material formerly accreted is subject to erosion and may reenter the convergent margin. Loading of the convergent margin by the growing wedge flexes the subducting plate. This process may lead to the subduction of formerly accreted material (by subduction erosion) and – in order to maintain the wedge's critical taper – to further surface uplift and erosion.

In the case of the Swiss Alps, morphogenesis resulted from a continent-continent collision which occurred in the past ca. 40 Ma. This collision led to the exhumation of high grade metamorphic rocks in the Lepontine area where denudation removed some 25 km of the nappe pile. Further north, denudation removed about 10 – 15 km of section following surface uplift owing to crustal scale folding and thrust faulting associated with the Aar massif. The large scale 1st order geomorphic characteristics of this chain include two water divides and two belts of high elevations. On an erodibility map these areas of high elevation correlate to bedrock types with low erodibility (granitic rocks).

Numerical surface process modeling was carried out to examine the coupling between surface and deep processes. Surface processes include fluviatile and hill slope diffusive mass transfer. Deep processes are modeled with tectonic forcing as deduced from the crustal evolution of the Swiss Alps. This includes two uplift maxima: an earlier uplift in the model-Lepontine area which is followed by uplift of a model-Aar massif. A model-crust with rocks of homogeneous erodibility, subjected to such an Alpine-type tectonic forcing, results in a drainage pattern dominated by very stable rivers insensitive to changes in uplift rates. These rivers maintain their course perpendicular to the orogen axis almost irrespective of changes in uplift rates or erosional parameters. A natural analog of such a behavior can be found in the Coast Range of British Columbia.

If a highly erodible unit, intended to represent a 2 km thick nappe stack of sedimentary rocks sandwiched between crystalline basement, is included in the model, the drainage pattern undergoes a profound change. Instead of incising the later forming northern model-Aar massif uplift, axial rivers get captured by headward erosion of longitudinal rivers developing along the highly erodible units. The defeat of these axial rivers is held responsible for the creation of the secondary water divide and the ensuing migration of the main water divide away from the maximum uplift of the model-Lepontine area.

Applied to the Swiss Alps the model results suggest that the primary signature of the collision, a nappe stack composed of rocks of very different erodibilities, together with the late-collisional uplift played an important role in the reorganization of the Miocene drainage pattern with axial rivers to the longitudinal rivers flowing today. In their lower course, rivers are more sensitive to tectonic uplift. An example can be found in the ancestral Aar river, which was deviated and forced around the uplifting Jura Mountains in Mio-/Pliocene times.

Ti-releasing reactions within biotites: the step from a magmatic precursor to a metamorphic biotite. SEM, TEM and electron microprobe investigations on biotites from the Kellerjochgneiss (Northern Zillertal, Tyrol, Eastern Alps)

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Petrological investigations of the Austroalpine Kellerjochgneiss show a pervasive low-T/high(?)-P metamorphic overprint, which can be attributed to the Eo-Alpine orogeny. Thermobarometric calculations yield pressures ranging from 5.5 to 10.5 kbar and temperatures ranging from 380 to 430°C. Pre-metamorphic minerals present are K-feldspar and albite porphyroblasts and biotite porphyroblasts, which now contain abundant Ti-phases which form grid-like structures (sagenite grid). The Eo-Alpine mineral assemblage is: muscovite + biotite (Ti-poor) + albite + chlorite + quartz ± stilpnomelane.

Investigations with the polarizing microscope, SEM (scanning electron microscope), TEM (transmission electron microscope) and the electron microprobe are conducted on samples from the Kellerjochgneiss and the adjacent, strongly deformed Stengelgneiss. The Ti-phases occuring within or in the vicinity of biotite are rutile, ilmenite and titanite. The presence of titanite also indicates possible reactions involving the addition of Ca by a fluid or through adjacent phases such as plagioclase and/or clinozoisite. The textural investigations of the exsolutions down to the Å-scale within the biotites should help to identify the possible reactions leading to the formation of the Ti-phases within the biotites as well as to identify possible chemical protolith domains within the biotites and determine their compositions.

Textural investigations of biotites with the polarizing microscope, SEM and microprobe show abundant Ti-phases occurring within the biotite porphyroblasts. Most biotites contain rutile needles which occur as sagenite grids. Electron microprobe analysis yields high Ti-contents of biotites of up to 5 wt% TiO_2 due to contamination of the analysis by rutile needles, whereas analyses of biotites outside the areas of the sagenite grids yield lower Ti-contents between 1 – 3 wt% TiO_2.

The TEM investigations of the basal section of biotite crystals also verifies the presence of abundant rutile needles with a spacing of 3.3 Å in the bright filed image. The rutiles are not comprised of one single crystal but insted they seem to form a cluster of small crystals. In addition, the rutiles do not show any structural relation with the biotite so far, at least looking down the c-direction in biotite. AEM (analytical electron microscopy) measurements revealed that the biotites do not change their composition near the areas containing rutile. Due to the high spatial resolution of the AEM analyses, this should also help to identify the exact chemical composition of biotites within the sagenite grid domains without being affected by contamination from adjacent Ti-phases. In some areas, 14 Å-spaced lattice fringes occur indicating that chlorite lamellae also occur inside the biotites. TEM investigations also revealed the presence of not yet identified Fe-oxides within the biotites.

The final goal of these investigations is to identify the mineral inclusions within the biotites, investigate their textural relations and obtaining the uncontaminated chemical analyses of the biotites. Combining these data will set constraints on the chemical substitutions in biotites involving Ti and nature of the Ti-releasing reactions (e.g. oxidation/reduction reaction vs. hydration reaction etc.).

Structural evolution of the Austro-Alpine nappes in the northern Zillertal area, (Tyrol, Eastern Alps)

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In the frame of the TRANSALP project, this investigation addresses the tectonic evolution of the Austroalpine nappes in the northern Zillertal Area (Tyrol). The units to be studied in the course of this investigation are the Kellerjoch Gneiss (Schwazer Augengneiss) and the Innsbruck Quartzphyllite. The Innsbrucker quartzphyllite is part of the Lower Austroalpine units and the Kellerjoch Gneiss is still of debated origin, since it has been attributed over the years to either the Lower- or the Middle Austroalpine units. Both lithological units show an Eo-Alpine metamorphic overprint under low- to high greenschist facies conditions. Thermobarometric investigations in the Kellerjoch Gneiss, by using multi-equilibrium methods yield temperatures of 350 – 430°C and pressures of 5.5 – 10.5 kbar whereas in the Innsbrucker Quartzphyllites pressures are significantly lower and yield 3.5 – 6 kbar for the same temperature range. The two units are separated by relatively small shear zones, ranging from less than a meter in diameter up to several meters diameter. Detailed field mapping of an area of ca. 60 km^2 in the northern Zillertal was performed and the structural data were compared to the previous structural observations of ductile and brittle deformation from these units and also the adjacent units such as the Northern Calcareous Alps (Schmidegg 1964; Roth 1983; Eisbacher and Brandner 1995; Ortner and Sachsenhofer 1996; Steyrer et al. 1996; Kolenprat et al. 1999; Ortner et al. 1999; Reiter 2000; Grasbon 2001). Our observations suggest the following tectonic evolution of the Kellerjochgneiss and the Innsbruck Quartzphyllite: Six stages of deformation could be distinguished in both units whereas the first five stages (D1 – D5) are ductile, and the last stage (D6) took place in the brittle regime. The first stage (D1) is associated with relict deformation structures of a possible Pre-Alpine (Variscan or Permian) event. The second stage (D2) is the result of the NW-SE oriented compression and isoclinal folds and shear bands indicate a transport top to W-NW. The third stage (D3) is manifested through narrow to open folds indicating a NE-SW oriented contraction. The fourth stage (D4) is also characterized by open folds and a penetrative axial plane foliation which is the result of NNW-SSE oriented compression. During the last ductile stage (D5) semi-ductile kink bands form. The structures related to D5 are interpreted to be associated with the beginning uplift of the Tauern Window. The subsequent brittle deformation can also be divided into four stages. The earliest stage is the result of a NW-SE contraction. The following stage is characterized by brittle faults indicating a NE-SW contraction. Faults of the third stage are the result of an E-W extension. The youngest stage is related to a N-S compression. Overall, the obtained deformation sequence is in agreement with the two-stage Alpine geodynamic evolution model of Neubauer et al. (2000).

Eisbacher, G. & Brandner, R., 1995: Geol. Paläont. Mitt. Innsbruck 20, 389-406.

Grasbon, B., 2001: Unpubl. MSc. Thesis, University Innsbruck, 141 p.

Kolenprat, B., Rockenschaub, M. & Frank, W., 1999: Tüb. Geowiss. Arb., 52, 116-117.

Neubauer, F., Genser, J. & Handler, R., 2000: Mitt. Österr. Geol. Ges., 92, 117-134.

Ortner, H., Brandner, R. & Gruber, A., 1999: Tüb. Geowiss. Arb., 52, 192-193.

Ortner, H. & Sachsenhofer, R.F., 1996: EAPG Special Publ. 5.