faults in NW–SE- or WSW–ENE-striking directions, and also related syn- und antithetic faults, respectively (LINNER et al., 2009).

The varying anisotropy affects the spatial distribution and extent of potential rockfall source areas within the study region (MELZNER et al., 2012):

Due to the young landscape evolution an almost preserved, oversteepened glacial and post-glacial relief can be recognized. Hence, nearly all of the lithological units form cliffs starting from 48 or 50 degree of slope inclination. However, more competent rock has greater proportions of steeper terrain than less competent rock.

Typically, steep cliffs occur within the Upper Austroalpine Prijakt-Polinik complex (LINNER & FUCHS, 2005; PESTAL et al., 2009). The lithological properties of this complex and the orientation of its rock mass structure (gently dipping from the NW to NE) favour the development of significant rockfall source areas. Field investigations demonstrated that these cliffs are generally very susceptible to rockfalls due to the heterogeneous anisotropy of this lithological unit. The heterogeneous anisotropy results in a range of failure mechanisms as well as considerable diversity in block size and shape:

- Small-scaled transitions between competent and less competent rock together with the ongoing process of detachment along a few widely spaced discontinuities sets are likely to cause selective weathering and subsequent susceptibility to comparatively large volume rockfalls.
- The number of brittle faults increases from the Prijakt-Polinik complex towards the Melenkopf complex. This results in rockfall source areas that are very small but highly fractured and loosened.
- Some cliffs have been constructed from a sequence of scarps generated by several large volume rockfall events. It is striking that the scarps follow the same orientation as some of the dominant fault planes, which occur with a high degree of separation.

Several rockfall areas are associated with deep-seated slope deformations. These mass movement types shape the landscape in the Tauern Window and have their origin (in regard to mechanism, location etc.) in the varying anisotropy of rock as mentioned above. Depending on the mass movement type (e.g. rock slides, rock creep, rock spreads, etc.) and its stage of development rockfall either occurs within the scarp area, along/ within the body or along the oversteepened front parts of the slope deformations.

Due to the glacial and postglacial landscape evolution, most of the slopes are covered by moraine deposits or scree. The (re-)mobilization of boulders caused by erosion processes, mass movements or wind throw, are common processes. Such „secondary“ rockfalls can be triggered nearly everywhere throughout the whole study area.

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LINNER, M. & FUCHS, G. (2005): Das Ostalpine Kristallin der Sadnig-Gruppe – mit einem Fragment einer unterostalpinen Decke am Südrand des Tauernfensters. - Arbeitstagung Geol. B.-A. Gmünd 2005, 155-158, Wien (Geol. B.-A.).
LINNER, M., HABLER, G.& GRASEMANN, B. (2009): Switch of kinematics in the Austroalpine basement between the Defereggen- Antholz-Vals (DAV) and the Pustertal- Gailtal fault- Eastern Alps. - Alpine workshop 2009, Cogne/Italy.
MELZNER, S., LOTTER, M., TILCH, N. & KOCIU, A. (2012): Rockfall susceptibility assessment at the regional and local scales as a basis for planning site-specific studies in the Upper Moelltal (Carinthia,Austria).- Ber. Geol. B.-A., 91: 105 pages, Vienna. ISSN 1017-8880.
PESTAL, G., HEJL, E., BRAUNSTINGL, R. & SCHUSTER, R. (Ed., 2009): Geologische Karte von Salzburg 1:200.000, Erlaeuterungen. - Geol. B.-A., 162 p., Vienna.
SCHMID, S. M., FUEGENSCHUH, B., KISSLING, E. & SCHUSTER, R. (2004): Tectonic map and overall architecture of the Alpine orogen. Eclogae geol. Helv., 97, p. 93-117, Basel (Birkhaeuser).

Deformation and metamorphism of blueschists within the Phyllite-Quartzite Unit of the External Hellenides, Greece: a comparative study on fluid inclusions

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The Phyllite-Quartzite Unit, exposed in the southernmost part of the Mani peninsula, occurs between the medium-grade metamorphosed Plattenkalk Unit and the low-grade metamorphosed Tripolitsa Unit. The unit contains blueschists arranged as boudins which are surrounded by chloritoid-bearing micaschists. HP/LT metamorphism resulted from subduction of the Adriatic plate beneath the Eurasian plate during Eocene time. Structural mapping indicates three phases of folding. Stage F1 is rarely preserved and results from uniaxial stretching by holding steep SW-plunging fold axes. Superposition of folding events F2 and F3 form a large km-scale fold interference pattern with tight S- to SE and shallow W-E plunging fold axes, respectively.

On microscale, blueschists contain glaucophane+chloritoid+phengite+quartz. The surrounding rocks consist of chloritoid+phengite+paragonite+chlorite+quartz. Mineral chemical analysis of chloritoid indicates a prograde growth. Chloritoide porphyroblasts reflect an earlier foliation S1 (D1) and show locally pseudomorphic transformations to phengite and chlorite that are accompanied with SSW-directed shearing (D2). D2 is responsible for the penetrative foliation S2.

Constraints for the post-peak P-T evolution of the Phyllite-Quartzite Unit have been performed by fluid inclusion studies on late-stage boudin necks close to the blueschists. Necks consist of coarse grained quartz aggregates. Fluid inclusions (FIs) show a frequent occurrence of aqueous saline inclusions predominantly with halite daughter crystals. FIs occur up to 3-phase (S,L,V) and indicate the chemical system H_2O-NaCl-$CaCl_2$. The system is established by eutectic temperatures Te and Raman spectroscopy. Te shows always very low temperatures in the range of -72°C which is interpreted as metastable phase behaviour or crystallization stage. Last ice melting of about -49°C occurs earlier than hydrohalite melting (~-35°C) which coincides well with respective Raman spectra. This indicates a fluid composition around 47 mass% H_2O, 36 mass% NaCl and 17 mass% $CaCl_2$. Densities lie between 1.24 and 1.17 g/cm3. Assuming proposed maximum peak temperatures from blueschists from this area of about 550°C, conditions for extension of boudin necks can be established due to fluid density isochore calculations between 7 and 9 kbar. This fluid inclusion study will now be compared with fluid inclusions in concordant quartz veins which act as host rocks of the blueschist boudin structures.

Middle Triassic eclogite in the Rila Mountains (Rhodope Upper Allochthon, Bulgaria): A vestige of Palaeotethys subduction?

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The Alpine nappe pile of the Rhodope Metamorphic Complex in Bulgaria and Greece was assembled during a protracted history of subduction and collision along the southern margin of Europe. It is subdivided into four thrust systems or tectonic superunits, the Lower, Middle, Upper and Uppermost Allochthon. Previous Lu-Hf dating (KIRCHENBAUR et al., 2012) yielded Eocene ages for eclogite at the base of the Middle Allochthon in the central Rhodopes, and Cretaceous ages for eclogite in the Upper Allochthon in the eastern Rhodopes. In addition, Jurassic HP and UHP metamorphism is suggested by zircon and monazite dating. The overall situation, with older eclogite in higher allochthons and younger eclogite in deeper ones, is analogous to the Caledonides and European Alps. Here we report new data from eclogite of the Upper Allochthon exposed in the Rila Mountains, in the northwestern part of the Rhodope Metamorphic Complex.

The eclogite crops out near Metoch Pchelino, about 3 km SW of the famous Rila Monastery. It is part of a lithologically heterogeneous and strongly sheared, N-S striking zone containing metabasic and –ultrabasic rocks as well as garnet-kyanite metapelites. Most of the eclogite is retrogressed but relics of omphacite are still present. Mn and Lu contents in garnet show typical bell-shaped profiles which are evidence of prograde garnet growth during P and T increase. Lu-Hf chronometry using the whole rock and three garnet separates yielded a well-defined isochrone with an age of ca. 238 Ma (Ladinian). As most of the Lu is in the garnet cores, this age is interpreted as the age of pressure increase during subduction.

Triassic eclogite has so far not been found in Europe but only from Turkey towards east. The distribution of Triassic eclogite and arc magmatites in Turkey (e.g. AKAL et al., 2011) suggests southward subduction of Palaeotethys during the Triassic, contemporaneous with opening of Neotethys to the South, and finally leading to collision of the resulting continental ribbon with Europe between Late Triassic and Middle Jurassic. The Rila eclogite fits in such a scenario, possibly representing the suture between the European margin to the north and a Gondwana-derived fragment to the south, the Ograzhden-Vertiskos terrane. When the Rhodope allochthons later formed, during subduction and closure of Neotethys and the Vardar ocean, the Rila eclogite and Vertiskos-Ograzhden terrane became part of the Upper Allochthon.

AKAL, C., KORALAY, O.E., CANDAN, O., OBERHÄNSLI, R. & CHEN, F. (2011): Geodynamic Significance of the Early Triassic Karaburun Granitoid (Western Turkey) for the Opening History of Neo-Tethys - Turkish J. Earth Sci., 20/3, 255-271.

KIRCHENBAUR, M., PLEUGER, J., JAHN-AWE, S., NAGEL, T.J., FROITZHEIM, N., FONSECA, R.O.C. & MÜNKER, C. (2012): Timing of high-pressure metamorphic events in the Bulgarian Rhodopes from Lu–Hf garnet geochronology - Contr. Mineral. Petrol., 163/5: 897-921.

Carnian-Norian tectonics and seawater from Silicka Brezova, Western Carpathians

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After the Middle Triassic extension and the break-up of the Neotethys Ocean intense tectonic characterize the Late Triassic distal carbonate shelf, expressed in facies changes and breccia formation. A first tectonic pulse in the Late Carnian (Tuvalian 1) results in the flooding of the formerly emerged Wetterstein carbonate platform by forming a pelagic plateau, which lasts until the Late Norian (compare Muerzalpen facies of the Northern Calcareous Alps). The overlying Late Triassic sequence is exposed in a system of several quarries and trenches all west of the village Silicka Brezova in the Western Carpathians (Silica nappes). In the Tuvalian 1 and 2 deeper slope deposits of hemipelagic filament limestones with intercalated resediments from the nearby Waxeneck carbonate platform are relatively high in their Li and Br palaeo-seawater ionisation. A higher Li concentration in the Tuvalian 2 may correspond to volcanic activity; as known e.g., in the Buekk Mts. The next tectonic pulse is reflected in a rapid deepening around the Tuvalian 2/3 boundary: On top of an unconformity hemipelagic reddish Hallstatt-like limestones were deposited; they show a rapid decrease in Li and Br concentration. The Late Carnian to Middle Norian time span is characterized by deposition of grey and reddish hemipelagic limestones, still low in Li and Br. Intense tectonic in the Late Norian result in a sedimentary sequence with a general fining upward trend. The Hallstatt Limestones components of Late Carnian to Middle Norian age differ in their litho- and microfacies from the underlying sequence. The provenance area of the clasts might be the outer shelf in the Hallstatt Zone indicating Late Triassic strike-slip induced basin formation as evidenced e.g., in the Karavank Mts. A low NO_3 concentration and a higher F concentration reflect a typical palaeo-seawater of this palaeogeographic realm. The Dachstein carbonate platform progradation is evidenced by shallow-water resediments in the latest Norian hemipelagic limestones, again with an increase in the Li concentration. The tectonic and the known Late Triassic crisis events are reflected in the palaeo-seawater composition.

Petrographic features of chloritoid schist from southeastern slopes of Mt. Medvednica, (Zagorje-Mid-Transdanubian zone, Croatia)

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In the frame of detail mapping of parametamorphic rocks on the southeastern slopes of Mt. Medvednica (Zagorje-Mid-Transdanubian zone, Croatia), samples of the chloritoid schists were analyzed in more detail.

This study is a part of preliminary research that included XRD, XRF, ICP-MS, SEM, electron microprobe and microstructural characterization of chloritoid schists in order to determine their petrography, microstructural features, mineral assemblages, phase composition, whole-rock and mineral chemical composition and morphology of accessory minerals (zircon typology).

The samples can be categorized as chlorite-muscovite-quartz schist, chloritoid-chlorite-quartz-muscovite schist, chlorite-muscovite-quartz-chloritoid schist and interbeds of marble. Accessory minerals in chloritoid schist are tourmaline, zircon and rutil. Microstructural features show two deformational events, the sinmetamorphic and postmetamorphic events. The latter deformational event is recorded in the development of flazer structure, where the mineral grains in cleavages are translated, fractured and rotated.

The whole-rock chemical analyses show high concentrations of SiO_2 (74.79 wt. %), K_2O (2.5 wt. %), Al_2O_3 (13.22 wt. %), and low values of MgO (0.99 wt. %) and CaO (0.08 wt. %).These results indicate that acid rocks could be a possible protolith. The REE distribution normalized to chondrite shows higher LREE to HREE concentrations ((La/Yb)N=5.68, (La/Sm)N=3.05, (Gd/Yb)N=1.21), while the Eu anomaly has a low value (Eu/Eu*=0.7).

Such metamorphic mineral assemblage is characteristic for low-grade metamorphism. The chlorite-chloritoid geothermometer gives metamorphic temperature values of approximately 450°C.

The source rocks of the chloritoid schist are argillaceous sandstones, derived from acid magmatic rocks, interbeded with carbonates. Carbonate interbeds indicate deposition in a marine environment. The morphology of zircons shows that the source for protolith is of granitoid composition, while their weak roundness indicates a short transport.

The role of rift-inherited hyper-extension in Alpine-type orogens

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The Alpine orogen is commonly interpreted as the imbrication of rifted margins and intervening “oceanic” domains. Notably, the understanding of the architecture and evolution of rifted margins underwent a paradigm shift thanks to new high-resolution refraction and reflection seismic imaging method developments combined with the Ocean Drilling Program. Indeed most continental rifted margins show evidence for hyper-extension prior to lithospheric breakup. Hyper-extended domains are characterized by: 1) extremely thin continental crust and exhumed subcontinental mantle extending over hundreds of kilometers, 2) necking zones marking sharp boundaries between little extended crust and hyper-extended < 10km thick crust.

The discovery of hyper-extended domains and necking zones in rifted margins still awaits to be fully integrated in conceptual and numerical models of collisional orogen evolution. This study aims to constrain the extent to which rift-inherited hyper-extension may control the architecture and evolution of Alpine-type orogens.

Based on the available geological and geophysical datasets, the Alpine orogen can be subdivided into external and internal domains. Notably, the external domains formed at the expense of the former proximal rifted margin associated with a poorly extended crust. In contrast, diagnostic elements for hyper-extended domains are being increasingly recognized in the internal domain of the Alpine orogen while the identification of former necking zone remains more problematic. However, based on the available data, we suggest that the transition between the external and the internal domains still preserves the evidence of a former necking zone.

As a result, we propose that the evolution of the Alpine orogen is strongly controlled by rift inheritance. We suggest that subduction is initiated within the hyper-extended domain rather than the oceanic crust. Subduction processes are enhanced by partial serpentinization due to rifting processes. The continental collision is then triggered by the arrival of necking zones at convergent plate margins. Since they mark the boundary between little extended proximal and hyper-extended domains, necking zones act as buttresses initiating the transition from a subduction to a collisional stage. The continental collision, controlled by the necking zone, will create a major boundary in the orogen delimiting (1) the highly deformed and overthickened internal domain preserving the relics of rift related hyper-extension from (2) the weakly deformed external domain which neither suffered significant rift-related crustal thinning nor orogeny-related thickening.

Eventually, adopting a more realistic pre-orogenic margin architecture may significantly modify our view on mountain building formation of Alpine type orogens. Besides, results of this work should be seen in the light of recent discoveries from present-day deep-water rifted margins questioning the nature of the Alpine Tethys as either related to a true Atlantic-type ocean or to hyper-extended rift basins showing hyper-extended continental crust and local mantle exhumation but failing to create a stable plate boundary.

Tectonics in the Swiss Molasse Basin

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The Swiss Molasse Basin is located to the North of the Subalpine Molasse and the Prealpes Klippen belt, and is forming along its northern edge an erosive limit with the first fault-related folds of the Jura fold-and-thrust belt (JFTB). Originally the Molasse Basin extended farther north into the JFTB as documented by the numerous Molasse occurrences in the box-shaped synclines. Towards the W-SW the Molasse Basin grades into the fault-related fold structures of the Subalpine Chains in France. In its wester portion the Molasse Basin forms a wedge-top foreland basin, whereas in its oriental part, east of the eastern tip of the JFTB, it forms a classic flexural foreland basin. This transition – where the alpine orogenic front jumps from the frontal Jura thrust (including the Mandach thrust) to the Alpine front s.str. – occurs along a series of major NW-SE trending faults such as the Neuhausen and Randen faults and the Hegau-Bodensee graben faults, as well as the St. Gallen fault system farther SE. The transition between the tip of the JFTB belt and these faults is formed by the Permo-Carboniferous Graben of N Switzerland.

Strain partitioning inside the Swiss Molasse Basin develops a complex pattern of evaporite-cored structures (folds and grabens, fault-related folds laterally terminated by steep oblique ramps, extensional structures (grabens), inversion features above Permo-Carboniferous basins, triangular structures (mostly at the transition with the Subalpine Molasse thrust zone), and strike-slip fault systems. The latter such as the Vuache fault system or the La Lance Fault and the Pontarlier Fault in the JFTB regionally form a conjugate fault system with left-lateral faults striking N-S and dextral faults striking NW-SE. They cut from the JFTB into the Molasse basin. Locally former normal faults are reactivated in a strike-slip mode such as in the N-S trending Fribourg Zone.

Strain partitioning also occurs in a vertical profile; thus the whole area, including the JFTB, is detached above a layer of Triassic evaporites. In the southern part of the Molasse Basin the Tertiary Molasse series s.str. are detached from the Mesozoic substratum. The basement also bears major tectonic faults that form a series of Permo-Carboniferous grabens, the extent and direction of which remains elusive, except in a few rare cases such as the graben of N Switzerland. The thrust faults and strike-slip faults are restrained to the cover series and root in the basal Triassic detachment and do not extend into the basement.

The structural development of the foreland basin is classically associated with the formation of the JFTB. Recent sedimentology studies from Molasse series in the Jura synclines show distinct facies pointing to syndepositional topographic barriers which we interpret to be embryonic folds. Combined with other information such as onlaps (from seismic studies) we suggest that the onset of folding in the Molasse Basin and the JFTB is much earlier as hitherto suggested – probably as early as Oligocene.

Recent studies have combined surface field data, subsurface data from seismic surveys, earthquake analysis (especially distribution of clusters) with 3D modeling. The objective is to construct a kinematically consistant 3D-model that will help orient and constrain hydrocarbon and deep geothermal energy exploration as well as seismic hazard analysis.

Aspects of the pre-Alpine and Alpine tectonic evolution of the Gurktal Extensional Allochthon, Eastern Alps: Constraints from structural studies and ^{40}Ar/^{39}Ar white mica ages

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The nature and extent of Alpine thrusting of the Gurktal nappe complex represents one of the most controversial topics of Austrian geology. New structural and white mica ^{40}Ar/^{39}Ar ages from the Gurktal nappe complex, Eastern Alps, indicate ESE-directed distributed shear mainly leading to the present-day juxtaposition of the deeper Murau nappe overprinted in higher greenschist metamorphic conditions during the Cretaceous, to the higher, nearly unmetamorphic Stolzalpe nappe. The boundary in between represents, therefore, a ductile low-angle normal fault and the unmetamorphic Stolzalpe nappe the main body of a Late Cretaceous extensional allochthon. The distributed extensional shear system along the western margin of the Gurktal nappe complex overprinted nappe stacking structures and operated from initial ductile via semi-ductile and finally to brittle conditions within the same kinematic framework. A plateau age of 89.0 ± 0.6 Ma was found for newly grown white mica in the basal Lower Triassic Stangalm Quartzite exposed at the base of the Mesozoic cover succession on the Bundschuh basement. For the first time, a plateau age of 85.78 ± 0.33 Ma demonstrates the pervasive Late Cretaceous metamorphic overprint on the Murau nappe in the footwall of the regional, ESE-directed ductile detachment fault. This age is interpreted to date cooling after the throughout recrystallization of rocks composing the Murau nappe.

Furthermore, a post-Variscan angular unconformity below the Lower Triassic Stangalm Quartzites (PISTOTNIK, 1976) proves the preservation of style and orientation of Variscan structures in the Bundschuh basement unit. Essentially, an open N-trending fold is unconformably overlain by the above mentioned Lower Triassic Stangalm Quartzite. The basement micaschist displays three stages of deformation. Deformation stage D1 relates to the formation of a penetrative foliation within amphibolite facies conditions as pseudomorphs after staurolite testify. The second deformation stage D2 is represented by formation of E-W-trending isoclinal folds similar as in the wider surroundings. The isoclinal folds are again refolded in open, N-trending folds, representing deformation stage D3. This fold is discordantly cut and overlain by the Stangalm Quartzite. These relationships argue for a Variscan age of the dominant metamorphism within amphibolite facies conditions.

The pre-Alpine deformational structures at this angular unconformity indicate Variscan N–S shortening as the most dominant structure. This is in line with reports suggesting Variscan ca. SSW-directed SSW–NNE shortening at the famous angular unconformity between Devonian limestones and the Permian Prebichl Fm. at the structural base of the Northern Calcareous Alps (NEUBAUER, 1989). Together, these structures indicate ca. N–S resp. NNE–SSW Variscan shortening within present-day coordinates. However, this must be confirmed by further regional investigations.

NEUBAUER, F. (1989): Late Variscan structures of the Eastern Greywacke Zone (Eastern Alps). - Neues Jahrbuch für Geologie und Paläontologie Monatshefte, 1989/7: 425–432.

PISTOTNIK, J. (1976): Ein Transgressionskontakt des Stangalm-Mesozoikums (Gurktaler Alpen, Kärnten/Österreich). - Carinthia II, 166/86: 127–131.

Emplacement mechanisms of evaporite mélanges: conceptual models and application to Northern Calcareous Alps

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Because of the very low shear resistance, evaporite mélanges often form decollément surfaces of extensional and contractional allochthons. Evaporites are commonly deposited in an early stage of passive continental margin formation and are overlain by thick successions deposited during the subsequent thermal subsidence stage. These latter rocks are resistant against penetrative internal deformation. Evaporite mélanges are common (1) at passive continental margins, where they are deformed during gravity-driven raft tectonics in an extensional geodynamic setting, and (2) in external foreland fold-thrust belts within a convergent geodynamic setting. In the following, we first review the most important features of both settings and then we apply these to the Northern Calcareous Alps (NCA). In gravity-driven raft tectonics at passive continental margins, an upper extensional domain is separated from a lower compressional domain at its toe. Ocean-directed rafting at low temperatures is mainly driven by thickness variations of the overburden, occurs during intermediate stages of the depositional history of the passive margin succession and may last as long as a topographic gradient is in existence. The resulting structure of the extensional domain is characterized by pronounced thickness variations of the syn-tectonic overburden within halfgrabens. In contrast, external foreland fold-thrust belts are generally transported continent-wards during episodic stages of shortening after the termination of the sediment deposition, and no pronounced thickness variations occur in the overburden except in wedge-top basins. In nature, earlier extensional deformation may have been overprinted by subsequent contraction causing complications in the structure of the thin-skinned fold-thrust belt. The central and eastern NCA are called to have formed by gravity-driven sliding of thick masses of mainly Middle-Upper Triassic carbonate platform and basin sediments on the uppermost Permian-Lower Triassic evaporite mélange (Haselgebirge Fm.) during Mid–Late Jurassic times. Main arguments for this interpretation are the presence of major Haselgebirge bodies within mainly Upper Jurassic formations and the presence of up to hill-sized blocks (mainly limestones of the Hallstatt facies realm) in a Haselgebirge matrix. This interpretation also assumes a continent-ward motion, considered as sliding into local basins, e.g. the Lammer basin. We challenge the interpretation of gravity-driven emplacement of the present structural edifice and present the following arguments for an essentially Early–early Late Cretaceous age of emplacement of cover nappes with evaporitic mélange at the base. Based on cross-sections between Hall/Tyrol and the eastern margin of NCA distributed over ca. 450 km, we distinguish three architectural modes of Haselgebirge occurrences: (1) sulphate-dominated N-vergent thrust sheets; (2) double-vergent halite-rich diapiric bodies soling in N-vergent thrust faults; these bodies are sometimes overprinted virtually by mixed thrust-strike-slip faults; and (3) sulphate-dominated post-metamorphic normal faults (e.g., Rettenstein). Type (1) N-vergent nappes were transported continent-wards against gravity on ductile evaporite mylonite zones partly over the Lower Cretaceous siliciclastic Rossfeld Fm. Ductile mylonite zones are well preserved mainly in sulphates (anhydrite, polyhalite) and partly dated at ca. 110 Ma. Such mylonitic ductile shear zones were mapped in several areas from the southern margin (Werfen Imbricate zone) to close to the northern margin of the NCA (Berchtesgaden – Dürrnberg). Except differences between Hallstatt and Dachstein facies realms, no significant local thickness variations and wedge-shaped strata are known in neither Middle–Upper Triassic nor Jurassic stratigraphic units. Exclusive Jurassic raft tectonics as mechanism for evaporitic mélange emplacement seems therefore unlikely. Of course, the new interpretation does not exclude earlier stages of local gravity sliding, e.g. during Jurassic/Cretaceous, likely in front of convergent allochthons. However, the main body (Juvavic tectonic units) emplaced along a “high”-temperature sulphatic ductile shear zone (Haselgebirge evaporite mélange) in a Cretaceous fold-thrust belt.

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Source rock investigations and organic geochemistry of a Cretaceous succession of the Outer Dinarides (Mokra Gora, Tara Mountain, SW Serbia)

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A Cretaceous (Albian to Turonian) succession containing organic-rich sediments is exposed in the area of Mokra Gora and Tara Mountain (SW Serbia). Four sections representing different positions of the basin were investigated regarding source rock potential and organic geochemical characteristics. The Cretaceous geodynamic history and the depositional settings of organic-rich sediments in the Alpine-Dinaric realm is still not completely understood and controversially discussed. After an orogenetic process with decreasing tectonic activity during the Late Jurassic to Early Cretaceous a new depositional cycle started around the Early/Late Cretaceous boundary. In the Outer Dinarides of SW Serbia a Cretaceous sedimentary succession on top of the former nappe stack is preserved. The investigated succession is characterized by a basal transgressive part (Albian) followed by a series of alternating layers of siliceous to marly limestones and thin bedded black marls rich in organics (Cenomanian). This series represents a deepening upward. The black marls contain pithonellas, rarely heterohelicides, hedbergellas, ammonites, echinoderms and molluscs. On top of the investigated succession light limestones with rudists, shell fragments and gastropods represent a shallow water development of Upper Cenomanian to Turonian age.

The stratigraphic age of the organic-rich interval is proven as Cenomanian by means of *Aeolisacus inconstans, Ovalveolina maccagnae, Rhapidionina laurinensis* and *Cisalveolina fraasi.*

All samples were investigated by means of Leco- and Rock Eval analyses regarding their source rock characteristics. For selected samples organic-geochemical analyses were performed to determine the origin and composition of the organic matter.

The black marl development in the investigated area can be divided into two parts due to the gained results. The samples of the stratigraphic lower part reach peak values of more than 18 % total organic carbon (TOC) and hydrogen indices (HI) of greater than 700 mg HC/g TOC. Based on a modified van-Krevelen-diagram the kerogen of the samples can be classified as type I and II. Lamalginite is by far the most abundant maceral in these samples and indicates algae to be the primary source of the organic matter. In the stratigraphic higher part values for TOC and HI are below 2.5 % and 400 mg HC/g TOC, respectively. The samples plot in the field of type II and III kerogen. The frequent abundance of vitrinite also indicates a stronger terrestrial influx for these samples. Tmax-values between 400 and 426 °C indicate low maturity of 0.3 to 0.5 % Ro for all investigated samples of the succession. This is confirmed by organic geochemical results (sterane-ratio, MPI). Results of organic geochemistry analyses further argue for open marine to transitional depositional environments with anoxic to partly euxinic conditions poor in oxygen. The organic matter is mainly of marine origin, terrestrial input is more important for the upper units of the succession. This argues for differing water depths. The presence of arylisoprenoids is an indicator for photic zone anoxia. Cadalene, which is typical for terrestrial input, could be detected in the higher parts of the succession displaying the transition to more shallow water environments.

Due to these results the investigated black sediments can be seen as excellent potential source rocks featuring high potential to generate hydrocarbons in the nappe stack of the Dinarides.

In-sequence and out-of-sequence thrusts: nappe structure of the western Northern Calcareous Alps revisited

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In fold-and-thrust belts, syntectonic sediments provide a means to date deformation. The youngest sediments below a thrust sheet give the maximum age of thrusting, and growth strata record growth of individual structures. Applying this concept shows that the Northern Calcareous Alps (NCA) thrust sheets were emplaced from the Barremian onwards. Thrust activity propagated from the SE to the NW and reached the South Penninic units in the Turonian or Coniacian. Shortening did not cease after thrust sheet emplacement, while the NCA were carried piggy-back over Penninic units. Growth strata in the various Cretaceous syntectonic clastics (Branderfleck Fm., Gosau Group) document significant contraction after thrust sheet emplacement well into the Maastrichtian.

As defined by previous authors, the major thrust sheets of the western NCA are from base to top: The Allgäu thrust sheet, the Lechtal thrust sheet and the Inntal thrust sheet. The first two are part of the Bajuvaric nappe complex, whereas the last belongs to the Tirolic nappe complex. This model of the NCA thrust sheets assumes far-travelled nappes that are entirely separated and have a continuous thrust at their base. If the NCA thrust sheets would adhere to such a simple model the thrusts should display ramp-flat geometry and form a hinterland dipping duplex, which they do not.

Using the information from syntectonic sediments following problems with the traditional nappe subdivision emerge:

(1) The Inntal thrust sheet was emplaced out-of-sequence after thrusting of the Lechtal thrust sheet in its footwall. In the Karwendel mountains, it is connected to the Lechtal thrust sheet in a north-facing anticline dissected by out-of-sequence thrusts. These were originally interpreted to be the base of the Inntal thrust sheet.
(2) The Albian Lechtal thrust ends in a tight anticline in the Arlberg area and is replaced by the Coniacian to Santonian Mohnenfluh thrust.
(3) The Tirolic basal thrust has an Eocene age, where it was drilled (well Vordersee1 east of Salzburg); At the surface, the sinistral Inntal shear zone separates the Bajuvaric Lechtal thrust sheet from the Tirolic nappe complex, and not a flat-lying thrust.

In fact the western NCA are one single tectonic unit. All thrusts end laterally. However, individual thrusts do have offsets in the range reported previously, but thrusts loose offset laterally. In many cases, thrusts do display to out-of-sequence geometries: The Inntal out-of-sequence thrust truncates folds in its footwall and hanging wall, as it should. However, also the Lechtal thrust dissects pre-existing anticlines and synclines. We speculate that only a model of thrust propagation involving significant footwall deformation can describe these thrusts correctly.

Relict rock glaciers- complex aquifer systems in alpine catchments, Niedere Tauern Range, Austria

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In the 1990s water resources investigations in the Niederen Tauern Range, Austria demonstrated that springs draining relict rock glaciers are of importance for water supply and human consumption as well as for the alpine ecosystem. Recent studies show that in the easternmost subunit of this mountain range, the Seckauer Tauern Range, up to 20% of the area above 1500 m a.s.l. and more than 40% of the area above 2000 m a.s.l. drain through relict rock glaciers. Thus, the hydraulic properties of these alpine aquifers are considered to have an important impact on the hydrology of the region. Their storage capacity affects and regulates strongly the risk of natural hazards such as floods and debris flows and the possibility for economic use of the water resources. However, the hydraulic properties of relict rock glaciers and their inner structure are still poorly understood.

The investigation area is the Schöneben Rock Glacier (SRG) located in the central part of the Seckauer Tauern Range. The SRG cover consists predominantly of coarse-grained, blocky gneissic sediments and extends from 1720 to 1905 m a.s.l.. It covers an area of 0.11 km² and drains a total catchment of 0.76 km² with its maximum elevation of 2282 m a.s.l.. Discharge of the rock glacier spring is recorded since 2002. Natural tracers, electrical conductivity and water temperature are continuously monitored since 2008. Furthermore, a tracer test with simultaneous injection of the fluorescent dyes naphthionate and uranine at two injection points (one close to the front and one close to the rooting zone of the rock glacier) was performed. The analysis of the spring hydrograph on the one hand shows a slow base flow recession indicating a high storage capacity and on the other hand sharp discharge peaks immediately after rainfall events referring to a high hydraulic conductivity. The spring hydrograph therefore reveals similarities to the flow dynamics of karst springs. Results from analytical recession models are consistent with the conceptual model of a heterogeneous aquifer that is composed of multiple overlapping exponential segments with recession coefficients ranging from 0.06 to 0.002 d-1. The peak of the uranine breakthrough curve was recorded after approximately 100 days. This agrees well with the reciprocal of the intermediate recession coefficient, which may be interpreted as the mean residence time of the corresponding flow component. In addition to this intermediate flow component, the rapid spring responses to recharge events with sharp discharge peaks and negative electric conductivity and temperature peaks within a few hours suggest the existence of a fast flow component. Using electrical conductivity to separate the discharge components of the hydrograph yields up to 20% event water with residence times in the order of hours whereas 80% of the discharge is found to be pre-event water with longer residence times. The highest percentage of event water coincides with the highest discharge rates. The natural and artificial tracers thus support the conceptual model of a heterogeneous aquifer with at least two different storage components. While a coarse grained, blocky upper zone is believed to provide the fast run off component, a fine grained (sandy, poorly silty although with larger embedded blocks) inner zone provides the base flow component.

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Pre-Alpine and Alpine evolution of the Seckau crystalline basement (Seckau mountains, Eastern Alps)

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The massif of the Seckau mountains (Seckauer Tauern) is mainly built up of granitoids, overprinted by Eoalpine (Cretaceous) deformation during nappe stacking and subsequent extension, and greenschist facies metamorphism. Whole rock Rb-Sr age data of ca. 432 Ma and 350 Ma were assumed to indicate the protolith ages (SCHARBERT, 1981). In this study, a suite of granitoids was geochemically analysed by X-ray fluorescence (Bruker Pioneer S4) in order to derive the processes of magmatic evolution and differentiation. In general, three types of magmatites can be distinguished: granites, granodiorites and quartz-monzodiorites. The first two form the majority, whereas the intermediate quartz-monzodiorites are only locally exposed.

Following the A/CNK discrimination diagram a clear distinction between S- and I-Type granitoids can be established. The S- type granites are mainly part of the structurally uppermost sections and are covered by Permian to Lower Triassic metasedimentary sequences of the Rannach Formation.

Within the AFM diagram all granitodis are characterized by a calcalkaline trend. This suggests formation of the melts during a subduction process. Within the R1-R2 digram, the granitoids are related to both pre-plate collision, syn-collision and post-collision uplift settings. We therefore suggest that the granitoids of the eastern Seckau massif are part of an intrusion sequence during distinct stages of a plate tectonic cycle, i.e. from pre- to post collision, and that the related magmas differentiated from intermediate (quartz-monzodiorites) I-type to acidic (granites, granodiorites) S-type.

Biotites separated from the granitoides yield Rb-Sr age data between 83 and 87 Ma, and 80 to 76 Ma. These ages are assumed to represent cooling ages related to the exhumation of the Seckau massif subsequent to Eo-Alpine greenschist facies metamorphism.

SCHARBERT, S. (1981): Untersuchungen zum Alter des Seckauer Kristallins. - Mitt. Ges. Geol. Bergbaustud. Österr., 27: 173-188.

Jurassic and Lower Cretaceous tectonics of the Western Carpathians: coupled vs. uncoupled hinterland shortening and foreland stretching

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During Jurassic and Early Cretaceous, tectonic evolution of the Western Carpathians was governed by two competing, but mutually related processes – hinterland collision and prograding nappe stacking after closure of the Neotethys-related Meliatic oceanic domain, while the external zones underwent lithospheric stretching that graded into opening of the Atlantic-related Penninic oceanic zones. This contribution attempts at interpretation of these processes from the point of view of crust dynamics as revealed by deep-seated structural-metamorphic and surface sedimentary records.

Opening and ensuing spreading of the Meliatic branch of Neotethys was initiated in early Middle Triassic and lasted until Late Triassic (245–210 Ma) while overall distensional tectonic regime acted on its broad northern European passive margin. The geodynamic situation changed by the earliest Jurassic, when this shelf underwent wide rifting during Lias to Middle Dogger with formation of extensional, gradually pelagic basins (200–170 Ma). Contemporaneously, subduction of the Meliatic oceanic lithosphere commenced. These processes were likely triggered by a change in large plate kinematics – SE-ward drift of Africa and Adria with respect to Europe during opening of Central Atlantic. The Western Carpathian orogenic wedge nucleated by accretion of material scraped off the subducted Meliatic crust, accompanied by formation of early melanges rich in ophiolite material. In the Middle Jurassic time, the continuing rifting in distal European foreland resulted in breakup of the South Penninic-Vahic Ocean (ca 170–165 Ma). During the next periods, the Western Carpathian orogen behaved as an autonomous converging system driven by the downgoing Meliatic slab.

The Late Jurassic epoch started with incipient collision after closure of the Meliatic basin and by subsequent overriding of the Carpathian Austroalpine passive margin by the Meliatic accretionary complex, including a blueschist nappe (originally a distal passive margin element). In the peripheral foreland, compressional basins developed sequentially in front of thin-skinned thrust sheets of the later Hronic and Silicic nappe systems, which were filled with synorogenic, partly mass-flow deposits with decreasing amount of ophiolitic material (165–155 Ma). Activity of the pro-wedge slowed down during the latest Jurassic – earliest Cretaceous, while the retro-wedge grew at this time (155–140 Ma). After all the Meliata-related oceanic zones were consumed, thrusting relocated to the pro-wedge again, where the Gemeric basement sheets were stacked above the Veporic basement/cover superunit (140–125 Ma). In a coupled system, the collisional crust thickened considerably, as registered by structural-metamorphic and thermochronological data from the Veporic basement.

Throughout the late Lower Cretaceous, the wedge remained in a contractional regime. After foundation of an intracontinental underthrusting zone between the Fatric and North Veporic zones at ca 110 Ma, the pro-wedge began to grow rapidly by incorporation of the entire Fatric-Tatric crust. This was enabled by thermal softening of the Veporic basement and resulting decoupling of the Neotethyan collisional stack from the lower Fatric-Tatric plate. Subsequently the uplifted plug in the wedge centre – supra-Veporic mountainous area, which supplied the mid-Cretaceous peripheral flysch basins with clastic material (110–95 Ma), collapsed by orogen-parallel extension during the Late Cretaceous (90–70 Ma).

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Possible amounts of tectonic overpressure in the Adula nappe (Central Alps) derived from a new restoration of the NFP-20 East cross section

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Within the NFP20-East cross section through the Eastern Swiss Alps, the Adula nappe is remarkable for eclogite and garnet peridotite lenses testifying to Late Eocene high- to ultrahigh-pressure metamorphism. The pressure values established for these rocks by petrological methods exceed those of the over- and underlying units and define a gradient spanning from c. 17.5 kbar in the north to c. 30 kbar in the south. The oldest pervasive structures postdating high-pressure metamorphism are related to strong top-to-the-north-northwest shearing ceasing under amphibolite- to higher greenschist-facies conditions. Paradoxically, but similar to other ultrahigh-pressure units in the Alps, these movements were top-to-the-foreland, i.e. thrusting movements associated with decompression. Conventional kinematic reconstructions for the exhumation of the Adula nappe assume that peak pressures recorded in different parts of the nappe were lithostatic and combine the depths thus obtained with radiometric ages. In all published kinematic restorations, the Adula nappe is therefore restored to a depth from which it could only be exhumed to mid-crustal levels by a major to-to-the-south normal fault for which there is no evidence in the structural record. As an alternative to such models accepting that large part of the structural history during exhumation may have been completely erased by later shearing, we propose a purely structural restoration of the central part of the NFP20-East cross section. Benefitting from a probably unmatched wealth of structural and geochronological studies performed along this cross section, the new three-step restoration not only takes into account folding and relative movements between individual units but also nappe-internal thinning resulting from shearing which significantly contributed to the exhumation of the Adula nappe. The restoration results in maximum burial depths of the Adula nappe reaching from c. 47 km in the north to c. 62 km in the south. Assuming a density of 2700 kg/m^3 for the overburden, these depths would correspond to pressures between c. 12.4 and 16.6 kbar while the pressures actually observed are c. 40% (north) to 80% (south) higher. Various numerical and analytical studies have shown that tectonic overpressure, i.e. the isotropic part of the stress tensor exceeding lithostatic pressure, can be up to about the same amount as lithostatic pressure for realistic rheological properties and strain rates of rocks. Admitting such an amount of tectonic overpressure would therefore reconcile the petrological and structural records of the Adula nappe. Hence, we suggest to consider the possibility that tectonic overpressure rather than excessive deepening caused the high- to ultrahigh-pressure metamorphism in the Adula nappe.

The central Alps - eastern Alps boundary in western Austria: a crustal-scale cross section

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A N-S oriented crustal-scale cross-section was constructed east of the Rhine valley in Vorarlberg, western Austria, addressing the central Alps - eastern Alps boundary. The general architecture of the examined area can be described as a typical foreland fold-and-thrust belt, comprising, from bottom to top, the Subalpine Molasse, (Ultra-)Helvetic, Penninic, and Austroalpine nappes. These units overthrusted the autochthonous Molasse along a south-dipping listric basal thrust. The European basement together with its autochthonous Mesozoic/Cenozoic cover is found below this basal thrust.

In the northern part of the section seismic data allow to place the top of the autochthonous Mesozoic at a depth of 3500 m BSL with a moderate dip to the south along the cross section. Several seismic sections show normal faults offsetting the top of the European basement as well as the autochthonous cover and the overlying autochthonous Lower Marine Molasse. In the wider area of Lake Constance and the Rhine Valley (SW Germany, NE Switzerland, SE France) the European Basement is characterised by a mostly ENE – WSW striking Palaeozoic trough system. The observed faults are interpreted as fault structures originally belonging to this Palaeozoic trough system and reactivated during the flexure of the lower plate, due to the N-S convergence of the European and the African plates.

This flexure resulted also in the formation of the North-Alpine foreland basin, filled first with Flysch deposits followed by Molasse sedimentation. Due to the ongoing shortening the Subalpine Molasse was multiply stacked, forming a triangle-zone. The shortening within the Subalpine Molasse in the cross section has been calculated using the Lower Marine Molasse as a reference and amounts to approx. 46 km, (~70%).

During top to the N thrusting of the Austroalpine and Penninic nappes the Mesozoic – Cenozoic sediments of the European continental margin were detached from its basement, stacked and thrusted to the N, until reaching their actual position on top of the Subalpine Molasse. This stack is known as the Helvetic nappe stack. The internal structure of the Helvetic nappe stack differs east and west of the Rhine Valley; e.g. the Swiss Säntis nappe contains only Cretaceous sediments, whereas the Vorarlberg Säntis nappe, holding the same tectonic position in the nappe stack, is build up by Jurassic and Cretaceous strata. Former studies supposed the presence of a major fault structure parallel to the Rhine Valley to decouple the tectonic evolution. Based on our data we alternatively trace these differences back to lateral level changes of the detachment horizons, caused by the reactivation of the lateral ramps and the differences in the original thickness of incompetent lower Jurassic basement strata in pre-existing Jurassic basins.

Plio-Quaternary deformation of the Jura mountain belt: a quantitative geomorphology approach

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The Jura mountain belt is the westernmost and one of the most recent expressions of the Alpine orogeny. The Jura has been well studied from a structural point of view, but still remains the source of scientific debates, especially regarding its current and recent tectonic activity. It is deemed to be always in a shortening state, according to old leveling data and neotectonic observations on paleo-meanders of the Doubs river. However, the few GPS data available on the Jura don't show evidence of shortening, but a small extension parallel to the arc. Moreover, the traditionally accepted assumption of a collisional activity of the Jura raises the question of its geodynamic origin. The Western Alps are themselves in a post-collisional regime and characterized by a noticeable isostatic-related extension, due to the interaction between buoyancy forces and external dynamics.

The quantitative morphotectonic approach coupled with neotectonic study applied to Quaternary deposits and speleothems aims to characterize the current tectonic regime of the Jura. In particular, the analysis of watersheds and associated rivers profiles allow quantifying the degree and the nature of the equilibrium between the tectonic forcing and the fluvial erosional agent. Slope profiles of rivers are controlled by climatic and tectonic forcing through the expression:

$$S = (U / K)^{1/n} A^{m/n}$$

(with U: uplift rate, K: erodibility, function of hydrological and geological settings; A: drained area, m, n: empirical parameters).

We present here a systematic study of these profiles coupled with a morphological study of oxbows, which help to identify and characterize the morphological evolution of rivers in response to vertical movements, hence potential tectonic forcing. Associated to this morphotectonic approach, the tectonic analysis of karst cavities located in the vicinity of the main faults of the belt, allowed to characterize tectonically active zones, both in terms of age and displacement's quantification.

Progress in integrated Late Triassic stratigraphy of the Northern Calcareous Alps

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During the Late Triassic, despite new important originations a general decline in biodiversity was marked by a series of steps between the Carnian and the Rhaetian, with the T-J boundary event as final strike. The Reingraben Event and the Julian-Tuvalian boundary are two first massive turnovers; the Carnian-Norian boundary records a major vertebrate turnover, the early to middle Norian boundary comes up with a turnover in both the reefal and pelagic fauna and the most dramatic loss (70%) in biodiversity among Late Triassic molluscs. Around the Norian-Rhaetian boundary, the pelagic fauna of higher trophic level starts declining, whereas the reefs show a blooming time. A refined stratigraphy and a construction of a well-calibrated carbon isotope reference curve are necessary to decipher between gradual environmental changes and abrupt or even catastrophic events during the Late Triassic.

A first step was the formalization of the Late Triassic stages. The base of the Carnian and Hettangian are now formally defined, the base of Norian is still under discussion and the Rhaetian's base is proposed at Steinbergkogel, Austria. Its newly accepted definition is based on the FO of the conodont species Misikella posthernsteini, close to the FO of the ammonoid Paracochloceras suessi, of a radiolarian turnover and of the extinction of most species of the bivalve Monotis. The oldest stratigraphic record of reliably identified coccolithophores lies just below the FO of M. posthernsteini, whereas the FO of the coccolith Crucirhabdus minutus is recorded slightly above. This first appearance takes place along with a discernible increase in abundance of the nannolith Prinsiosphaera triassica, the most important Rhaetian pelagic carbonate producer. These bio-events represent the initiation of the pelagic carbonate production. It is interesting to notice that they occur together with a major turnover in the pelagic fauna of higher trophic level (ammonoids, conodonts, bivalve Monotis) and the beginning of a flourishing time for the reefs.

Improvement in the Upper Triassic delta13Ccarb curve shows that after a gentle increase until the base of the Carnian, the early Carnian records three negative excursions of 2 to 3‰ amplitude. The two first excursions rebound to previous values, whereas the third negative excursion, at the Julian-Tuvalian boundary, is followed by a positive excursion up to +5‰. The remaining upper Carnian displays stabile values around 2‰. The Carnian-Norian boundary interval is marked by a minor increase of less than 1‰. The early to middle Norian crisis is marked by a turning point from lower Norian slowly increasing carbon isotope values to gradually decreasing ones. In the late Norian the isotopic values are relatively stable around 2.5‰, before increasing again in the early Rhaetian and reaching a maximum around the lower-upper Rhaetian boundary. The isotopic record remains constant until the top of the Rhaetian with its significant negative shift identified in a number of marine sections in close proximity to the extinction event.

From an isotopic point of view, only the two lower Carnian excursions, the early-late Carnian boundary and the Triassic-Jurassic boundary can be interpreted as events, whereas other biotic crises of the Late Triassic seem to have occurred during periods of gradual changes in the carbon isotopic composition of seawater.

Base level changes and landscape response in the Eastern Alps: Tectonics versus Climate

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The landscape of the Eastern Alps is strongly bimodal with two observed landscape types that differ in their morphological appearance. At low elevations, in vicinity to the active valley floors, the landscape is characterized by steep topographic gradients, incised gullies and disequilibrium landforms. In contrast, the second landscape type occurs at high elevations relative to the actual base levels and is characterized by low slopes and gentle channel gradients. The transient state of the landscape between the two described landscape types is characterized by planation surfaces located at distinct levels (relict landscape) dissected by deeply incised gorges (modern landscape).

The bimodality and the transient state of the landscape is commonly interpreted in terms of glacial erosion driven by the climate change during the Pleistocene where large parts of the Eastern Alps (e.g. Salzach catchment) were coined by several glaciation cycles, scouring deep alpine valleys and establishing new erosional base levels. However, it is striking that landscapes in the Eastern Alps with minor glacial impact during the LGM (e.g. Mur catchment), are also in a transient state indicated by similar geomorphic features (non-equilibrium channels, migrating knick points and active hill-slopes) suggesting different tectonic or climatic regimes at different time slices. Recently, these observations were interpreted as reaction of the drainage system on new base levels caused by a large scale pulse of uplift since around 5 my.

To understand the evolution of the landscape during the last 5 my we pose the following questions: a) What is the spatial distribution of old versus young landscapes in the Eastern Alps? b) When did the transition from "old" to "young" landscapes start and what are the process rates? c) What are the driving forces for the formation of the young landscape?

In this study we present first results of a detailed and systematic morphometric analysis of drainage systems covering large parts of the Eastern Alps. We compare catchments covering different lithological units with different glacial impact to understand the modes of alpine landscape evolution due to uplift driven topography and erosion driven relief formation.

The catchment wide analysis of digital elevation models shows several eye-catching anomalies in the hyposmetric curves, in the relationship between surface elevation and topographic gradient, in the stream power pattern of the drainage system and in longitudinal channel profiles. First order anomalies detected by these numerical analyses are consistent with numerous field observations on planation surfaces, incised gullies and knick points and can be identified in catchments with and without glacial impact. Therefore we suggest that recent uplift of the Eastern Alps and subsequent incision is NOT only controlled by glacial scouring but shows also a tectonic signal beyond isotactic rebound due to glacial erosion and unloading.

Late Oligocene to Miocene exhumation and cooling history of the Tauern Window (Eastern Alps) – new age constraints

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The Tauern Window exposes a nappe stack of Subpenninic (European lower plate) and ophiolite-bearing Penninic units. It is surrounded by overthrusted Austroalpine nappes (Adriatic upper plate). After nappe stacking and metamorphic overprinting the units within the Tauern Window were refolded and exhumed in Miocene time in response to Adriatic indentation. The western and eastern margins of the window are characterized by two ductile extensional fault zones, the Brenner- and Katschberg shear zone systems (BSZS, KSZS), respectively. Amount of exhumation is greatest in the footwalls of these Neogene shear zone systems.

Rapid exhumation (≥ 1mm/a) in the footwall of the BSZS lasted from 20-15 Ma and was triggered by sinistral transpression along the Guidicarie Belt beginning at 23-21 Ma. Rapid cooling (≥ 25° C/Ma) from 550-270° C lasted from 18-12 Ma (VON BLANCKENBURG et al., 1989; FÜGENSCHUH et al., 1997). In contrast, the exhumation and cooling history of units in the footwall of the KSZS was still poorly constrained. New 40Ar/39Ar laser ablation ages on white micas from the KSZS indicate that mylonitic shearing started at an unknown time before 20 Ma and ended before 17 Ma, as supported by the following arguments: (1) post-kinematic white mica located at the base of the KSZS overgrow the main Katschberg foliation and yields similar ages as found in white mica oriented parallel to the foliation (20.05 ± 0.19 Ma and 19.5 ± 0.17 Ma, respectively) and hence, is interpreted as a cooling age; (2) a sample from the top of the KSZS yields almost identical ages for re-folded and foliation-parallel white mica (17.34 ± 0.16 Ma and 16.48 ± 0.25 Ma, respectively) and are interpreted to date cooling below 400° C. Hence, mylonitic shearing that exhumed the footwall of the KSZS must have ended before 17 Ma. Rb/Sr cooling ages of white mica indicate that cooling from c. 550° C began at c. 22.5 Ma or earlier (Favaro & Schuster et al., in prep.). The end of rapid cooling is poorly constrained owing to the large range of the zircon fission track ages (16-11 Ma; DUNKL et al., 2003; BERTRAND et al. in prep.), which most likely reflects the long time spent within the partial annealing zone of zircon (BERTRAND et al., in prep.).

The age data suggest that Adriatic indentation (23-21 Ma, according to stratigraphical constraints) rather than extension in the Pannonian Basin (starting after 20 Ma) triggered the onset of rapid exhumation in the Tauern Window. The data also suggest that there was a delay in time between the onset of rapid exhumation and rapid cooling in the west, in contrast to the east. The later onset of rapid cooling in the west (BSZS) is probably due to the greater contribution of upright folding and hence, erosional exhumation to total exhumation. In the east the contribution of normal faulting predominates, allowing for a shorter delay time between the onset of rapid exhumation and cooling.

However, an onset of rapid exhumation before 23-21 Ma cannot be excluded in the case of the eastern Tauern Window. An onset of exhumation before Adria indentation would necessitate an alternative trigger for exhumation, e.g., the counterclockwise rotation of the northwards subducting Adriatic slab beneath the Eastern Alps, as inferred from the obliquity of the trace of the slab tip at 150 km depth to the Tauern Window (LIPPITSCH et al., 2003).

DUNKL, I., FRISCH, W. & GRUNDMANN, G. (2003): Zircon fission track thermochronology of the southeastern part of the Tauern Window and adjacent Austroalpine margin, Eastern Alps. - Eclogae Geol. Helv., 96:209–217.
FÜGENSCHUH, B., SEWARD, D. & MANCKTELOW, N.S. (1997): Exhumation in a convergent orogen: the western Tauern Window. - Terra Nova, 9:213–217.
LIPPITSCH, R., KISSLING, E. & ANSORGE, J. (2003): Upper mantle structure beneath the Alpine orogen from high-resolution teleseismic tomography. - J Geoph R 108(B8):2376. doi:10.1029/2002JB 002016
VON BLANKENBURG, F., VILLA, I.M., BAUR, H., MORTEANI, G. & STEIGER, R.H. (1989): Time calibration of PT-path from the Western Tauern Window, Eastern Alps: the problem of closure temperatures. – Contrib. Mineral. Petrol., 101: 1–11.

Crystalline nappes in the Cental Alps: case study Suretta nappe and Bernhard nappe complex

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The Suretta nappe in the Grisons (eastern Switzerland) and the Bernard nappe complex in the Valais (western Switzerland) are both part of a major basement-bearing nappe stack attributed to the Middle Penninic nappe system of the Swiss Alps which is derived from the Briançon swell. They formed in the course of Alpine southward subduction of the Briançon swell beneath the Piemont-Ligurian ocean and the Adriatic continental margin and subsequent collision with the European continental margin. Their present-day shape intrigued Emile Argand who reconized much of their structure and kinematics.

The *Suretta nappe* is exposed on the eastern flank of the Lepontine dome in eastern Switzerland. The general axial plunge of about 30° towards the ENE of all units in this area together with the Alpine topography provides an oblique section through the entire Suretta nappe. The Suretta nappe was detached by a basal thrust within the crystalline basement. Its internal structure is governed by a major thrust fault and several folds in the upper part of the nappe. A Permian shallow intrusion (Rofna Porphyry complex) occupies the frontal part of the nappe.

The *Bernard nappe complex* is exposed on the western flank of the Lepontine dome in western Switzerland. It consists of an imbricate stack of basement slices and Permian-Triassic clastics. A large-scale fold is associated with an inverted Permian basin.

The structure of both nappes is controlled by pre-existing structures, leading to regional complexities and differences between and within the study areas, which are difficult to predict in any general model. In the case of the Suretta nappe, Jurassic normal faults probably served as a trigger for the localization of early folds and thrusts, and the occurrence and shape of the Rofna Porphyry complex influenced the level of basal detachment of the Suretta nappe. In the case of the Bernard nappe complex, a Permian graben structure largely controlled the deformation style, i.e. fold versus thrust relationships.

The structural architecture of both the Suretta nappe and the Bernard nappe complex can be interpreted as being basically the result of three main deformation phases:

(1) The Avers phase and the Evolène phase respectively are responsible for the northward detachment of Briançon cover units (e.g. Schams nappes, Klippen nappe) and for the contemporaneous emplacement of Piemont-Liguria rocks (e.g. Avers nappe, Tsaté nappe) onto Briançon basement and its adhered cover. This is a typical example for cover substitution. Relics of brittle deformation features at thrust contacts point to an early brittle thrusting stage, marking the onset of a continuous thrusting history during the Paleocene and Eocene.

(2) The Ferrera phase of the Penninic system of the eastern Swiss Alps equals the Anniviers phase of the Penninic system of the western Swiss Alps. These phases represent the main stage of ductile deformation during nappe formation. Mainly nappe imbrication, associated with isoclinal folding affected the Briançon continental crust. The transport direction is inferred to be NNW and deformation probably took place during the Eocene.
(3) Eocene-Oligocene backfolding and backshearing severely modified the geometry of the Middle Penninic nappes: the Niemet-Beverin phase (in the Grisons) and the Mischabel phase (in the Valais). While thrusting continued at the base of the nappes, large-scale folding affected parts of the nappes. The upper levels of the nappes were strongly affected by top-to-the-S(E) shearing in this process, resulting in the formation of mélange zones. Fold axes associated with this phase constantly trend ENE-WSW in both study areas.

The Tauern Window (Eastern Alps. Austria): a new tectonic map, with cross-sections and a tectonometamorphic synthesis

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We present a tectonic map of the Tauern Window and surrounding units (Eastern Alps, Austria), combined with a series of crustal-scale cross-sections parallel and perpendicular to the Alpine orogen (Swiss Journal of Geosciences in press). 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 crustal-scale 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 time (around 90 Ma) and culminating in Lutetian to Bartonian time (45-37 Ma).

The Tauern Window exposes a Cenozoic nappe pile consisting of crustal slices derived from the distal continental margin of Europe (Subpenninic Units) and the Valais Ocean (Glockner Nappe System). These were accreted to an upper plate already formed during the Cretaceous and consisting of the Austroalpine Nappe pile and previously accreted ophiolites derived from the Piemont-Liguria Ocean. The present-day structure of the Tauern Window is characterized primarily by a crustal scale Late Alpine duplex, the Venediger Duplex, which formed during the Oligocene. This duplex was severely overprinted by doming and lateral extrusion, most probably triggered by the indentation of the Southalpine Units east of the Giudicarie Belt, which offset the Periadriatic Line by some 80 km, beginning at around 20 Ma ago and linked to a lithosphere-scale reorganization of the geometry of the mantle slabs.

While this work hopefully contributes to a better understanding of the three-dimensional structure of the Tauern Window, two important problems remain. Firstly, what was the relative contribution of orogen-parallel extension by normal faulting, escape-type strike-slip faulting and orogen-normal compression, all of which acted contemporaneously during the Miocene? The answer to this question has a strong bearing on the relative importance of tectonic vs. erosional denudation. Secondly, there remains the unsolved problem of the quantification of kinematic and dynamic interactions between crustal (Adria-indentation, Carpathian roll-back and Pannonian extension) and mantle structures (reorganization of the mantle slabs underneath the Eastern Alps) that fundamentally and abruptly changed the lithosphere-scale geometry of the Alps-Carpathians-Dinarides system during a very severe Miocene overprint, initiating at around 20 Ma ago.

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The structure of the Hallstatt evaporite body (Northern Calcareous Alps, Austria): a compressive diapir superposed by strike-slip shear?

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Based on previous detailed mining- and surface geological maps and on own structural observations in the Hallstatt salt mine, we reinterpret the structure of the Hallstatt evaporite body of the uppermost Permian Haselgebirge Fm. within the Northern Calcareous Alps (NCA). The Haselgebirge Fm. is now a rock salt mylonite, which contains, at all scales, abundant lenses of protocataclasite composed of sulphates, mudstones, clay and host limestones. In comparison with results of analogue modeling we interpret the present shape of the Hallstatt body as a WNW-ESE elongated compressive diapir. This diapir is overprinted by N-S shortening and dominantly sinistral shearing along a W-trending shear zone, resulting in elongation and thinning of the evaporite body along the shear zone. The internal structure shows steeply dipping rock units and a steep foliation and the structures are formed by either pure shear flattening or simple shear under mainly subhorizontal maximum principal stresses. Earlier ductile fabrics of likely Early Cretaceous age are preserved in sulphate rocks like anhydrite and polyhalite and are subsequently overprinted by mylonitic fabrics in rock salt and cataclastic fabrics in other rocks. These processes caused cataclastic disintegration of mechanically strong lithologies and the foliation of rock salt wraps around these lenses mainly as a result of shearing.

Because of the low strength of halite, the Hallstatt evaporite body is now subject of recent subvertical shortening and the strain rate of this process could be quantified by deformed subhorizontal boreholes. We quantified the strain rate at 8 x 10-10 [s-1]. This value is similar to such strain rates (10-10 to 10-9 s-1) estimated by the grain size of halite from other salt mines in the NCA (Leitner et al., 2011). The coincidence of both values argues, therefore, for a sub-recent formation of the halite microfabrics.

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Leitner, C., Neubauer, F., Urai, J.L. & Schoenherr, J. (2011): Structure and evolution of a Rocksalt–Mudrock–Tectonite: the Haselgebirge in the Northern Calcareous Alps. - Journal of Structural Geology 33, 970–984.

Chemostratigraphic constraints of marbles from the medium-grade, partly polymetamorphic Austroalpine Basement (Eastern Alps)

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Calcitic marbles of different tectonic units from the Austroalpine Crystalline Basement (Eastern Alps) were studied regarding their geochemical and isotope characteristics. The investigated units, the Greim, Wölz, Rappold, Koralpe-Saualpe, Pohorje, Millstatt, Plankogel and Radenthein Complexes are part of the polymetamorphic Koralpe-Wölz nappe pile, composed of garnet-bearing micaschists and paragneisses, quartzites, amphibolites, eclogite relics and different types of metacarbonate rocks.

For stratigraphic purposes samples were selected by geochemical screening using Mn/Sr- and Rb/Sr-ratios as well as Sr-, C, and O-isotope signals to control their primary compositions. Limiting factors for Mn/Sr are proposed by ≤2 and for Rb/Sr by ≤0.02. Limits for primary isotope ratios are given by the spread of well-established secular Phanerozoic seawater curves. Marbles reflecting primary signals do not exceed 0.70925 for 87Sr/86Sr and O- and C-values scatter between -8 to 0 and -1 to 6‰ respectively (V-PDB).

Although high-P/T metamorphic conditions within the nappe pile may facilitate a high level of post-depositional changes of the signals, a sufficient quantity of samples falls within the primary fields. Mn/Sr-ratios vary between 0.036 and 2.814 and Rb/Sr-ratios between 0 and 0.132. Delta18O- and delta13C-values range from -12.95 to 0.10‰ and -1.58 to 4.78‰ respectively.

The evaluation of the geochemical and isotope signals allows distinguishing two distinct groups of marbles within the Koralpe-Wölz nappe pile. The Rappold, Plankogel and Koralpe-Saualpe Complexes are summarized within group I which is characterized by relatively low and less variable Sr-values (between 0.707997 and 0.708465). In contrast O- and C-data are strongly scattering with ratios between -11.08 and 0.10‰ and -1.58 and 4.78‰ respectively. Just a few samples of this group show altered values not in equilibrium with the primary seawater. Group II, including the Wölz, Greim, Millstatt and Radenthein Complexes, shows variable and relatively high Sr-ratios from 0.708556 and 0.711090, most of them exceeding the possible values provided by the seawater curve. The oxygen-isotope signature fluctuates within -12.95 and -4.01‰ and carbon-ratios scatter from -0.9 and 2.02‰.

For each group a complex showing the best fitting dataset was used for chemostratigraphy by comparing the obtained isotope ratios with the seawater curves. For group I, represented by the Rappold Complex, a deposition age in the late Early to Middle Devonian is likely. Marble-chemistries from the Millstatt Complex as a representative of group II point to sedimentation ages from the late Silurian to the earliest Devonian.

The obtained deposition ages as well as lithologic successions allow comparing both groups with un- or weakly metamorphosed Paleozoic counterparts from the Austroalpine and Southalpine. The lack of an Ordovician magmatic event and a minor influence of the Variscan tectonometamorphic evolution are characteristic for the complexes of group I, lying in the south-eastern parts of the Koralpe-Wölz nappe pile. These facts as well as isotope signatures and ages are similar to the Paleozoic of Graz. Group II, mainly within northern and western areas, however shows similarities with the other Austro- and Southalpine Paleozoic units including the Greywacke Zone, Gurktal nappes, Carnic Alps and the Karawanken.

Lithostratigraphy and internal structure of the Austroalpine units in the Niedere Tauern and northern Gurktal Alps (Eastern Alps, Austria)

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South of Schladming, between the Enns and Liesing valley in in the North and the Mur valley in the South the Niedere Tauern form an about 100 km long West-East orientated mountain chain with a rough morphology. Its peaks reach up to 2800 m in the West and drop down to about 2400 in the East. South of the Mur valley the Gurktal Alps are characterized by a smoother landscape and a lower altitude. The whole area is built up by nappes of the Austroalpine unit. Crystalline basement rocks are dominating, whereas metamorphosed Permomesozoic sedimentary sequences occur in some places. As indicated by fission track ages the break in morphology is due to Neogene south dipping normal faults including the Prebersee and Seetal fault (EDER & NEUBAUER, 2000). However, the position of the normal fault system and the internal structure and lithostratigraphy of the Austroalpine nappes was only locally known until now.

The tectonic lowermost Upper Austroalpine nappes in the area belong to the Silvretta Seckau nappe system. These nappes consist of Neoproterozoic to Ordovizian paragneisses (partly magmatic), micaschists and amphibolites. Orthogneisses of presumably Ordovizian and/or Carboniferous intrusion age occur and partly a post-Variscan cover including Permian metaconglomerates and metapelits and Lower Triassic quartzites is preserved. The medium to high grade imprint in the basement rocks occurred during the Variscan tectonometamorphic event, whereas only greenschist facies metamorphic conditions were reached during the Alpine event in the Cretaceous. Nappes of the Silvretta-Seckau nappe system built up antiformal structures in the West (Schladminger Tauern) and East (Seckauer Tauern) of the Niedere Tauern.

On top of the Silvretta Seckau nappe system several nappes of the Koralpe-Wölz nappe system occur. They consist of Neoproterozoic to Devonian sequences dominated by micaschists and paragneisses with intercalations of marbles, quartzites and amphibolites. From bottom to top the Ennstal phyllite, Wölz (including Gensgitsch Complex), Greim, Rappold and Radenthein Complex can be distinguished. A Permian upper greenschist facies imprint is proofed for the southern parts of the Wölz Complex, whereas amphibolite facies and the intrusion of pegmatites can be recognised in the Greim and Rappold Complexes. The Alpine metamorphic grade increases from lower greenschist facies at the base to amphibolite facies in the Rappold Complex, whereas the overlying Radenthein Complex shows again a greenschist facies imprint.

Good outcrops of the south dipping Neogene normal faults are scarce, but they can be localised by mapping the boundaries of the crystalline complexes. Between the southern slopes of the Niedere Tauern and the Mur valley they dissect the Cretaceous nappe pile and create a complex pattern in map view. One major fault continues from the “Lessach phyllonit lamella” along the northern boundary of the Rappold Complex until Schöder. Further to the East some of the faults are turning to Southeast and most probably continue into the Görschitztal fault at the western margin of the Seetaler Alpen and Saualpe.

Rb-Sr biotite ages covering large parts of the area range from 60 to 87 Ma. They are interpreted to reflect cooling of the rocks below 300 °C. Their distribution is complex and can’t be explained by the Neogene fragmentation alone.

EDER, N. & NEUBAUER, F. (2000): On the edge of the extruding wedge: Neogene kinematics and geomorphology along the southern Niedere Tauern, Eastern Alps. - Eclogae geol. Helv., 93: 81-92.

Listvenite from Serbia as Gemstone Resource

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Listvenite occurrences in Serbia are mostly related to Jurassic ophiolites of Vardar zone, but also to the Palaeozoic ophiolites in Eastern Serbia, as hostrocks which were altered by hydrothermal fluids genetically related to Late Oligocene-Early Miocene volcanic activity. In the last decades listvenite exploration was mainly focused on potential ore mineralisation, while minor attention was related to study the gemstone within listvenite. Therefore, this paper focuses on the study of mineralogical and petrologic characteristics of listvenite in terms of utilisation as a gemstone and, in addition, to estimate preliminary the overall potential of listvenite as a resource of gemstone and decorative stone.

Samples of listvenite were obtained from trenches and outcrops. Optical and scanning electron microscopy methods were used to study gemstone minerals, which were also subjected to trial lapidary processing.

In the Fruska gora listvenitized serpentinites the Kozje Brdo deposit and numerous smaller deposits and minor occurrences of silica gemstones were explored. Relatively small masses of Late Oligocene – Early Miocene volcanic rocks had enough heat source which enabled formation and circulation of hydrothermal fluids which altered serpentinite along the tectonised zones and led to formation of listvenite. The gem raw materials of the Fruska Gora mountain are represented by chalcedony and carbonate-silica breccia with agate. Magnesite is the oldest mineralisation phase of hydrothermal activity, highly tectonically shattered, and subsequently pervaded and cemented by dolomite, ankerite and calcite with admixed silica.

The Vuckovica deposit of carbonate-silica breccia and greyish-blue agate is located around 15 km southwest of Kragujevac in a small listvenite/serpentinite mass in tectonic contact with Cretaceous sediments. Numerous magnesite-dolomite-silica veins 0.1 - 3 m thick occur in this serpentinite, among which the most decorative is serpentinite breccia cemented by carbonate and silica minerals. In the veins magnesite is tectonically broken and subsequently cemented by dolomite and silica (opal-chalcedony) of green, greenish-dark or yellow colour.

The Sirca occurrence is located around 5 km ENE of the Kraljevo town. Gemstones occur within small lens of hydrothermally altered serpentinite, which is in tectonic contact with surrounding Early Cretaceous sandstone and marlstone. During Late Oligocene – Early Miocene volcanic activity, listvenite was formed and later on partly covered by labradorite andesite and pyroclastics of the third volcanic phase. Post volcanic hydrothermal fluids reacted with serpentine minerals forming carbonate-silica onyx, colourless chalcedony, opal, silicified magnesite and quartz crystals.

Palaeozoic listvenite in Eastern Serbia is hosted in structures within an obducted ophiolite sequence of mainly gabbroic rocks with associated serpentinite. Listvenite as gemstone resource was studied at the Antina cuka deposit, around 15 km SSW of the Kucevo town. The Antina cuka listvenite appears as small lenses formed at the contact of andesite and serpentinite. According to mineralogy and petrography, they are subdivided into serpentine-rich, silica-rich and silica-carbonate-rich varieties, all of which can be used as an attractive gemstone.

The potential of listvenite deposits and occurrences in Serbia as a resource of dimension stone is restricted due to the small volume of deposits. On the other hand, favourable aesthetic and polishing properties of the listvenite make them a very potential resource of gemstone and decorative stone.

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Towards a quantitative evaluation of the degree of coincidence between the orientation of a magnetic fabric of deformational origin and the stress tensor calculated from microtectonic measurements

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In the geophysical and geological literature both the magnetic susceptibility tensor (k) used for the evaluation of magnetic susceptibility anisotropy (AMS) measurements and the stress tensor (T) of fault tectonics determined by inversion methods are associated with the deformation of the material in some extent. Although the relation of these tensors to the strain tensor is widely debated, results of AMS and tectonic measurements on identical or close localities from the Transdanubian Range demonstrated fairly good agreement between the directions of the extension calculated from the results of the two independent approaches. Beyond the graphical similarity of the stereograms (especially the directions of the principal axes associated with the ellipsoids of the tensors) we aim to establish a statistical framework to provide a quantitative comparison.

The main difficulty in the quantitative comparison is that the number of computed parameters is typically different for the two tensors: while it is 6 for the AMS tensor, it is less or equal to 6 for the stress tensor (the exact value depends on the specific inversion method used to determine the stress). This fact permits to apply such transformations, when one, ore more (maybe all the three) tensor invariants of T and k coincide. By this transformation in hand we accommodate Hotelling's T-squared distribution to establish a multivariate test to investigate our null hypothesis stating T=k. As long as the computed significance level exceeds the conventional 5%, the null hypothesis is accepted. This approach can be extended to provide a quantitative comparison between a vector and one of the principal directions of a tensor. For example, in case of extensional deformation, which is the dominant mode of tectonic deformation during Cenozoic in the Transdanubian Range, it is possible to investigate the degree of coincidence between the principal axis of the minimal compressive stress (i.e. the direction of the tension) and the direction of the magnetic lineation (i.e. the principal axis with the largest eigenvalue of k). Several examples for such applications will be presented for Eocene and Oligocene clay rich localities with well-developed magnetic fabric from the Transdanubian Range.

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New constraints on kinematics and timing of the Periadriatic Fault System from the petrology and Lu-Hf apatite geochronology of Giudicarian magmatic lamellae and the Presanella intrusion (Southern Alps, Italy)

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The Periadriatic Fault System (PFS) extends from west to east over 700 km through the Alps. Along this prominent Tertiary corridor of strike-slip faulting all the major Alpine intrusions are emplaced. The Adamello batholith is the largest of these intrusions consisting of five major intrusive units with a progressive younging towards the NE from mid-Eocene to mid-Oligocene times. The Presanella tonalite is the youngest of these intrusive units. It is located where the W-E to WSW-ENE trending dextral transpressive Tonale fault segment of the PFS is truncated by the SSW-NNE trending Giudicarie fault. Along the northern Giudicarie fault (NGF) a sequence of magmatic lamellae is aligned. To constrain the intrusive relationships and the age of these magmatic lamellae with respect to the Adamello batholith, we analyzed major and trace element compositions of the igneous units and dated representative samples by Lu-Hf apatite geochronology. Five samples were taken from the NW Presanella, the NE Presanella, and the southern Rumo, northern Rumo and Meran lamellae. Petrologically, the Presanella samples represent tonalites, while the Rumo and Meran lamellae have quartz-dioritic compositions, but differences in modal composition are small. All five samples define a metaluminous, sub-alkaline trend. The most significant feature is the decreasing SiO_2-content from SW to NE with the exception of the northernmost sample from the Meran lamella displaying a slightly higher SiO_2-content than the northern Rumo lamella sample. Trace element characteristics indicate a syn- to post-collisional setting. Epsilon Hafnium-values of all bulk rock samples are negative and very similar ranging from -3.5 to -4.2, except for the sample from the NW Presanella with a slightly lower radiogenic composition (ε_{Hf} = -5.1). As expected, apatite separates from the NE Presanella and the Meran lamella exhibit high Lu/Hf-ratios and radiogenic Hf isotope compositions. Calculated whole rock-apatite Lu/Hf-ages of the two samples range from 30-32 Ma, with errors of less than 1 Ma, and overlap within error. Since the closing temperature of apatite is very high (>650°C; BARFOD et al., 2005), these ages can be assumed to represent intrusion ages. The small variations in petrology and geochemistry of the Presanella intrusion and the magmatic lamellae as well as the corresponding apatite Lu-Hf ages suggest that both originate from the same magma source. Variations within the Adamello batholith and even within the Presanella intrusion are larger than the variations between NE Presanella and the three investigated magmatic lamellae samples from the NGF. This observation together with the field record of a tectonic rather than an intrusive emplacement with intense brittle deformation (POMELLA et al., 2011) imply that the magmatic lamellae have been tectonically dissected from the NE Presanella intrusion and transported up to 50 km northwards by sinistral transpressive displacement along the NGF.

BARFOD, G.H., KROGSTAD, E.J., FREI, R. & ALBARÈDE, F. (2005): Lu-Hf and PbSL geochronology of apatites from Proterozoic terranes: A first look at Lu-Hf isotopic closure in metamorphic apatite. - Geochim. Cosmochim. Acta, 69: 1847-1859.

POMELLA, H., KLÖTZLI, U., SCHOLGER, R., STIPP, M. & FÜGENSCHUH, B. (2011): The Northern Giudicarie and the Meran–Mauls fault (Alps, Northern Italy) in the light of new paleomagnetic and geochronological data from boudinaged Eo-/Oligocene tonalites. - Intern. J. Earth Sci., 100: 1827–1850.

What Happened 5 Million Years Ago in the Alps?

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There is rising evidence that some 5 million years ago a surface uplift event started in the Alps that caused a renewed and ongoing phase of tectonic activity. This uplift event appears to encompass not only the Alps, but also the surrounding regions including the foreland basins (in particular the northern Molasse basin), the Styrian and Vienna basins in the east and parts of the Bohemian Massif. The event is particularly visible in the eastern half of the orogen where topography is lower, convergence is more active and pervasive Miocene strike slip tectonics provides a backdrop against which the Post-Miocene events may be evaluated more clearly than in the west. The evidence includes (i) young karst-cave formation ages at elevations high above current ground water tables, (ii) the indirect evidence of ancient fissions track ages at surface elevations above 2000 m, (iii) bimodal landscapes with substantial planation surfaces about 500 meters above current valley floors (iv) coalification and compaction studies in the sedimentary basins surrounding the eastern Alps, (v) current geodetic surface uplift rates, as well as: (vi) numerical modeling evidence that appears to indicate that the Alps are geomorphologically premature. Overall, it appears that some 1000 m of surface uplift occurred within the last 5 million years. Along the eastern margin of the Alps, the event has been described as an inversion event in the sedimentary basin and has been brought in connection with the cessation of a subduction zone underneath the Carpathian arc. However, the event appears to be associated with little horizontal tectonics and it is regionally widespread, so that we suspect that more deep-seated drivers are responsible. The implications of the event for the discussion around tectonic versus climatic drivers as causes or consequences of young erosion and tectonics in the Alps are profound: Modern consensus holds that the global deterioration of climate some two million years ago is the principal driver for the youngest phase of uplift and erosion in the Alps. We argue here that the glaciation of the Alps was only possible because the 5 million year tectonic event uplifted the range enough so that an icecap could form. As such, we diplace the "chicken or egg debate" (currently in the vogue of climatic drivers) one step back: We argue for a deep seated uplift event as the cause for glaciation in the Alps.

Statistical analysis of a huge fault database around the bend of the Western/Eastern Alps

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The internal arc of the Western and Central Alps underwent an important brittle deformation stage, expressed on the field by meso-scale to kilometric scale brittle structures. Regional paleostress studies achieved all around the arc highlights two distinct extensional phases.

The first is an orogen-parallel extension phase, dated of about 10 Ma using pseudotachylites in the Lepontine Dome (ALLANIC & GUMIAUX, 2013). The strike of the extensional axes turns with the alpine arc, from the Lepontine Dome to the back of the Argentera massif. This major signal increases to the NE of the belt, and could be compatible with the roughly E-W extension observed in the Eastern Alps, particularly within the Tauern

Window, where the maximum age of the brittle deformation at 20 +/-1 Ma is given by the ZFT ages, whose closure temperature is ~240°C±10°C (BERTRAND et al., in prep.).

The second brittle deformation phase corresponds to an orogen-perpendicular extension. This last one becomes more important toward the South of the belt, especially in the Briançonnais zone, from the Vanoise massif to the North of the Argentera massif. This phase appears to be linked to the current activity of the belt, as shown by seismotectonics, especially in the Briançon area (review in SUE et al., 2007).

This paper focus on a new global statistical approach of the sub-databases available, that we compile in a huge database of more than 12.000 individual measurements all-around the bend of the Western/Eastern Alps. Beyond the paleostress mapping, we propose to statistically characterize both extensional phases. Assuming that the second one (perpendicular) is linked to the current activity of the belt, itself ruled out by isostatic processes, we concentrate on the first orogen-parallel extension, which origin remains a matter of debate. "Unfolding" the alpine arc, using a simple geometrical modeling of the belt, allowed unraveling the surprising stability of the orogen-parallel extension in the Whole Western, Central, and Eastern Alps. This approach rises up the issues of (i) the geodynamic origin of this extension developed during Miocene times within an active collisional belt; (ii) the precise timing of its development; and (iii) its continuity between Western and Eastern Alps in terms of both kinematics and time.

ALLANIC, C. & GUMIAUX, CH. (2013): Are there any active faults within the Lepontine Dome (Central Alps)? – Bull. Soc. Geol.. Fr., 184, in press.

SUE, C., DELACOU, B., CHAMPAGNAC, J.-D., ALLANIC, C., TRICART, P., BURKHARD, M. (2007): Extensional neotectonics around the bend of the Western/Central Alps: an overview. - Annu. Rev. Earth Planet. Sci., 96: 1001–1029.

The abandoned Remshnig mine, occurrence of rare minerals; Palaeozoic or Tertiary ore mineralization?

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Parallel with the Pohorje mountainous chain and north of the Drava River, a hilly area of Kobansko extends in northern Slovenia. In the central part of the region, polymetallic Remshnig mine is situated in the thrust zone of weakly metamorphosed old Palaeozoic rocks of the Magdalensberg formation, the Remshnig nappe in the hanging wall, and the retrogressed schists of the Pohorje formation in the footwall. Though the Remshnig ore deposit is known more than 250 years, its origin and mineral association is still not known completely. Some new findings are presented in this contribution. The results are based on field observations and SEM investigations.

Macro- and microstructures of the rocks reveal several phases of tectonic activity, including twice reactivated subhorizontal shear movements, due to which dynamometamorphic imprint can be followed in all rocks. The first one reflects as ductile deformations, yielding mylonitization and foliation. The second shear produced slaty cleavage, which broadly follows foliation. The origin of these two structures is associated with upper Cretaceous nappe stacking and Tertiary Austroalpine eastward escape (e.g. FODOR et al., 1998, 2002, 2008). Own unpublished model of the Pohorje tectonic block origin suggests that Pohorje and Kobansko/Kozjak were still one common block at the time of the Pohorje granodiorite magma emplacement in Lower Miocene and were separated later.

Hydrothermal ore mineralization and silicification follow slaty cleavage in partly brecciated marmorized dolomite lenses and subordinately in metatuffites and phyllites. Younger oblique fractures cut foliation and slaty cleavage, developed as a consequence of renewed shearing. Secondary cleavage plains were formed indicating dextral sense of shear. All structures are cut by younger subvertical faults of prevailingly southwest-northeast trend, and subordinately transversely to this direction. These fractures are not silicified and contain no primary (sulphide) ore mineralization.

The present state of investigations does not allow strict definition of the Remshnig ore deposit genesis. Nevertheless, some important relations can be drown, which neglect its Palaeozoic origin: ore mineralization occurs within the thrust zone; sulphide mineralization and strong silicification followed cleavage, which is of Tertiary (probably of Miocene) origin; the Kobansko block separated from the Pohorje block in middle to upper Miocene and Kobansko was until then, within the impact area of the granodiorite intrusion; mineral composition and sulphur isotope composition of the Remshnig and Okoska gora (Pohorje) ore deposits are closely related (DROVENIK et al., 1976, 1980). Consequently, there is a great probability that the Remšnik ore mineralization is connected to the Miocene Pohorje magmatism, as has already been proposed by some authors. The question is, whether the mineralization could be related to remobilization of pre-existing ore minerals.

Characteristic Remshnig mine ore veins are composed mostly of quartz and carbonates, of which the most frequent is dolomite. Paragenesis of predominant Pb, Cu and Zn silver-bearing sulphide ore minerals is represented mostly by chalcopyrite, galenite, sphalerite and pyrite. They are associated with numerous secondary minerals. Among them, coatings of two rare hydrous sulphates of Cu and Zn occur, found for the first time in Slovenia. The emerald green, tabular monoclinic crystals of slightly rounded shape and only some tenth of millimetre in size were determined as ramsbeckite. Platy, hexagonal crystals most probably belong to namuwite. Its submicroscopic structure and small quantity have not permitted reliable determination, yet.

DROVENIK, M., DUHOVNIK, J. & PEZDIČ, J. (1976): Izotopska sestava žvepla v sulfidih rudnih nahajališč v Sloveniji. - Rud.-Metal, zb., ê-3, Ljubljana.

DROVENIK, M., PLENIČAR, M. & DROVENIK, F. (1980): Nastanek rudišč v SR Sloveniji. –Geologija, 33, 1-157, Ljubljana.

FODOR, L., JELEN, B., MÁRTON, E., SKABERNE, D., ČAR, J. & VRABEC, M. (1998). Miocene-Pliocene tectonic evolution of the Slovenian Periadriatic Line and surrounding area - implication for Alpine-Carpathian extrusion models. - Tectonics, 17: 690–709.

FODOR, L. JELEN, B., MÁRTON, E. ZUPANČIČ, N., TRAJANOVA, M., RIFELJ, H., PÉCSKAY, Z., BALOGH, K., KOROKNAI, B., DUNKL, I., HORVÁTH, P., HORVAT, A., VRABEC, M., KRALJIĆ, M. & KEVRIĆ, R. (2002): Connection of Neogene basin formation, magmatism and cooling of metamorphic rocks in NE Slovenia. — Geologica Carpathica, 53, spec. issue: 199–201.

FODOR, L. I., GERDES, A., DUNKL, I., KOROKNAI, B., PÉCSKAY, Z., TRAJANOVA, M., HORVÁTH, P., VRABEC, M., JELEN, B., BALOGH, K., FRISCH, W. (2008): Miocene emplacement and rapid cooling of the Pohorje pluton at the Alpine-Pannonian-Dinaric junction: a geochronological and structural study. - Swiss Journal of Earth Sciences, 101 Supplement 1: 255–271. DOI 10.1007/s00015-008-1286-9

The tectonometamorphic evolution of the Austroalpine Complexes in the Vinschgau (Ötztal Complex, Campo-Ortler Complex, Texel Complex) in the course of the mapping project CARG 012 (sheet Schlanders)

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The Austroalpine nappe stack in the investigated area, located in the Vinschgau area (Southern Tyrol), comprises from bottom to top the Campo-Ortler (COC), the Texel (TC), the Ötztal (ÖC) complexes and the Matsch (M) nappe. All these units have been known for a long time and were essentially defined based on the degree and age of their metamorphic overprint. Their delimiting faults are only partly well known (e.g. Vischgau shear zone (VSZ), Schneeberg Fault Zone (SFZ) while in other areas they are hard to pin down. This is partly due to the lack of obvious fault rocks such as mylonites or cataclasites as well as to missing petrological/geochronological data (e.g. the contact between TC and ÖC).

The currently mapped sheet Schlanders (CARG 012) offers the chance to carefully investigate the above mentioned units and their tectonic contacts and to implement them into a tectonic model based on new petrological, geochronological and structural data.

Based on our current observations the tectonic contact beween the ÖC and the overlying M nappe is characterized by a two-stage evolution. A subhorizontal mylonite layer can locally be mapped, revealing a top-to-the-west sense of shear. Unfortunately these mylonites can not be continuously traced and therefore the exact position of the contact between ÖC and M still stays enigmatic. Especially in places where the inferred Permian dykes are missing within the M nappe the paragneiss and micaschist lithologies can hardly be attributed to either of the two nappes. The younger overprinting contact is fully brittle and marks the southern contact of the ÖC and M nappes near the Vinschgau valley. There several meters thick cataclasites and gouge layers offset and obliterate the original mylonitic contact. The nature of this E-W trending contact is not yet fully understood since arguments in favour of a south-directed thrust as well as a top-north normal fault could be found. Most likely the mylonitic contact has be folded prior to brittel faulting.

The VSZ, marked by mylonites and ultramylonites in the northern flank of the Vinschgau valley can be traced along a steeply west-dipping synform/antiform pair towards north(east) and finally into the SFZ. The exact location of the triple point between ÖC, TC and Schneeberg complex has still to be mapped. Yet another and more southerly located segment of the VSZ remains to be looked for at the contact between the Texel complex and the Meran Mauls basement.

In conclusion the Schlanders map sheet is a key area for deciphering the pre-Eoalpine (ÖC-M contact) as well as the Tertiary (post-nappe folding/faulting) evolution of the Eastern Alps.

How good do simple experiments using natural rocks reproduce natural observations and theoretical calculations: selected examples ranging from high-P to high-T settings

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The metamorphic evolution of a rock can be deciphered using three approaches: 1.) the practical geothermobarometric approach, 2.) the theoretical pseudosection approach and 3.) the experimental approach. Whereas with the first two approaches it is possible to constrain several stages of the P-T-X evolution, the experimental approach allows mostly only the investigation of a distinct P-T condition of a rock. On the other hand, experimental investigations allow to put additional constraints on the evolution of a rock under defined P and T conditions. These constraints consider additional variables such as textures, aH_2O, nH_2O, fO_2 etc. In order to obtain results as close as possible to the natural rocks it is best to use natural rocks as starting materials. The disadvantage of this method being the complex chemical compositions of the rocks and therefore the deviation from chemical end-member systems. Therefore these experiments need to be evaluated not only 1.) in terms of their ability to reproduce the natural observations but also 2.) in their ability to reproduce theoretical calculations. In this study, a brief summary of three experimental investigations from a variety of P-T settings will be given with respect to the points discussed above.
The first example are the high-T low-P experiments concerning contact metamorphism of metapelites at the rim of the Permian Brixen Granite. In order to put experimental constraints on the temperature of contact metamorphism, experiments were performed in a hydrothermal apparatus at 0.3 GPa and temperatures of 580°C and 650°C using two natural quartzphyllite samples from the area as starting materials. The agreement between the observed textures and mineral compositions therefore allows putting additional constraints on the T conditions of this contact metamorphic event. On the other hand it was not possible to reproduce the variation of Na contents in cordierite throughout the contact aureole.
The second study deals with the experimental investigation of high-P/high-T granulites from the Bohemian Massif. Large bodies of felsic high-P/high-T granulites with the assemblage quartz + ternary feldspar (mesoperthite) + garnet + rutile ± kyanite occur in the Southern Bohemian Massif. They are thought to have formed during the Variscan orogeny in a Carboniferous subduction setting, at 950-1050°C and 1.5-1.9 GPa, from granitic protoliths. We used granitic gneiss as starting material whose chemical composition almost perfectly matches the main granulite type of the Southern Bohemian Massif. Although the natural phase assemblages were well reproduced, the presence of F in the starting material lead to severe inconsistent results concerning theoretical calculations.
The third study is concerned with the gabbro-eclogite transformation. The aim of this study was to provide experimental constraints on the gabbro-eclogite transition and compare the results to the locality Bärofen in the Koralpe (Styria, Austria) where a well-described gabbro-eclogite transformation has been observed. The experimental investigations using natural starting materials used drilled cores of fine-grained gabbros from the Odenwald. Recalculation of the mineral assemblages assuming relevant buffer assemblages was only partly successful. The experiments have shown that it was possible to reproduce 1.) microtextures, present in the Bärofen locality and 2.) mineralogical changes as a function of P, T, $a(H_2O)$ and fO_2.
Overall there is a surprisingly good agreement between the experiments and the natural observations, theoretical calculations are still hampered by minor elements (e.g. F) not considered in the claculations so far.

From orogenic buildup to extensional unroofing: the evolution of the Adria - Europe collisional zone in the Medvenica Mountains of Croatia

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Quantifying the kinematics of the Miocene extension in the Pannonian Basin is of critical importance for understanding the evolution of Adria-Europe collision in particular in the transitional zone from the Alps to the Dinarides. Recent studies have demonstrated that large-scale extensional unroofing along low-angle detachments have affected the Europe-Adria contact in the Dinarides during Miocene times. The relationship between this extensional exhumation of Adriatic units in the Medvednica Mountains (Croatia), the roughly coeval Miocene extension affecting the Alpine-derived units during E-ward extrusion and the formation of the Pannonian Basin is still unknown and the focus of this study.

The Medvednica Mountains, a NE-SW striking mountain range within the internal Dinarides, has been the focus of a field kinematic study, complementary low-temperature thermochronology (apatite fission track), metamorphic petrology, isotope dating (Rb-Sr measurements) and microstructural analysis. The observations indicate that the mountains consist of two units, reflecting distinct Adriatic paleogeographical positions. The upper unit contains Paleozoic mostly fine-grained clastic sequence metamorphosed in sub-greenschist facies, overlain by a proximal Adriatic facies consisting of Triassic shallow water carbonates. The lower unit is made up by a volcanic sequence overlain by Triassic carbonates metamorphosed in greenschists facies that bears a strong resemblance to the Triassic break-up volcanism and subsequent sedimentation affecting the distal Adriatic units observed elsewhere in the Jadar-Kopaonik unit of the Dinarides. The strong contrast between the Middle-Upper Triassic facies of the Medvednica Mountains suggests large scale thrusting during Cretaceous nappe stacking.

Subsequently, the studied area has been affected by significant extensional deformation creating the present-day turtleback geometry. This resulted in the formation of brittle normal faults in both units, locally tilted by the uplift of the mountain core, which indicate mostly NE-SW extension. The lower unit is affected by a pervasive deformation characterized by a wide mylonitic shear zone with stretching lineations indicating consistently top-NE to E sense of shear. Low-temperature thermochronology and absolute age dating (in progress) will clarify the exact ages of nappe-stacking and subsequent extensional exhumation.

The present-day geometry of the mountains was established during the Pliocene-Quaternary inversion.

Furthermore, the results demonstrate that the extensional geometry and sense of shear is typical for the Miocene extensional exhumation and basin formation that affected the Adria-Europe contact elsewhere in the Dinarids, e.g. Kozara-Prosara-Motajica and Fruska Gora extensional structures. By comparing similar extensional features observed in for instance the Rechnitz and Pohorje extensional structures, the combined study potentially demonstrates that the Miocene mechanism of extension and sense of shear is structurally coherent at the scale of the entire Dinaridic and Alpine margins.

The influence of the rotation of Adria and extension in the Pannonian Basin on lateral extrusion in the Alps: insights from crustal-scale models

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The influence of slab-pull induced extension in the Pannonian Basin and rotation of the Adriatic indenter on lateral extrusion processes in the Eastern Alps has been studied through analogue crustal scale modeling. Extension at high angle to the shortening direction has been implemented in the models; these are analogues for the northward convergence of the Adriatic plate and the coeval back-arc type extension in the Pannonian Basin.

Cross-sections and top-view images of the models have been analyzed in detail using particle tracing techniques (DPIV) which enables to calculate surface vector fields and visualize strain localization and block rotations. In the models the amount, timing and direction of extension have been the main variables together with a 20 degrees counter clockwise rotation of Adria. Additionally, a rigid buttress simulating the Bohemian Massif has been implemented, thereby decreasing the width of the area that can accommodate deformation.

The modeling results demonstrated that all models feature a compressional, strike-slip and tensional domain from west to east, respectively. The strike-slip (extruding) domain shows 'en-bloc' rotations in response to displacement velocity variations. The crustal blocks are bounded by conjugate strike-slip faults, which is indicative for lateral extrusion processes. When extension is present the amount of rotation increases, the extruding domains propagate further to the west and the direction of extrusion is parallel to the direction of extension. When extension was ceased whilst convergence continued the extruding domain decreased in size but remained active.

The models which included rotation of Adria, are characterized by the absence of conjugate strike-slip faults and the area that accommodated extrusion is decreased. Thus, it is probable that an indenter rotation has a negative effect on the lateral extrusion tectonics and amount of extension. However, when a Bohemian Massif type boundary was present, along with rotation of Adria, the amount of extension and development of conjugate sets of strike-slip faults are similar to models without rotation. Due to the increase in wrenching, in response to a narrow domain that could accommodate deformation, the models actually featured an increase in the amount of conjugate faults.

The results of this study imply that slab-pull driven extension in the Pannonian domain facilitates the lateral extrusion processes in the Eastern Alps and determines the direction of lateral displacements. A 20 degrees counter-clockwise rotation of Adria does not enhance lateral extrusion whereas the presence of the Bohemian Massif type boundary in the north does, as it fosters the formation of extrusion type fault systems. Furthermore, ongoing lateral extrusion despite stagnation of back-arc extension is in line with recent GPS data.

The Alps/Apennines boundary: structures and kinematics of interfering orogens and comparison with other modern analogues

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Although debated for more than one century, the relationship between the Alps and Apennines remains a puzzling geologic question.

The Alps and the Apennines presently form two independent and adjacent segments of the Alpine orogen. They have opposite tectonic vergence, W/NW for the Alps, and E/NE for the Apennines, both oriented roughly perpendicular to their arcuate trends. The junction area of the two chains is characterised by tectonic domains (MOLLI et al., 2010) resulting from the kinematically complex interaction between the opposite dipping subductions active in the last 30 Myr, i.e. east-southeast "alpine" and west-northwest "apennine". At the junction deformation is represented by extensional fault system and basins development overprinting distributed, crustal-scale contractional structures and widespread block rotation.

Our understanding of the tectonic evolution of this junction can take advantage of comparisons with modern convergence systems such as the Ryukyu-Taiwan, Southern Chile-South Sandwich, Colombia-Lesser Antilles, Hikurangi-Puysegur, Manila-Philippine, New Guinea-Solomon-New Hebrides. In these other modern systems we can identify tectonic architectures controlled by both the structural association and the relative evolution of single structures and basins.

Here we analyse the differences of structural/tectonic evolution of junction areas as a function of the ways that plates kinematically interact. We also present the Alpine-Apennine junction as a key area to understand the dynamics of crustal evolution of interfering convergence systems.

MOLLI, G., CRISPINI, L., MALUSÀ, M.G., MOSCA, P., PIANA, F. & FEDERICO, L. (2010): Geology of the Western Alps-Northern Apennine junction area: a regional review. In: (Eds.) Marco Beltrando, Angelo Peccerillo, Massimo Mattei, Sandro Conticelli, and Carlo Doglioni, Journal of the Virtual Explorer, volume 36, paper 10, doi: 10.3809/jvirtex.2010.00215

Low thermal evolution of the Southern Veporic Unit crystalline basement (Central Western Carpathians) constrained by new fission track data

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New thermochronological data, combined with a previous one and geological knowledge enable to constrain the Late Cretaceous to Neogene tectono-thermal evolution of the southern zone of Veporic crystalline basement. Presented zircon and apatite fission track (FT) data can be correlated with sixth principal tectono-thermal stages. During the late Early Cretaceous period (TS1; ~120–90 Ma), the Veporic crystalline basement was buried below the palaeo-Alpine nappe stack in the depths of ~20–30 km and suffered a greenschist- to amphibolite-facies metamorphic overprint (~350–600°C and ~500–800 MPa). The Alpine metamorphism culminated with maximum temperatures at ca. 120–90 Ma and cooled below the 40Ar/39Ar blocking temperature on mica mostly between 90 to 80 Ma ago. After burial an orogen-parallel extensional exhumation and unroofing of the Veporic domain occurred during the Late Cretaceous to Palaeogene (TS2; ~90–35 Ma). The exhumation of the Veporic domain is documented by zircon FT ages of 75–71 Ma and apatite FT ages of 63–55 Ma, indicating a "rapid" cooling phase during the Late Cretaceous to Palaeocene followed by moderate cooling phase from the Palaeocene to Early Eocene. The exhumation of the Veporic domain continued till the Late Eocene–Bartonian, as it was revealed by preservation of its erosion level due to transgression of the Late Eocene sediments. The Late Eocene to Early Miocene period (TS3; ~35–20 Ma) is related to burial beneath the Upper Eocene to Oligocene strata. The Oligocene sedimentary sequences with thickness less than ~1.5–2.0 km were deposited on uncovered Veporic crystalline basement with only minor indication of reheating. The Early to Middle Miocene period (TS4; ~20–13 Ma) is characterized by uncovering of the Veporic domain after the deposition of the Late Palaeogene to Early Neogene sedimentary sequences. The Early to Middle Miocene denudation of the Veporic domain almost completely removed the Palaeogene sedimentary sequence before the creation of the Sarmatian Veporic volcano-plutonic complex. The obtained apatite FT data of Palaeogene cooling ages from the Slávča and Hrdzavá valleys near the Tisovec intrusive complex revealed that the wider area was not regionally reheated by the mid-Miocene thermal event. The volcanic activity at the centre of the Veporic volcano-plutonic complex occurred during the Middle Miocene (TS5; ~13–11 Ma), according to $^{40}Ar/^{39}Ar$ dating results. The mid-Miocene thermal event was revealed also by zircon FT age of 13 Ma. However, the extent of contact aureole did not exceed more than 1 km, according to maintain of low-thermal Palaeogene record in its neighbourhood. The final exhumation of the Veporic domain occurred in the Neogene to Quaternary times (TS6; ~11–0 Ma). An intensive denudation processes were documented by removing of at least the 1500 m of volcano-sedimentary rocks of upper stratovolcanic structure (cone) during the last 10 Ma. In addition, preservation of the planation surfaces suggests a relatively young (Pliocene and Quaternary) but most probably not so intensive exhumation of the mountains.

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Permian metamorphism and magmatism in the internal Western Alps: Constraints from high spatial resolution U-Th-Pb geochronology

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Evidence of the late Paleozoic HT-evolution in the Western Alps remains a controversial issue. As in other parts of the Alps, magmatic and metamorphic effects in the basement reflecting the Variscan HT-orogeny are well known, but the situation is not so clear for the subsequent Permian evolution. Permian extension in the Adriatic lithosphere has been linked to asthenosphere upwelling, causing high temperature metamorphism at medium pressure and widespread partial melting, which led to upper crustal magmatic activity (e.g. MAROTTA & SPALLA, 2007). However, the relation of the magmatism to the associated metamorphism is well documented in a few areas only, and age control is generally poor. This is particularly true for the Western Alps, where Permian metamorphism has long been proposed, but so far radiometric age data are lacking.

In this study, the use of high spatial resolution geochronology (SHRIMP and LA-ICP-MS U/Th-Pb dating) in combination with structural and petrological methods has proved successful to fill some of the gaps in the current knowledge on the pre-Alpine metamorphic evolution of several Austroalpine units of the Western Alps.

In the SW part of the Sesia Zone, in the II DK unit, upper amphibolite to granulite facies metamorphism was dated at ~277 Ma and at ~270 Ma in metapelites. A leucosome dates at ~290 Ma.

In the eclogitic micaschist complex (EMC), the Corio-Monastero metagabbro contains zircon with rims that crystallized at HT metamorphic conditions and date at ~277 Ma. Local recrystallized rims yield ages at ~230 and ~190 Ma, indicating two (fluid-induced?) episodes. During exhumation this gabbro was intruded by dikes. In one of these zircon shows two age populations at ~270 and ~235 Ma. Two intermediate to felsic intrusions in the EMC yield ~277 and ~266 Ma.

In the Valpelline Series of the Dent Blanche unit, three stages of amphibolite to granulite facies metamorphism are evident: The age data show ~287 Ma, ~274 Ma, and ~263 Ma. These metamorphic stages clearly postdate the Variscan metamorphic cycle, which occurred around 350 Ma, as confirmed by this study.

In the Emilius Klippe preliminary results indicate a Permain HT evolution as well: Basic intrusives have been dated at ~290 Ma (compare BUSSY et al., 1998) and a granitic intrusive at ~283 Ma. Zircon and allanite, both interpreted to be of metamorphic origin, cover an age range clustering at ~276 Ma.

These ages, together with petrological data, evidence that the middle and lower crust in several Austroalpine units in the internal Western Alps experienced a regime of high temperature in Permian times. The time span recorded in zircon ranges between ~290 and ~260 Ma. Age relics of the Variscan orogeny are sparse, and so far no evidence has been found of the regional HT metamorphism at ~310 Ma, known in the Ivrea Zone (e.g. EWING et al., 2013). It remains to be explored whether the differences among age data are due to differences in the Permian metamorphic history of these units or whether they merely reflect chemical differences (e.g. in the growth of zircon) due to local compositional differences or the structural position of the samples analyzed.

BUSSY, F., VENTURINI, G., HUNZIKER, J.C., MARTINOTTI, G. (1998): U-Pb ages of magmatic rocks of the Western Austroalpine Dent-Blanche-Sesia Unit. Schweizerische Mineralogische und Petrographische Mitteilungen, 78:163-168

EWING, T.A., HERMANN, J., RUBATTO, D. (2013): The robustness of the Zr-in-rutile and Ti-in-zircon thermometers during high-temperature metamorphism (Ivrea-Verbano Zone, northern Italy). Contributions to Mineralogy and Petrology, 165: 757-779

MAROTTA, A.M. & SPALLA, M.I. (2007): Permian-Triassic high thermal regime in the Alps: Result of late Variscan collapse or continental rifting? Validation by numerical modeling. Tectonics 26 (4).

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

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Many three-dimensional (3D) structures in rock, which formed during the deformation of the Earth's crust and lithosphere, are controlled by a difference in mechanical strength between rock units and are often the result of a geometrical instability. Such structures are, for example, folds, pinch-and-swell structures (due to necking) or cuspate-lobate structures (mullions). These structures occur from the centimeter to the kilometer scale and the related deformation processes control the formation of, for example, fold-and-thrust belts and extensional sedimentary basins or the deformation of the basement-cover interface. The 2D deformation processes causing these structures are relatively well studied, however, several processes during large-strain 3D deformation are still incompletely understood. One of these 3D processes is the lateral propagation of these structures, such as fold and cusp propagation in a direction orthogonal to the shortening direction or neck propagation in direction orthogonal to the extension direction. Especially, we are interested in fold nappes which 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). The Morcles nappe is mainly the result of layer parallel contraction and shearing. 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. We study the 3D evolution of geometrical instabilities and fold nappe formation with numerical simulations based on the finite element method (FEM). Simulating geometrical instabilities caused by sharp variations of mechanical strength between rock units requires a numerical algorithm that can accurately resolve material interfaces for large differences in material properties (e.g. between limestone and shale) and for large deformations. Therefore, our FEM code combines a numerical contour-line technique and a deformable Lagrangian mesh with re-meshing. With this combined method it is possible to accurately follow the initial material contours with the FEM mesh and to accurately resolve the geometrical instabilities. The algorithm can simulate 3D deformation for a visco-elasto-plastic rheology. Stresses are limited by a yield stress using a visco-plastic formulation and the viscous rheology is described by a power-law flow law. The code is used to study the 3D fold nappe formation, the lateral propagation of folding and viscoplastic necking from an initially localized perturbation and also the lateral propagation of cusps due to initial half graben geometry. Thereby, the small initial geometrical perturbations for folding and necking are exactly followed by the FEM mesh, whereas the initial large perturbation describing a half graben is defined by a contour line intersecting the finite elements, where more numerical integration points are applied.

Micro-seismic characterization of the Fribourg Lineament - Switzerland

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This analysis investigates low-magnitude seismicity generated within the Fribourg area (Western Molasse Basin (WMB) - Switzerland). It focuses on the Fribourg Lineament (FL), an alignment of weak seismicity that showed recent signs of increased activity (Kastrup et al., 2007). The FL runs in a North-South direction east of the city Fribourg and is parallel to the Fribourg syncline. Orientation of these two features differs strongly from the surrounding tectonic structures that show a general SW-NE trend.

The FL has been monitored since 2010 by two sparse mini-arrays (seismic navigating systems - SNS). Each SNS consists of one central 3D short-period (1Hz) sensor surrounded by three 1D short-period (1Hz) sensors. They are deployed in a tripartite geometry with an aperture of 100 m, which is best suited for azimuth and apparent velocities determination of incoming signal (Joswig, 2008). The recordings of the two SNS are complemented by records of three permanent stations of the Swiss Seismological Service (SED).

Event detection is done by visual event screening of continuous data sonograms (Sick et al., 2012). Sonograms are spectrograms based on power spectral density (PSD) matrix, noise adapted, muted and pre-whitened. Special features of sonograms allow for the extraction and recognition of earthquake signals by visual pattern recognition near to 0 dB signal to noise ratio. Detected events are then located using HypoLine, a software especially designed for SNS. Event location is done interactively whereby simulation results are immediately updated after every single parameter change. This enables to optimal use of prior information, such as geological knowledge, when determining hypocenter location in the multiple probable solutions (JOSWIG, 2008). Both the densification of the seismic sensors around the FL and the increased detection power of sonogram analysis permits lowering the detection threshold of the Earthquake Catalog of Switzerland (ECOS) by about one order of magnitude in the FL area. Our comprehensive catalog of earthquakes detected within the FL after 2010 comprises more than 200 events.

A set of seismic lines interpreted by InterOil was used to build a 3D structural model of the WMB. Fault planes have been extrapolated to the surface across five horizons from top basement to base of the Tertiary cover. An initial analysis of our seismic catalog shows that most of the local micro-seismicity is located in the sedimentary cover. Some events are collocated with interpreted structures; however, an important part of the seismicity is located in areas without known substructures (due to the lack of seismic lines). Since many earthquakes have similar origins over time, signal cross-correlation is used for collocation purposes and in order to identify possible fault zones.

JOSWIG, M. (2008): Nanoseismic monitoring fills the gap between microseimic networks and passive seismic, First Break, 26, 2008.

KASTRUP, U., DEICHMANN, N., FRÖHLICH, A. & GIARDINI, D. (2007): Evidence for an active fault below the northwestern Alpine foreland of Switzerland, Geophys. J. Int. (2007) 169: 1273-1288.

SICK, B., WALTER, M. & JOSWIG, M. (2012): Visual Event Screening of Continuous Seismic Data by Supersonograms. - Pure Appl. Geophys., 10.1007/s00024-012-0618-x.

Provenance analysis and paleogeography of the Gosau Group (Upper Cretaceous - Paleogene) in eastern Austria and western Slovakia

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The Upper Cretaceous to Paleogene sediments of the Gosau Group of the Northern Calcareous Alps (NCA) are unconformably and diachronously overlying folded and faulted Permian to Cretaceous units. Various Gosau Group deposits representing different basins are exposed at the eastern part of the Eastern Alps (Austria) at the south-western margin of the Vienna Basin, and at the western part of the Western Carpathians (Slovakia). In between, NE-SW-striking Gosau sediments are drilled in several wells below the Neogene fill of the Vienna Basin. The Gosau deposits were folded during the Alpine orogeny, and today form structurally complex synclines. From north to south several synclines on different tectonic units of the NCA and on Carpathian units are present: the northernmost Gießhübl Syncline, the Prottes Gosau Group, its Slovakian equivalents of Studienka and Brezová, the Glinzendorf Syncline and the southernmost Grünbach Syncline.

About 250 fine-clastic samples from outcrops, drill cores and cuttings of various Gosau locations and formations have been geochemically analyzed (bulk rock). Additionally, heavy mineral contents of coarse-clastic sediments (523 samples) have been evaluated and more than 600 grains of garnet, chromian spinel and tourmaline have been analyzed by electron micro probe with the aim to reconstruct the hinterland of the Gosau sediments and to distinguish different Gosau basins and to decipher the paleogeographic evolution in this area.

A general trend from chromian spinel dominated heavy mineral spectra of the Coniacian to the Campanian/Maastrichtian to a garnet dominated up to the Paleogene (plus relatively high amounts of tourmaline within the Slovakian Studienka area) can be observed for all Gosau deposits. Almandine is generally the dominant garnet component. Only Coniacian to

Campanian samples from the paleogeographically more southern Glinzendorf and Grünbach basins have significantly lower almandine and higher pyrope and grossular contents. These garnets are partly derived from a metamorphic sole remnant of Neotethys ophiolites to the south and this hinterland supplied only southern Gosau basins until Campanian age in contrast to the ordinary granitic to metasedimentary hinterland which is present for both northern and southern basins. In addition, these structurally high ophiolitic nappes, later on completely eroded, supplied mainly the paleogeographically southern Grünbach and Glinzendorf Gosau basins with ultramafic detritus represented by chrome spinels of a mixed harzburgite/lherzolite composition and high Cr and Ni as well as high Cr/V ratios in relation to low Y/Ni in associated shales. No direct indications for a northern ophiolitic source, the Penninic or Alpine Tethys accretionary wedge to the north of the Gosau basins, could be found. In the younger part of the Gosau basins fill, from the Maastrichtian to the Eocene, only almandine-rich garnets could be observed suggesting a southern provenance from low-grade metamorphic metapelites of exhuming Austroalpine metamorphic complexes. Ophiolite detritus is reduced in the Maastrichtian and disappears in the Paleogene. Major and trace elements generally indicate a mixture of different hinterland compositions and tectonic settings as source of the Gosau basins.

The St. Veit Klippenzone in Vienna - missing piece in the Alpine-Carpathian klippen puzzle

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The St. Veit Klippenzone (SVK) comprises a succession of mainly Mesozoic rocks in western Vienna and the Wienerwald area. Outcrop situation is generally extremely bad in this area, and thus a modern analysis of these disputed klippen strata was completely missing. In recent years unique exposures of the SVK and adjacent flysch formations were available due to a large railroad tunnel (Lainz Tunnel). This contributes significantly to the correlation of the SVK to other klippen zones and it's geotectonic position (Helvetic vs. Penninic vs. Austroalpine).

Geochemistry, heavy mineral data, isotope geochemistry and microfacies studies were used to describe and interpret the strata. Biostratigraphic results include data by macrofossils (rare ammonites) radiolaria, calpionellids and nannofossils.

The SVK and its overlying flysch units build a major tectonic unit within the nappe pile of the Eastern Alps in the Wienerwald area west of Vienna. Coming from the Vienna valley (Auhof), going SE, the tunnel hit first rocks of the Kahlenberg Nappe, up to 2165.5 m, then followed by rocks of the SVK. The SVK was found in a 1097 m long section within the Lainz tunnel. It comprises largely a block in matrix structure, partly tectonically mixed with flysch units (Hütteldorf Formation, Kahlenberg Formation). Tectonic blocks of hard klippencore rocks show sizes from cm to several tens of meters. The matrix consists of strongly deformed fine-grained rocks such as Jurassic and Lower Cretaceous shales and marls. No primary sedimentary contact of the flysch formations onto the SVK could be detected which precludes the interpretation that the SVK constitutes a primary basement for the Rhenodanubian Flysch.

The composite Klippenzone succession recorded within the tunnel and reported from additional outcrops in the area of the Lainzer Tiergarten (Vienna) includes the following stratigraphy: (1) coarse quartz sandstones (Norian/Keuper), (2) fossiliferous grey limestones (Rhaetian), (3) sandy-silty grey marls and limestones with crinoids (Lower/Middle Jurassic), (4) red chert and red shale (Bajocian-Oxfordian), (5) grey marl to argillaceous limestone (Tithonian-Valanginian), (6) aptychus limestones (Neocomian), (7) white silicified limestone (Berriasian), (8) green chert (Valanginian).

The geotectonic position of the St. Veit Klippenzone can be discussed based on our results and comparison samples from the Pieniny Klippen Belt (PKB). Neither the Gresten Klippenzone (Helvetic/Ultrahelvetic units of the European continental margin) nor the Ybbsitz Zone (Penninic units including Ophiolite remnants) provide similar successions. In contrast to former interpretations, a more reasonable correlation can be done with Austroalpine units, i.e. facies successions of the Lower Austroalpine Units (e.g. Mesozoic of Semmering and Radstädter Tauern), and the northernmost marginal units of the Northern Calcareous Alps, based on the occurrences of Keuper sandstones and Rhaetian limestones, and Jurassic strata. Thus, a "northern" Austroalpine derivation seems to be reasonable for the SVK. Comparing with the Western Carpathians we find strong similarities with the Drietoma unit, a unit which has affinities to Lower Austroalpine-Fatric elements such as the Krizna Nappe (i.e. Keuper strata), but was lateron affected by Klippen-style tectonism and incorporated into the PKB. Thus, the St. Veit Klippenzone can be seen as the westernmost extension of the Pieniny Klippen Belt (in a tectonic sense) in Austria and neither belongs to the Helvetic nor to the oecanic Penninic paleogeographic realms.

Composition of the Bohemian spur in the subsurface of the Eastern Alps: indications from exotic blocks

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The Bohemian Massif continues below the Eastern Alps as a basement promontory often referred as Bohemian spur (TARI, 2008). According to surface geology and wells in the Alpine foreland it consists of Variscan basement rocks of the Moldanubian and Moravian unit overlain on both sides by transgressive post-Variscan sediments (WESSELY, 1987). However, the continuation of the Bohemian spur below the Alps can be inferred from exotic blocks embedded in the Allochthone Molasse representing the northernmost and youngest tectonic units of the Alps. The exotic material allows an insight in the geology of a hidden segment of the former southern margin of Europe towards the Penninic Ocean.

The Allochthone Molasse consists of sediments deposited in the Alpine foreland basin, incorporated as tectonic slices into the orogenic wedge after 17.5 Ma. Its main part (Schuppenmolasse) is composed of Eggenburgian to early Ottnangian claystones, sandstones and conglomerates. North of the Danube an overlying slice (Waschbergzone) containing additional Paleogene sediments and tectonic slices of the Jurassic and Cretaceous cover of the underlying basement is present. Layers with exotic blocks of crystalline basement appear in early Ottnangian sediments. Such blocks from several outcrops in Lower Austria have been investigated by geochemical and geochronological methods to get information on their source area.

At Waschberg exotic material shows a polymict composition dominated by granites, often with amphibole and pinkish K-feldspar, and granitic gneisses. Further granite-porphyries, migmatic paragneisses and minor amphibolite and marble occur. The blocks are mostly well rounded, badly sorted and reach up to more than 1 m in size. Most probably this material represents debris flows generated from preexisting local gravel accumulations. At Heuberg blocks of monomict biotite-granite are exposed. They are not rounded or sorted and the largest ones are more than 10 m in length. This debris flows originated from a fault scarp (GEBHARDT et al., 2008).

Granite and granitic gneiss blocks and pebbles show an overall peraluminous composition. Additionally higher SiO_2-contents connected with increased Rb/Sr-ratios indicate considerable magmatic fractionation of largely S-type granites. Nevertheless granites with pinkish K-feldspar exhibit low $^{87}Sr/^{86}Sr$-initial ratios (0.705 – 0.707, 300 Ma) pointing to a significant I-type component in the magmatic source. Rb/Sr cooling ages of biotite from 12 samples (granites, granitic gneiss, migmatic paragneiss) range from 300 to 230 Ma, arguing for a prolonged cooling history of the hidden Bohemian spur.

By comparing the hidden part of the Bohemian spur which is indicated by the exotic blocks with the adjacent Variscan basement shows obvious differences. The granites of the Moravian unit, which are closest, are clearly different, with I-type composition (FINGER et al., 1989) and Neoproterozoic magmatic ages (FRIEDL et al., 2004). The Moldanubian unit contains a wide range of I- and S-type granites (VELLMER & WEDEPOHL, 1994). They are characterized by magmatic ages of 340–310 Ma (FINGER et al., 2009) but their cooling ages (320–310 Ma, SCHARBERT et al., 1997) are different from the granites of the exotic blocks. Younger cooling ages (around 290 Ma) are known only in the southwestern part of the Moldanubian unit in Upper Austria. The granitic gneisses of the Subpenninic unit in the Eastern Alps are predominantly early Permian in age (VESELÁ et al., 2011) and show mainly I-type composition. At least in the surrounding Variscan basement is no magmatic suite with granites comparable to the investigated exotic blocks.

FINGER, F., FRASL, G., HÖCK, V. & STEYRER, H.P. (1989): The granitoids of the Moravian zone of northeast Austria – products of a Cadomian active continental margin? – Precambrian Research, 45: 235-245, Amsterdam.

FINGER, F., RENÉ, M., GERDES, A. & RIEGLER, G. (2009): The Saxo-Danubian Granite Belt: magmatic response to postcollisional delamination of mantle lithosphere below the southwestern sector of the Bohemian Massif (Variscan orogen). – Geologica Carpathica, 60: 205–212, Bratislava.

FRIEDL, G., FINGER, F., PAQUETTE, J.-L., QUADT, A. VON, MCNAUGHTON, N.J. & FLETCHER, I.R. (2004): Pre-Variscan geological events in the Austrian part of the Bohemian Massif deduced from U-Pb zircon ages. – Int. J. Earth Sci. (Geol. Rundsch.), 93: 802–823, Stuttgart.

GEBHARDT, H., KRENMAYR, H.G., CORIC, ST. & ROETZEL, R. (2008): Grobklastika in der allochthonen Vorlandmolasse am Ostende der Alpen. – Journal of Alpine Geology, 49: 137–154, Wien.

SCHARBERT, S., BREITER, K. & FRANK, W. (1997): The Cooling History of the Southern Bohemian Massif. - Journal of the Czech Geological Society, 42: 24, Prague.

TARI, G. (2008): Influence of the Bohemian Spur on the evolution of the Eastern Alps. – Journal of Alpine Geology, 49: 110–111, Wien.

VELLMER, C. & WEDEPOH I, K.H. (1994): Geochemical characterization and origin of granitoids from the South Bohemian Batholith in Lower Austria. Contr. Miner. Petrol., 118: 13–32, Berlin.

VESELÁ, P., SÖLLNER, F., FINGER, F. & GERDES, A. (2011): Magmato-sedimentary Carboniferous to Jurassic evolution of the western Tauern window, Eastern Alps (constraints from U-Pb zircon dating and geochemistry). – Int. J. Earth. Sci. (Geol. Rundsch.), 100: 993–1027, Stuttgart.

WESSELY, G. (1987): Mesozoic and Tertiary evolution of the Alpine-Carpathian foreland in eastern Austria. - Tectonophysics, 137: 45-59.

Analogue modelling of continental subduction with laterally changing subduction polarity

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Tomographic images from the Alps reveal southeasterly-directed subduction of the European mantle lithosphere in the central Alps and a north-easterly dipping subduction of the Adriatic mantle lithosphere underneath the Eastern Alps. We studied the deformation and surface expression of this lateral change in subduction polarity by using lithospheric-scale physical models. The main parameters investigated for uni-polar and bi-polar subduction systems of the continental lithosphere are: (a) the weakness of the plate interface, (b) the presence of weak lower crust (c) the width of the transition zone between the oppositely dipping slabs.

The results of the analogue experiments show that upper crustal deformation initiated at the plate interface by the formation of a pop-up structure. Along the inclined plate boundary lithosphere-scale underthrusting and a significant amount of Moho displacement occurred. The downgoing plate experienced upper crustal thrusting and a foredeep basin developed. The thickness of the weak-zone interface plays a key role in the amount of continental subduction, and consequently on the onset of intraplate deformation, which occurs only after the weak interface is consumed or sufficiently thinned. However, continental collision and coinciding mantle lithosphere subduction beneath an orogenic wedge takes place only if the lower crust is weak enough to allow crust-mantle decoupling. During collision weak lower crust partly subducts, while the detached part thickens below the orogen affecting the upper crustal deformation pattern and topography.

From the bi-polar subduction models it can be observed that the first pop-up structure is laterally continuous pointing out its independence on the vergence and obliquity of subduction. Ongoing deformation causes the formation of a second pop-up structure on the downgoing plates resulting in lateral asymmetry and the development of a narrow transition zone. Cross sections of the model illustrate an asymmetry in the upper crustal wedge with a clear pro- and retro- side. On the contrary, a wide and symmetrical orogen overlying a vertical slab of mantle lithosphere is characterizing the zone of subduction polarity change, which is also the region of relative low topography. These lateral variations in crustal architecture are expected to be a direct response of lateral input variations of lower crust and mantle lithosphere. However, the width of the zone where interaction of crustal structures related to the different subduction domains occurs exceeds the initial with of the transition zone considerably. In additions, cross-sections reveal the underlying importance of lateral coupling between the mantle lithospheres of opposing dipping slabs resulting in subduction resistance forces on one hand, but in down bending of the neighbouring overriding plate on the other hand.

Our modelling results can be compared with the crustal and lithosphere-scale structure of the Alps, where the orogenic wedge in the Western Alps is asymmetric and a relatively large pro-wedge overlays the downgoing European plate. Eastwards, the upper crustal deformation is more symmetrically distributed above the colliding plates, and the orogen widens reaching maximum values along the TRANSALP profile. Hence, lateral variations of the crustal architecture (symmetry of mountain belts) may be indicative for changes in the subduction polarity of the lower lithosphere.

Pre-Alpine and Alpine Tectonic evolution of the western and northern parts of the Gurktal and Bundschuh nappe system

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The western and northern margin the Gurktal Nappe is classically defined as a structure of Alpine nappe emplacement with Permomesozoic sediments (nappe separators) decorating the thrust. The tectonic boundary stretches from Radenthein northwards and bends sharply to the east heading towards the Turrach sattle. Structural studies along that boundary display a complex tectonic history. (1) The contact between the Pfannock Gneiss and the Königstuhl Conglomerate is interpreted as late-Carboniferous cataclastic fault zone that formed in the course of exhumation of the crystalline and coeval deposition of Carboniferous sediments. Cataclastic pebbles are present within the Carboniferous sediments and suggest exhumation prior to deposition of rocks. The pre-Carboniferous fault can be traced all along the eastern and southern margin oft he Pfannock Gneiss. (2) The Pfannock Schuppe includes an inverted suite of Permian to Mesozoic sediments. It is interpreted as a tectonic sliver with the Pfannock Gneiss in the core of a northwest vergent fold. Shearing and folding is correlated with Cretaceous northwestward nappe stacking. (3) The actual geometry of the boundary is result of bulk extension during the late Cretaceous. Extensional structures with E- to SE displacement dominate N-S trending segments, dextral strike-slip zone the W-E trending segments. The overall geometry can be described as eastward spreading units with normal faults forming extensional bridges between strike-slip domains.

3D thermo-kinematic modelling of a crustal-scale low-angle normal fault: the Katschberg detachment, Eastern Alps.

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In this study we investigate a low-angle normal fault of the Eastern Alps, the Katschberg detachment. This major structure developed during Miocene lateral extrusion and is largely responsible for the exhumation of the eastern Tauern Window. We investigate two E-W profiles that extend 25 km in the footwall and 20 km into the hanging wall. An extensive set of already published and new thermochronological data provides the basis for 2- and 3-D thermokinmatic models. We use a finite-element code (Pecube) to solve the heat equation in 3D and predict the thermal evolution around the Katschberg detachment under given spatially and temporally variable boundary conditions. An inversion routine is used to find the best-fitting parameter combination, which reduces the misfit between modelled and measured thermochronological ages.

According to our preliminary inversion the Katschberg normal fault was active from 21.4±2.2 Ma until 8.3±1.7 Ma with a mean slip-rate of 2.6±0.5 km/Ma, integrating to an offset along the fault of 33.8±4.1 km. This agrees with previous studies, that suggest that the Katschberg detachment was active between ~23 and 12 Ma.

Middle- to Late Miocene exhumation of the central Eastern Alps: new structural-, fission track and apatite (U-Th)He data.

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New structural-, fission track and apatite (U-Th)/He data refine the Eocene/Oligocene to Late Miocene exhumation history of the Seckauer- and Niedere Tauern in the Eastern Alps. Both areas belong to the Austroalpine basement units but experienced different temporal and spatial exhumation. The Seckauer Tauern already cooled to upper crustal levels (2-3 km) during Eocene times, followed by stagnation and very low erosion rates. In contrast, the Niedere Tauern cooled to upper crustal levels during the Middle- and Late Miocene, contemporaneously to the Penninic units within the Tauern Window. Structural investigations suggest that the displacement between these two Austroalpine units occurred along the northern section of the Pöls-Laventtal fault system. We suggest that extrusion became not only lateral in terms of parallel to the trend of the Eastern Alps, but was characterized by a displacement vector at a high angle to the strike of the orogen. This resulted in exhumation of the Niedere Tauern and Pohorje Block that were exhumed within extensional bridges at the northern and southern termination of the Pöls-Lavanttal fault system, respectively.

Thermal modeling of an external Unit of the Eastern Alps - the Helvetic zone of western Austria and Upper Allgäu

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The Helvetic zone of the Eastern Alps is a thin-skinned fold-and-thrust belt comprising Jurassic to Cenozoic shelf deposits. They were detached from their substratum during Cenozoic nappe formation. From the Oligocene onward, they were transported to the north and thrust onto the Alpine Foreland Basin, carrying the Penninic and Austroalpine units piggy-back.

To study the thermal evolution of this external part of the Eastern Alps, maturation of organic matter was measured using vitrinite reflectance. Organic rich dark-colored shales and carbonates build a large part of the Helvetic stratigraphic succession. Fission track dating was done to obtain some time related temperature information on the thermal evolution of the Helvetic nappes. In order to get a more complete image, samples from the Subalpine Molasse in the footwall and from the overlying Penninic Rhenodanubian Flysch were included. Apart from surface outcrops deep wells (Dornbirn 1, Hohenems, V-Au1, Kierwang 1 and Maderhalm 1) were sampled as well. Modeling was done using the PetroMod 2001.1 software by Schlumberger Ltd.

Vitrinite reflectance measurements from the Helvetic zone yielded three different trends: first of all a stratigraphic trend is given – the mean reflectivity (%Rr) decreases for about 0.4% from the Malmian Quinten Limestone to the Late Cretaceous sandstones of the Garschella Fm. Secondly, coalification rises with increasing depth (ca. 0.3%Rr per km). Finally, coalification in general increases from north to south, starting at the high volatile bituminous coal stage and reaching the low volatile bituminous coal- to semi-anthracite stage along the Penninic thrust contact. Measurements deep well samples show a coalification trend that is offset along numerous faults which are known from the drill record. Therefore, a pre- to syntectonic coalification of the Helvetic units has to be claimed.

Preliminary apatite fission track data show that all investigated units were subjected to post-depositional temperatures above the APAZ (i.e. >120°C) since all grains are fully reset. Partially reset zircon samples from few analyzed samples from Helvetic and Rhenodanubian Flysch units argue for maximum temperatures between 180 and 300°C.

By combining results from coalification and fission track analyses a maximum overburden of more than 8 km could be modeled for the Early to Late Oligocene.