Symposium
Basement-cover relationships in the Alps: structural, metamorphic, and chronological aspects

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Abstracts of contributions

Thierry Baudin and Didier Marquer (Neuchâtel):

Comparaisons des relations socle-couverture entre les zones internes et externes dans les Alpes centrales (voir p. 453–457 ce fascicule).

Comparison of the basement-cover relationships between internal and external zones in the Central Alps (see p. 453–457 this issue).

Gerhard Bax and Rolf L. Romer (Stockholm, Paris):

Style of basement-cover interaction along the Nasafjäll-Arjeplog section in the Scandinavian Caledonides (see also p. 469–481 and 521–522 this issue).

Two discontinuous chains of basement culminations, which represent antiformal stacks of basement slices, form the backbone of the Scandinavian Caledonides (Fig. 1). Along strike these rows of culminations show a pinch and swell behavior, which indicates thinning or absence of correlative units. These topographic heights are built up by antiformal stacks of basement slices from the former continental margin of the ancient continent Baltica. This continental margin was imbricated during the continental collision between Laurentia (present Greenland and Canadian Shield) and Baltica about 400 Ma ago. Two of the largest culminations of the northern Caledonides are now exposed in huge tectonic windows, the Nasafjäll window (NFW) and the Rombak-Sjangeli window (RSW). The northern margin of the RSW culmination, which is part of the European Geotraverse EU13 (Lofoten-Torneträsk-Malmberget), represents on of the best studied sections of the Scandinavian Caledonides. Detailed field work showed that (1) along the margins of these culminations, the higher nappe cover is cross-folded above large lateral ramps in the underlying imbricated basement, (2) the Caledonian foreland was affected by late-orogenic extension, and (3) mineralizations formed in conjunction with tectonic basement reactivation both in the culminations and in the foreland. We investigated a geologic section across the NFW basement culmination and the corresponding foreland segment to learn whether these features are specific for the EU13 Geotraverse or can also be recognized in other parts of the Caledonian orogen.

The northern margin of the NFW basement culmination coincides with the along-strike northwestward projection of the Lake Hornavan (LH) fault zone, which is geophysically very distinct to the east of the erosional front of the Caledonides. At its northern margin, the NFW is associated, like the RSW, with a swarm of minor tectonic windows in the higher nappe units. The floor thrust of the higher nappes is resting on basement blocks that show an orogen-transverse staircase-pattern with steep faults running slightly oblique to the main-thrusting direction. These faults dip in most cases approximately perpendicular to the dominant southeastward direction of thrusting. The segmented blocks acted as lateral ramps for the overgliding higher nappe units during the latest phases of thrusting. In the NFW

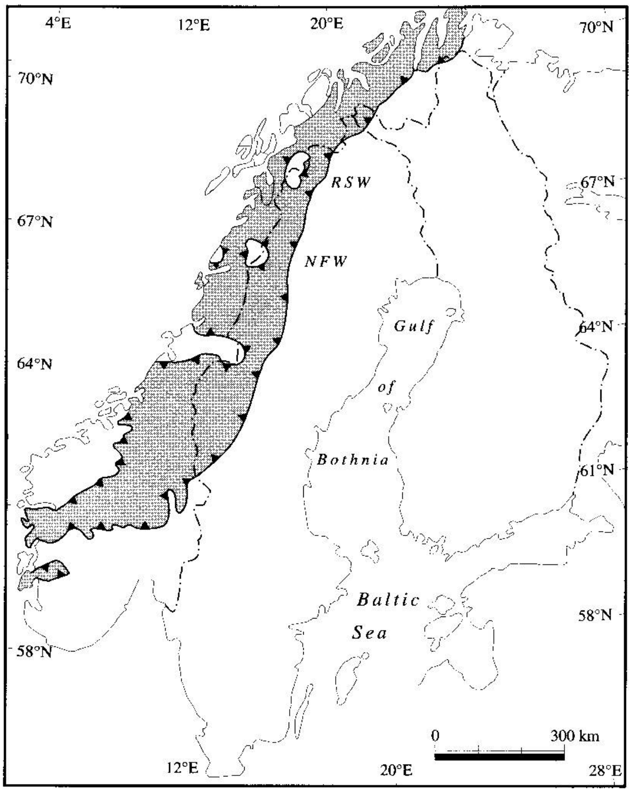

Fig. 1 Scandinavian Caledonides (shaded) with basement culminations.

basement culmination late ductile to brittle faults, which formed during the post-thrusting collapse, are cemented with quartz-calcite-sulfide, quartz-ankerite-sulfide, and calcite-sulfide-fluorite assemblages. Lateral ramps and veins are confined to the margin of the NFW basement culmination. Their proximity to the continuation of the LH fault zone indicated that the orogen-transverse LH structure as active during the latest stages of Caledonian thrusting. In the foreland of the NFW basement culmination, to the east of the exposed thrust front of the higher nappes, occur several erosional remnants of sedimentary basement cover (mainly sandstone) in asymmetric orogen-parallel graben and half-graben structures. Along fault zones that confine these extensional structures the pore space of the sandstones is impregnated with graphite and Pb–Zn sulfides. Fluid circulation in these reactivated fault zones in the basement resulted in the redistribution of lead, zinc, and copper and locally formed mineralizations. Above some basement fault zones occur lead-zinc deposits in the autochthonous sedimentary cover of the basement (e.g., Laisvall, Maiva). At larger distances from such fault zones, the cement of the sandstones consists of calcite and quartz, and there occur no or very minor lead and zinc sulfides.

The section between NFW and the Caledonian foreland exhibits similar features as comparable areas in EU13, which illustrates that basement-cover interaction involving multiple mobilization of old fault zones is an important mechanism for the structural evolution of the Scandinavian Caledonides. The present position and internal structure of antiformal basement stacks and the surrounding nappe piles of the Caledonides is controlled by old sutures in the pre-Caledonian Baltic Shield.

Giuseppe G. Biino (Fribourg):

The mafic-ultramafic rocks of the Helvetic basement: a synthesis.

This contribution presents new data on the stratigraphy, magmatism and metamorphism in the oldest part of the Helvetic basement (Central Alps). These data were collected during the last few years in collaboration with A. Abrecht, M. Meier, Th. Meisel, I. Mercolli, F. Oberli, P. Stille.

The oldest part of the Helvetic basement consists of dismembered oceanic- and detrital continental sequences. The sediments were deposited in an accretionary wedge (Abrecht et al., 1991). An upper Proterozoic oceanic stage is inferred from characteristic chemical and isotopic signatures of some of the mafic and ultramafic rocks (Biino and Meisel, 1994 a, b, 1993). The initial εNd values show the smallest scatter for protolith-ages between 900 and 1000 Ma. Therefore the oceanic stage probably occurred between 1000 and 900 Ma, as already suggested by Stille (1987), Schenk and Stille (1991) for the amphibolites of the Penninic nappes. Later the oceanic crust was transported and accreted onto an active plate margin. The closure of this oceanic domain involved both obduction and subduction. Accretion of the oceanic terranes in a wedge containing continental-derived sediments constrains compressive tectonic along an active plate margin near a Gondwana-like craton. Younger gabbros intruded into the wedge (Abrecht et al., 1991; Biino and Meisel, 1993). The emplacement of these metagabbros represents the next magmatic event. The chemical and isotopic composition for these gabbros are typical of subduction related magmas in island arc (IA) settings. Single-crystal U–Pb ages from abraded zircons in retrograded eclogitized IA gabbros yield ages of ~ 468 Ma (Oberli et al., 1994). After the supra-subduction gabbroic intrusions, the entire terrane experienced several phases of metamorphism.

Textural and structural observations yield information on the relative timing of metamorphic mineral growth and recrystallization. They provide a basis for assessing the significance of P-T data aquired from petrologic calculations. The most important information on the first metamorphic (eclogite facies) event has come from mafic rocks, nevertheless field evidence (intrusive contact between eclogitized metagabbros and paragneiss) strongly support that the whole sequence underwent high pressure metamorphism. An early high pressure assemblage includes lawsonite (Lw) as key mineral phase. The estimated temperature for this event is below 600 °C. Later on, Lw was replaced by a higher temperature eclogite assemblage (in the range of 650–700 °C). A down-P up-T, or isobaric heating (ca. 50 °C) path is responsible for the eclogitic temperature peak assemblage. The stable assemblage at temperature peak is Grt-Omp-Ky-Qtz-Zo-Hbl-Ilm-Mt-Py and Rt. Estimated temperatures and minimum pressures at this stage are 700–750 °C and 1.8 GPa, respectively. The eclogite rocks preserve a rather unique evidence for the pre-relaxed stage of the thermal evolution. The subsequent granulite facies event is characterized by Grt-Di-Opx-Olig-Qtz-Hbl-Ilm-Mt-Py-Tit. This assemblage is observed only at the local equilibrium scale and yields temperatures ranging from 600 to 700 °C and pressure of approximately 0.8 GPa. Advection of the isotherms during rapid uplift was responsible for the granulite event. Subsequent uplift and cooling were accompanied by hydration and partial melting of the metasediments. The minimum age of the migmatitic overprinting is constrained by the post-orogenic intrusion of granitoids ~ 440 Ma old (SERGEEV and STEIGER, 1993). The resulting path reflects the style and rate of unroofing.

In term of regional geology this investigation shows many new features and defines more clearly the role of the already documented granulite event. The presented quantitative results are important in order to understand isotope geochemistry, and they constrain the thermo-tectonic evolution of the region. I concluded that the old geodynamic models considering formation and closure of small intra-cratonic basins has to be abandoned since they are inconsistent with the presented petrologic observations.

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Christian Böhm and Martin Meier (Zürich):

Provenance of the Lucomagno basement nappe: first geochemical and isotopic indications.

The aim of the current study is to unravel the origin and evolution of the Lucomagno basement nappe (LucBN). This requires a geochemical classification and interpretation of these polymetamorphic amphibolite facies rocks. We then want to investigate possible petrogenetic relations of the Penninic LucBN with the Simano nappe and in particular with the Gotthard massif, traditionally considered as Ultrahelvetic.

On the basis of field observations, the following three lithological units in the LucBN can be distinguished: 1) the prevalent metapelitic biotite gneisses and schists (variably garnet, muscovite and hornblende bearing), both including minor hornblende gneiss and amphibolite, 2) metagranitoid bodies which intruded the above units and now form foliation-aligned meta-igneous lenses, 3) layered and banded gneiss of mixed origin (mixed gneiss) which often form transition zones between the metapelitic and meta-igneous rocks. The metagranitoids often have border zones of augengneiss which display diffuse contacts to the surrounding metapelites. As a consequence of strong deformation during the Variscan and Alpine events, distinction of the different lithological units is difficult in the field.

X-ray fluorescence analyses indicate distinct element trends for the different rock types. Particularly TiO_2–SiO_2, Ni–Sr and Cr–Sr variation diagrams, allowing distinction of meta-igneous from meta-sedimentary rocks (e.g., WINCHESTER et al., 1980), show mainly meta-sedimentary distribution patterns for the metapelitic rocks, whereas the metagranitoids plot in the igneous field. Some of the genetically questionable mixed gneisses tend to have an igneous composition, but using the discrimination method of SHAW (1972), all mixed gneisses show sedimentary affinity. Trace elements including REE were determined by ICP-MS. At first glance, REE distribution patterns look quite similar for all rock types and are characterized by highly fractionated REE distributions with pronounced LREE-enrichment (LaN/YbN = 7.1–15.8) and slightly to distinctly negative Eu anomalies (Eu/Eu* = 0.25–0.90). These features are typical for upper crustal rocks and post-Archean shales (TAYLOR and MCLENNAN, 1985). Despite these uniform patterns, the following properties can be discerned: metagranitoid samples show relatively minor total REE concentrations (77–126 ppm) and, on average, higher LaN/YbN ratios (7.8–15.8) compared to metapelitic samples (REE = 137–264 ppm, LaN/YbN = 6.5–13.5). Characteristic for the mixed gneiss are intermediate total REE concentrations and key ratios (REE = 135–169 ppm, Eu/Eu* = 0.48–0.78, LaN/YbN = 7.2–9.1), suggesting probable mixing between sedimentary and igneous sources.

Compared with an average upper crustal La/Sc ratio of 2.7 (TAYLOR and MCLENNAN, 1985), the mixed gneiss and metapelitic rocks generally show similar values ranging from 1.2 to 5.7, whereas metagranitoid La/Sc ratios (4.4–7.7) point to more differentiated rocks. Based on these geochemical data, an upper crustal source for the mixed gneiss and the metapelitic rocks can be assumed. The present association of the lithological units is caused by post-formational tectonic juxtaposition.

The Sr isotopic data scatter for all lithologies, indicating mobile behavior of Sr and especially Rb under amphibolite facies metamorphic conditions. Nevertheless, four metagranitoids define a vague "isochron" of about 320 Ma, which may point to significant Sr reequilibration during the Variscan metamorphic event. However, the Nd isotopic composition displays more ancient signatures and is distinct for the above lithological units: $^{143}Nd/^{144}Nd$ ratios for metagranitoids are significantly higher than for metapelitic samples, depleted-mantle separation model ages are about 1.3–1.4 Ga for the metagranitoids and about 1.54–1.6 Ga for the metapelites. Nd isotopic data for the mixed gneiss display intermediate values with closer affinity to the metapelites. These pre-Caledonian model ages are compatible with upper intercept ages for zircons in the Silvretta nappe (GRAUERT and ARNOLD, 1968) and Gotthard massif (NUNES and STEIGER, 1974) and probably reflect middle- to late-Proterozoic provenances for the main lithological units of the LucBN.

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François Bussy and Jürgen von Raumer
(Lausanne, Fribourg):

U–Pb geochronology of Palaeozoic magmatic events in the Mont-Blanc crystalline massif, Western Alps.

The Mont-Blanc crystalline massif is one of the basement areas of the external domain of the Alpine arc, which was part of the Alpine lower plate during Tertiary orogenic events. Its pre-Mesozoic basement is an updomed tectonic window in the Helvetic nappe pile. It consists of a complex assemblage of polymetamorphic Precambrian to Palaeozoic sediments, interlayered volcanics, ultramafic lenses and granitic bodies of variable age. Its long lasting geological evolution, characteristic of the complex history of the suture zone between Gondwana and Laurasia, is comparable to that of other pre-Mesozoic basement areas of Variscan age outside the Alps (VON RAUMER et al., 1993). U–Pb techniques have been used to put time constraints on the Palaeozoic evolution of this region, mainly through the dating of its magmatic rocks.

The most conspicuous magmatic rocks, besides the Mont-Blanc granite, are coarse-grained, calc-alkaline K-feldspar augengneisses accompanied by rather homogeneous looking, fine-grained acidic gneisses of identical chemical composition. These gneisses outcrop as long and narrow bodies parallel to the main schistosity of the polymetamorphic basement and are interpreted as the products of Lower Palaeozoic magmatic activity. The coarse-grained facies yields a concordant crystallization age on zircon of 453 ± 3 Ma with an upper intercept at 1196 ± 40 Ma. These augengneiss underwent partial fusion along pervasive dextral N10 strike-slip zones. The corresponding mobile anatectic melts appear as crosscutting dykes of fine-grained granite, dated at 317 ± 2 Ma using monazites. N10 structures are cut by the highly deformed Montenvers peraluminous granite, whose zircons yield an age of 307 +6/–5 Ma. The subsequent intrusion of the Mont-Blanc granite (Bussy, 1990; Bussy et al., 1989) is dated at 304 ± 3 Ma using zircons, while adjacent cogenetic rhyolites yield a concordant crystallization age on zircon at 307 ± 2 Ma and an upper intercept at 639 ± 30 Ma.

These results provide new constraints for a general Palaeozoic evolution model of the Mont-Blanc massif, based on structural and metamorphic studies. The following scenario is proposed:

(1) *late Proterozoic / early Palaeozoic*: terrigenous sedimentation in an extensional regime;

(2) *Ordovician:* crustal shortening and subduction of a lateral oceanic crust, calc-alkaline magmatism (450 Ma);

(3) *Silurian / early Devonian:* first stages of collision and formation of large-scale nappes, kyanite-bearing assemblages in metapelites and mylonites;

(4) *Devonian / Dinantian:* rising geothermal gradients, formation of mineral assemblages with sillimanite-cordierite. High erosion rates in an uplift context with detrital sediments accumulated in transtensional basins, major dextral strike-slip zones;

(5) *Upper Carboniferous:* partial fusion (317 Ma), mobilization of peraluminous melts along major strike-slip zones (307–313 Ma). Intrusion of alkali-calcic melts from deeper crustal- to subcrustal levels (304–307 Ma) along the same tectonic discontinuities, pull-apart and/or transtensional basins with detrital sediments and volcanics.

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G. Capponi and L. Crispini (Genova):

Structural evolution of the metasediments of the Voltri Group (Ligurian Alps).

This poster shows a brief description of the ductile and brittle – ductile structures linked to the last stage of the Alpine evolution in the Voltri Group (Ligurian Alps). We discuss their geodynamic implications with particular emphasis to the extensional phases; the structural evolution is particularly referred to the southeastem margin of the massif.

The metasediments of the Voltri Group show a non-coaxial deformation history, deleveloped within an overall shear regime. Though the ductile stuctural evolution can be regarded as a progressive deformational event, nevertheless we can recognize and divide different superimposed steps. While folds and foliations related to the HP-LT events are present only as relics in preserved domains, the structures related to greenschist facies (GF) conditions have a wider occurrence and are extensive at the regional scale. The earlier GF deformations (F1 and F2) are characterized by tight to isoclinal shear folds, with a pervasive schistosity, parallel to the axial plane. The usual interference pattern between the two phases is a type 3 after Ramsay.

Extensional crenulation cleavages or shear bands, asymmetric boudinage, and other extensive features deform the Fl-F2 folds and give useful constraints as kinematic indicators.

The next step of the progressive deformation is a stage of megaboudinage with the same sense of shear, which deforms the regional schistosity and the other structures. A third folding stage is represented by gentle to open parallel folds, developed by flexural slip/flow; they show no associated pervasive schistosity and only a spaced disjunctivc cleavage is sometimes present.

Brittle-ductile shear planes cut all the previous structures. They have been recognized at the outcrop scale but are associated with more extensive thrusts and can be divided in compressional and extensional elements. The compressional thrusts are older and are W–NW vergent; the extensional ones are E–SE vergent and often re-use the older compressional planes.

L. Crispini (Genova):

Microstructure and fabric analysis of some quarzites from the Voltri Group (Ligurian Alps): quartz c-axis differences between porphyroclasts and recrystallized grains.

We performed an integrated microstructural (c-axis) analysis, shape and strain–analysis and petrofabric study on quartzites belonging to a metamorphic sequence of pre-Piemontese affinity, associated to the Voltri group (Ligurian Alps).

We have found a good correlation between the patterns of c-axis fabrics and the symmetry of the strain ellipsoid (flattening strain) for the detrital quartz grains. The c-axis fabric of syntectonically recristallized quartz grains (small circle girdles centered about the Z-axis) is different from the c-axis fabric of the old deformed grains (type I vs type II crossed girdles). We discuss these results taking in account the influence of recrystallization, plastic deformation and the presence of microshear bands.

J.-L. Epard and A. Escher (Lausanne):

Transition des déformations du socle à celles de la couverture: modèle géométrique.

Deformation transitions from basement to cover: geometric model.

Les Alpes de Suisse occidentales montrent principalement deux types de nappes (ESCHER et al., 1993):

a) les nappes-plis de socle et de certaines couvertures, formées par cisaillement simple hétérogène, dans des conditions métamorphiques permettant la déformation ductile des roches;

b) d'autres nappes de couverture (p. ex. Préalpes, Jura), limitées à leur base par une zone de cisaillement de faible épaisseur et formées à des pressions et températures plus basses.

Ces deux systèmes de nappes peuvent être liés, le socle formant un grand pli couché d'amplitude pluri-kilométrique (nappe-pli) et, simultanément, la couverture étant décollée et translatée. Il faut alors que le mouvement reparti au travers d'une large zone de cisaillement dans le socle soit transféré sur un niveau de décollement d'épaisseur faible à très faible. Du point de vue géométrique, il y a donc une transition ductile/cassant qui est la clé de la compréhension des relations socle-couverture. Ce problème géométrique, bien décrit par RAMSAY (1980), n'a pas trouvé de solution satisfaisante. Le modèle géométrique simple, présenté ici, tente d'expliquer les relations géométriques et cinématiques des déformations dans le socle et la couverture. Il est basé sur la différence de comportement rhéologique entre un socle subissant une déformation ductile, de type cisaillement simple et une couverture, plus rigide qui se déforme principalement par glissement couche sur couche. Il résulte de cette différence de comportement que la quantité de raccourcissement produite au niveau du socle par le cisaillement n'est pas entièrement absorbée dans la couverture, impliquant un mouvement relatif entre ces deux niveaux structuraux (cf. figure). Ce modèle peut être appliqué à certaines nappes des Alpes.

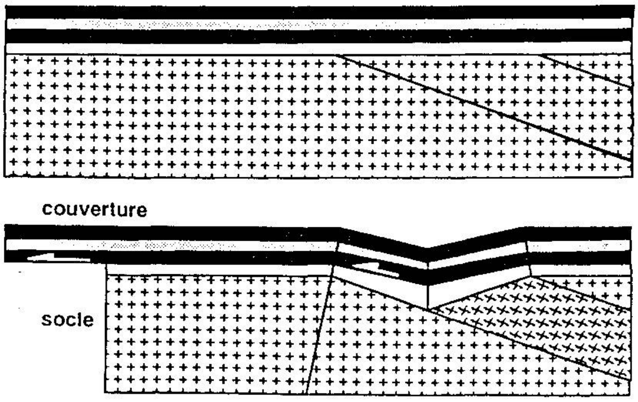

Fig. 1 Nappe geometry in the Swiss Alps.

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Nikolaus Froitzheim and Stefan M. Schmid (Basel):

Relations between cover nappes, basement nappes, and deep structure along the Alpine transect of eastern Switzerland.

Geophysical investigations in connection with NFP-20 and the EGT traverse primarily offer new constraints for the deep structure of the Alps but also provide new insight concerning the geometry of shallow crustal structures. These geophysical data, combined with recent field work, led to the compilation of a N–S section along which basement-cover relationships will be discussed.

The Austroalpine nappe pile formed in Cretaceous times and constituted a rigid orogenic lid during Tertiary orogeny. The basement-cover relations in the Austroalpine nappes reflect extensional faulting during the *Jurassic rifting* phase of the Apulian passive continental margin. These extensional faults predetermined the localization of Cretaceous thrust faults. Anomalous thrust geometries (younger-on-older thrusting) resulted from interference of Cretaceous low-angle thrusts with Jurassic high-angle normal faults. The basement-dominated Bernina nappe, characterized by very thin cover synclines separating basement sheets, originated directly from the outer basement high of the passive margin. In the distal part of the margin (Err nappe), tectonic basement-cover contacts were formed by low-angle detachment faulting, related to simple-shear opening of the South Penninic ocean in the Middle Jurassic.

Imbrication of the nappe pile in the *Cretaceous orogeny* was followed by exhumation during a late Cretaceous extensional event. Both these Cretaceous events are associated with predominantly E–W-directed transport, hence the kinematics of these early phases are unrelated to the structures visible in a N–S section. During Late Cretaceous extension large basement units were stretched by discrete normal faulting while previously inclined sedimentary nappe units were vertically shortened by folding. The deep structure during Cretaceous orogeny remains unknown, since only the upper parts of a former Cretaceous orogen are preserved above the base of the Eocene orogenic lid situated below the Platta oceanic unit.

Eocene collision is associated with accretion of the following elements to the orogenic lid: (1) relatively thin (48 km) flakes of continental crust (European margin and Briançonnais) forming the basement nappes of the Penninic domain, (2) parts of the Briançonnais platform sediments devoid of any preserved basement equivalents (Schams, Falknis-Sulzfluh), and, (3) impressive volumes of calcareous shales (S-Penninic Avers and N-Penninic Bündnerschiefer), again devoid of their original basement (deduced to be predominantly of oceanic nature). However, the volume of continental crust of the Briançonnais domain was very severely reduced already during passive margin formation when the mid-Penninic rise occupied an upper plate margin position both in respect to the Piemont-Liguria and the Valais oceanic domain. Even so, a considerable volume of upper and lower continental crust must have been subducted without subsequent exhumation.

The geometry and kinematics of post-nappe folding and vertical shortening starting in early *Oligocene* times is strongly governed by basement-cover competency contrasts. The kinematics of late Oligocene backthrusting and dextral strike slip movements in the vicinity of the Insubric line is controlled by the high strength of the Ivrea lower crustal and mantle material, largely exhumed already during passive margin formation. Thrusting of the Helvetic cover nappes is synchronous with movements along the Insubric line and late Oligocene E–W extension in the Pennine nappes. The former basement of the Helvetic nappes is accreted to already detached higher Penninic nappes below the Pennine frontal thrust.

While the present-day geometry of the Penninic domain was largely established by the end of the Oligocene, ongoing convergence resulted in *Miocene* deformation restricted to the N and S foreland near the earth's surface. At depth, bivergent foreland tectonics is kinematically linked with the indentation of a wedge of Apulian lower crustal material. Ongoing S-directed subduction of European upper and lower crust produced local failure within the foreland regions, leaving the Penninic domain largely untouched.

Véronique Gardien, Didier Marquer and Francis Persoz (Neuchâtel):

Metamorphic evolution of the lower crust during lithospheric extension: the example of the Valpelline series (Western Alps), (see p. 489–502 this issue).

Luzi Hitz und Adrian Pfiffner (Bern):

Die Tiefenstruktur des Sediment-Kristallin-Kontakts in Mittelbünden: Geologische Projektionen und seismische Daten (siehe p. 405–420 in diesem Heft).

Sediment-basement contact in central Grisons: geological projections and seismic data (see p. 405–520 this issue).

Eva M. Klaper (Bern):

Microstructural evolution of the Arolla gneiss, Austroalpine Dent Blanche Nappe, Western Switzerland.

The Austroalpine Dent Blanche nappe is the highest tectonic unit in western Switzerland / northern Italy and overlies the south-Penninic ophiolite and schistes lustrés units of the Tsaté nappe (part of the former Combin zone) and Zermatt-Saas zone. The Arolla Series, an equivalent of the Sesia zone, forms the topographically lower part of the nappe in its Swiss sector and includes mainly orthogneisses of granitic to granodioritic composition. These rocks have been variably deformed during nappe emplacement (D1) and subsequent folding (D2) and crenulation (D3) under Tertiary (Lepontine) greenschist-facies conditions. Deformation is most intense at the base of the nappe and decreases towards its interior.

Strongly correlated with the intensity of deformation is the amount of metamorphic mineral growth and the intensity of dynamic recrystallization. In the little deformed rocks, primary magmatic minerals (hbl, bi, kfs, plg, qtz) or their metamorphic pseudomorphs (act, ep, chl, ab) are still recognizable. A striking feature is the extensive albitization of K-feldspar and plagioclase mainly during D1. Progressive deformation destroys the primary or pseudomorphic fabrics and leads to a considerable decrease in grain size accompanied by further mineralogical changes. K-feldspar always behaves brittly under the prevailing metamorphic conditions. Plagioclase behavior is also predominantly brittle if the mineral is not decaying into saussurite and albite, a process which favours local, cm-scale metamorphic differentiation. Occasionally, the onset of bulge recrystallization of plagioclase can be observed. Primary quartz is often elongated, showing strong undulous extinction and deformation bands before it begins to recrystallize dynamically along the grain boundaries. The dominant mechanisms of quartz recrystallization are bulge recrystallization and subgrain rotation forming core-mantle structures.

Didier Marquer and Martin Burkhard
(Neuchâtel):

Circulations fluides, transferts de matière et déformation progressive dans la croûte supérieure: exemple des relations socle-couverture dans les massifs cristallins externes (Alpes centrales suisses).

Fluid circulation, mass transfer, and progressive deformation in the upper crust: example of basement-cover relations in the external crystalline massifs (Swiss Central Alps).

Le domaine externe des Alpes suisses est composé d'une couverture sédimentaire (représentée par une série à dominante carbonatée, continue du Permien au Tertiaire) et d'un socle cristallin pré-alpin (Massifs cristallins externes), composé essentiellement d'anciennes roches cristallines et de granites varisques. Ces unités ont subis une déformation ductile tertiaire dans les conditions métamorphiques du faciès schistes verts (300–450 °C; 3–4.5 kb). Dans cette partie de la croûte superficielle (10–15 km), l'évolution des circulations fluides et les transferts de matière sont étudiés dans ces deux unités de composition

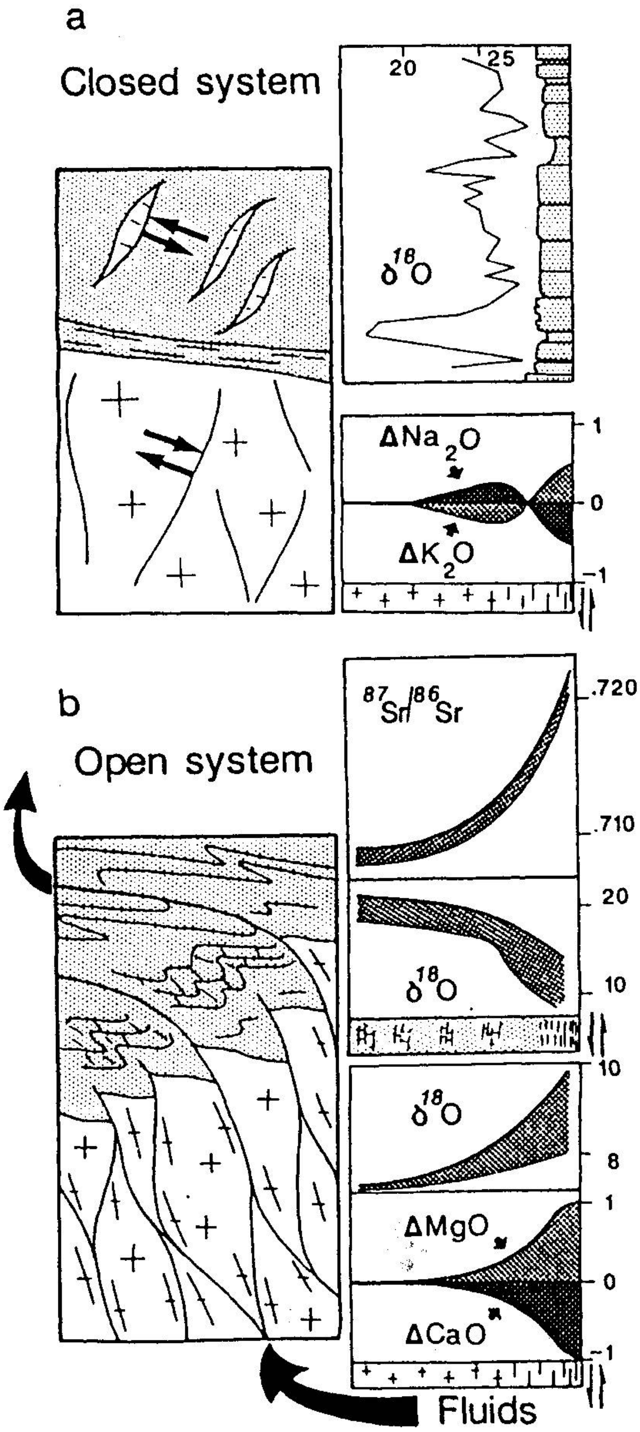

Fig. 1 Les relations socle-couverture: schéma de l'évolution des transferts de matière, des circulations fluides et de la déformation progressive dans la croûte supérieure. (a) Initiation des instabilités mécaniques dans le socle et la couverture. (b) Propagation de la déformation et création d'un réseau anastomose de discontinuités structurales permettant la circulation des fluides entre le socle et la couverture.

géochimique contrastée. L'origine et l'importance des fluides interagissant avec le socle et la couverture sont abordés par l'utilisation des variations de composition des isotopes stables de l'oxygène. Les résultats des profils de variation des éléments chimiques le long de structures majeures (veines, zones de cisaillement, chevauchements) permettent de différencier deux types de comportement:

(i) Système fermé: dans la couverture Helvétique, aucune modification de $\delta^{18}O$ n'est associée à la formation des veines syntectoniques. Les variations de $\delta^{18}O$ reflètent les hétérogénéités chimiques initiales de chaque niveau sédimentaire. Dans les zones de cisaillement des granites, les teneurs en Na_2O montrent des augmentations (orthogneiss) puis des diminutions (mylonites) sur le même profil de déformation. Un comportement antagoniste est établi pour les teneurs en K_2O. En d'autres termes, pour certains oxydes, les gains et les pertes de matière sont compensés sur un même profil de variation.

(ii) Système ouvert: les profils de variation dans la couverture mylonitique montrent une augmentation continue du rapport $^{86}Sr/^{87}Sr$ et une diminution de $\delta^{18}O$ jusqu'à des valeurs proches de celles des mylonites du socle. Dans les zones de cisaillement des granites, la diminution de CaO et les augmentations de MgO et de $\delta^{18}O$ sont également continues sur les profils de variations chimiques.

Un modele couplant la tectonique et la géochimie est proposé pour rendre compte des relations socle-couverture dans la croûte continentale superieure: (i) L'initiation et la propagation des instabilités mécaniques sont responsables de l'évolution progressive des instabilités chimiques en système fermé. (ii) Avec l'augmentation de la déformation, le réseau de zones de cisaillement interconnectées prend de l'importance et permet la circulation des fluides et les transferts de matière en système ouvert. Les sources probables de fluide et les mécanismes de transport des éléments chimiques sont discutés.

Franz Neubauer (Graz):

Basement-cover relationships in the Eastern Alps: significance for Variscan geodynamics and Alpine tectonics.

Relationships along the contact between prelate Carboniferous basement and Late Paleozoic to Mesozoic cover sequences display variations both in nature, intensity and timing of pre-Alpine tectonometamorphic overprint on the basement complexes, as well as in Alpine structure along this post-Variscan disconformities (see VON RAUMER and NEUBAUER, 1993, for compilation of previous data).

The Penninic Tauern window exposes a plutonometamorphic complex basically formed between ca. 330–310 Ma with older, frequently calkalkaline and younger minor alkaline suites.

In contrast, based on new Rb–Sr and $^{40}Ar/^{39}Ar$ mineral data, a section through the eastern portions of the Austroalpine nappe complex exposes from footwall to hangingwall: 1) A supposed Early Paleozoic accretionary wedge with a Devonian high-pressure metamorphic overprint within the Wechsel unit; 2) early Carboniferous plutonometamorphic complex within the Lower Austroalpine Raabalpen and the Middle Austroalpine units within which 360–340 Ma old I-type granitoids may reflect subduction-related processes and ca 345–330 Ma old granites together with high temperature metamorphism may record collisional processes; 3) a Silurian/Devonian metamorphic complex in a lower level, and a Visean to Westfalian nappe complex in upper levels within Upper Austroalpine units with imbricates of a Silurian/Devonian rift and passive continental margin system. The latter unit extends into the Southalpine unit. In consequence, a major Variscan suture is supposed to exist between the future Upper Austroalpine nappe complex and plutonometamorphic complexes of other Austroalpine, respectively Penninic units. The entire cross-section is interpreted to record a two-step Variscan terrane accretion and subsequent collision of Gondwana-derived terranes along southern sectors of Central European Variscides.

Within central portions of the Eastern Alps, only the Austroalpine unit displays strong internal imbrication due to Alpine thrusting. Basic features of eastern sectors of the Austroalpine nappe complex in respect to the basement-cover boundary are: 1) Northwest-directed climbing of basal thrusts through the stratigraphy from the basement to the cover; 2) detachment of all cover formations younger than Middle respectively Late Triassic. These detached units most likely accumulated within northern portions of the Northern Calcareous Alps; 3) systematic increase of Cretaceous metamorphic overprint from greenschist facies in the north to amphibolite facies in the south within the Raabalpen and Middle Austroalpine units.

In consequence, Alpine thrusting may have been resulted from footwall propagation of thrusting which likely reactivated pre-Alpine structural boundaries between distinct basement units. Alpine metamorphic overprint is explained to result from loading by an orogenic wedge beneath a late Jurassic ophiolitic suture. Alpine metamorphic overprint extends into the Southalpine unit of the Eastern Alps within which low grade metamorphic conditions were reached at the basement-cover boundary.

Within Austroalpine units, the present shape of the nappe stack resulted from Late Cretaceous reactivation of major thrust surfaces as ductile low angle normal faults which operated subperpendicular to the supposed contractional direction.

VON RAUMER, J. and NEUBAUER, F., eds (1993): Pre-Mesozoic geology of the Alps. Springer-Verlag, Heidelberg.

Felix Oberli, Martin Meier and Giuseppe G. Biino (Zürich, Fribourg):

Time constraints on the pre-Variscan magmatic/metamorphic evolution of the Gotthard and Tavetsch units derived from single-zircon U–Pb results (see p. 483–488 this issue).

Adrian Pfiffner (Bern):

The basement-cover contact: a useful tool for the analysis of the structure and deformation of the upper crust in the Alps.

In the course of the Alpine collision crustal shortening lead to a stack of crystalline basement nappes which represent flakes of upper crust peeled off their substratum. Much of the crustal shortening was accomplished by thrusting and imbrication within the upper crust, associated with subduction of lower crust. But pervasive, partly post-nappe deformation modified the internal structure and geometry of the basement nappes considerably. Quantitative shortening estimates can be obtained by restoring the Triassic quartzites overlying basement. The absence of these quartzites – if not primary – can be due to Jurassic or Tertiary normal faulting and must be carefully assessed by detailed mapping.

The response of the basement rocks (and the overlying sediments) is best depicted by the 3D geometry of the basement-cover contact and depends on the p-T conditions prevailing during deformation. At modest metamorphic grades, folding and faulting occur hand in hand at various scales. The resulting large scale structures resemble seemingly simple recumbent folds, while deformation at smaller scale occurred on more discrete shear zones and surfaces.

In the case of the central Aar massif a major thrust fault defines a crustal flake of at least 10 km thickness and resulted in a large scale antiformal structure with a vertical relief of ca 5 km. Smaller scale thrust faults and folds affect the basement-cover contact typically at the 1–3 km scale.

At higher metamorphic grades ductile overprint modified or even obliterated earlier, more brittle reactions, often giving the false impression that folding alone was the dominant deformation style. Detailed mapping of the basemet-cover contact in the Suretta nappe, for example, revealed that Jurassic breccias directly overly cristalline basement, which points to Jurassic extensional faulting. But also the early Tertiary compression produced both, thrust faults and folds. Basement slices here have restored thicknesses of 4 (Suretta nappe) to 8 km (Tambo nappe).

Pascal Philippot (Paris):

Fluid-melt-rock interaction in crustal eclogites and coesite-bearing metasediments: constraints on volatile recycling during subduction.

The question as to whether the metasomatizing-slab agent needed to form island-arc magmas is an aqueous fluid or a hydrous melt requires a knowledge of fluid-melt-rock interaction during high-pressure / low-temperature metamorphism. In order to document the devolatilization/melting behaviour of a representative subducted slab component, microstructural, isotopic and fluid inclusion analyses have been performed in two natural examples from the Western Alps: 1) Typical omphacitc/garnet-bearing mafic eclogites from the Monviso metaophiolitic complex that have equilibrated at a minimum pressure of 1 GPa for a temperature of 450–550 °C. This example can be considered as representative of an average oceanic crust composition (basalt system). 2) The coesite-bearing metasediments of the Dora-Maira Massif which equilibrated at 3.0–3.5 GPa and 700–800 °C. These highly-magnesian rocks are not diagnostic of an average subducted sedimentary component but provide constraints on fluid flow processes in high-grade blueschist rocks to be extrapolated to an average subducted sediment composition.

In the Monviso eclogites, 90% of the fluids were released at pressure ≤ 1 GPa. During eclogite facies metamorphism, crystal plastic flow processes liberated a low salinity aqueous brine (0.3 weight %) that went into in situ formation of omphacite veins. Continuous fluid redistribution on a cm-scale during successive episodes of brittle/plastic deformation modified the salinity, composition and isotopic imprint of the fluid phase, but the fluid phase retained the host rocks.

In the Dora-Maira pyrope-quartzites, most of the fluids were released prior to 1.6 GPa. With increasing pressure and temperature, prograde dehydration reactions released a low-salinity aqueous brine containing minor amounts of CO_2. Partial melting and crystallization of dense hydrous silicates (ellenbergerite) absorbed water out of this dehydration fluid phase and leaved a highly-saline residue in the host pyrope-quartzites, but the fluids did not escape the host rocks nor was an external fluid introduced into the system.

The anhydrous nature of most eclogites (basalt composition at > 1 GPa) suggests that large amounts of oceanic crust water are released prior to 15 ± 10 km depths in subduction zones. In that respect, the Monviso eclogites can be considered as representative of the degree of hydration of the oceanic crust at depths greater than ca 40–60 km. Segregation veins containing material (including hydrous minerals) derived from their adjacent wallrock are abundant in all types of eclogitic and high-grade blueschist rocks from the European Alps. This suggests that the style of fluid flow processes described in the Monviso eclogites could occur in most mafic eclogites.

Tectonic erosion at modern convergent margins delivers large amounts of terrigenous sediments (KMASH system) in subduction zones. In contrast to the basalt and peridotite systems, the KMASH system is characterized by a wide range of pressure-sensitive reactions which allow the reconstruction of dehydration/hydration depths in the subducted slab. Terrigenous sediments will begin to melt at pressures lower than 2 GPa, independent of the thermal structure of subduction zones. The melt phase can absorb enormous quantities of water and represent major sinks for devolatilization fluids. Dense hydrous silicates (sudoite, Mg-carpholite, Mg-chloritoid, Mg-staurolite, K-cymrite...) will form in many subducted sediments at all depths. These silicates can store significant amounts of water in their structure and represent important fluid reservoirs. This suggests that the style of fluid behaviour documented in the Dora-Maira coesite-bearing metasediments could apply to most, if not all, subducted metasediments.

Accordingly, it is suggested that at sub-arc depths (50 ± 10 to 80–150 km) and for any geothermal gradient, continuous internal buffering of volatile activities will retain the fluid phase in the subducted slab. This is in contrast with shallow, sub-forearc depths (20 to 50 ± 10 km), where tectonic vein arrays, localized thrust faults, serpentine diapirs, mud volcanoes and boninite magmas attest to the release of large volume of fluids into the overriding mantle wedge. The 50 ± 10 km depth level, which has long been recognized as a major rheological boundary by seismologists, could be the site of a major change in fluid flow behaviour as well. Some geodynamic consequences at convergent margins are discussed.

Rolf L. Romer and Gerhard Bax, G.
(Paris, Stockholm):

Basement-cover interaction: examples from the Scandinavian Caledonides (see also p. 469–481 and 511–512 this issue).

The structure of the underlying basement controls to a high extent the lithologic, metamorphic, and deformational evolution of the cover-rocks. This nicely illustrated in the deeply eroded Scandinavian Caledonides (Fig. 1) that form a more than 1500 km long mountain range along the northwestern margin of Scandinavia. The Scandinavian Caledonides are part of the Caledonian-Appalachian orogen, which had an extension of more than 5000 km along strike before the opening of the North Atlantic during the Tertiary. The structural pattern of the Caledonides is dominated by two discontinuous chains of basement culminations. The culminations are controlled by old, reactivated structures in the basement. The basement to the east of the Caledonides is dominated by two sets of fault zones. One set of faults strikes at a high angle to the orogen. These faults continue into the orogenic belt and coincide with the northern and southern margins of the basement culminations. The other set of fault zones strikes parallel to the orogenic belt and the alignment of the basement culminations (Fig. 1).

Field data from the Rombak-Sjangeli basement culmination demonstrate that fault zones in the basement were reactivated during (1) the crustal extension before the orogeny, (2) the compressional phase involving the thrusting of the nappes and the post-collisional deformation of the basement, and (3) the final orogenic collapse. Reactivation of old fault zones during crustal extensional, which resulted in the Iapetus opening, is illustrated by lateral facies variations in the sedimentary cover of the deeply eroded basement. Especially indicative are local olistostromes, which are related with fault zones, in otherwise mature clastic sediments and abundant mafic dikes. As mafic dikes only occur in a few fault-bound crustal blocks, but are lacking in ad-

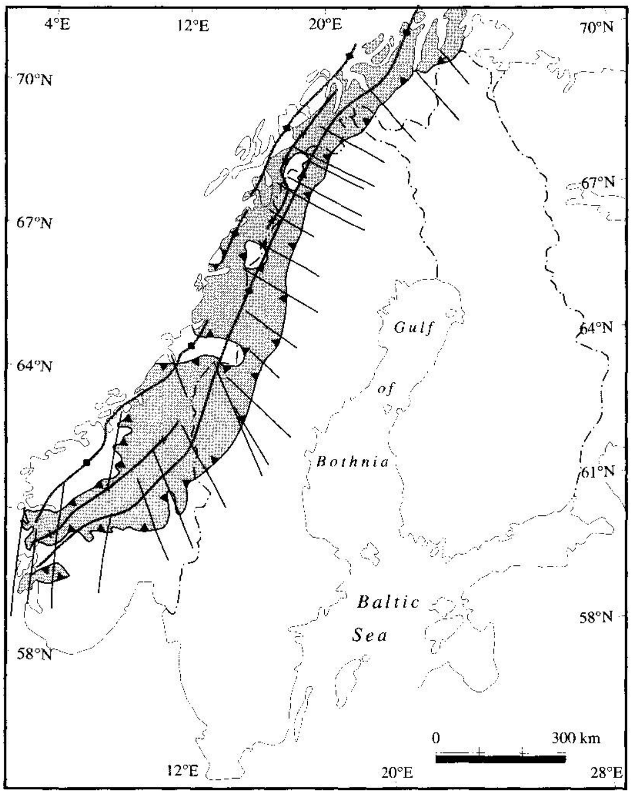

Fig. 1 Scandinavian Caledonides (shaded) with orogen-parallel and orogen-transverse lineaments.

jacent blocks, their geographic distribution implies that fault zones delineating the areas with such mafic dikes were active during the crustal extension and dike emplacement. The syn-thrusting reactivation of the basement is demonstrated by "beheaded" basement horsts. Such horsts represent sheared-off basement slices that were transported at the base of the overlying tectonostratigraphic unit. Post-collisional basement deformation resulted in a more intense deformation of the basement and a decreasing translation of the nappes. Basement highs were no longer sheared-off, but assembled to large culminations. Structurally, these culminations consist of a series of stacked basement slices that form an antiformal stack. The culminations are bordered by orogen-transverse fault zones that can be traced southeastwards into the foreland. During several phases of he Caledonian orogeny, single basement blocks were tilted around axes perpendicular to the direction of main compression. Basement segments that were lifted towards the hinterland are now characterized by antiformal stacks of basement rocks, as the rotation allowed for locally deeper thrusting levels on these segments. The overlying nappes developed lateral-ramp folds at the margins of these stacks. Subsequent to collision and convergence of the continental blocks Baltica and Laurentia, orogenic collapse resulted in extensional brittle failure along the same structures that were used during earlier phases of basement reactivation. Some of these collapse-related faults are extensively filled with vein quartz whereas others host galena-sphalerite-calcite-fluorite mineralizations.

Comparison of (1) the pattern of the Caledonides and their eastern basement on a large scale as well as comparison of (2) the lithology, deformational style, and metamorphic evolution on both sides of orogen-transverse lineaments on a small scale demonstrate that the reactivation of old basement structures during the Caledonian orogenic cycle strongly influenced the lithological, deformational, and metamorphic evolution of the overlying (and overthrust) cover rocks. The Scandinavian Caledonides overlie from north to south Archaean (ca 2.7 Ga), Svecofennian (ca 1.9–1.8 Ga), and Sveconorwegian (ca 1.2–0.9 Ga) crust, respectively. Each basement segment is characterized by its own distinctive, old, multiply reactivated fault pattern. In the overlying Caledonian nappes orogen-parallel and orogen-transverse structures change their attitudes across the transition zone between adjacent basement segments. Thus, as a direct result of the reactivation of old structures in the basement during the Caledonian orogenic cycle, the Caledonian nappes inherited the structural pattern of the underlying basement.

Mario Sartori (Genève):

Relations socle-couverture dans les nappes penniques supérieures: aux limites de la méthode?

Basement-cover relationships in the higher Penninic nappes: limits of the methods?

Sur la transversale des Alpes nord-occidentales, les unités penniques moyennes, issues du domaine paléogéographique briançonnais, montrent des relations socle-couverture relativement claires. Les critères qui permettent de rattacher les Préalpes médianes plastiques et rigides aux socles de la nappe du Grand St-Bernard sont:

– la reconnaissance des niveaux de décollement (base du Trias moyen et/ou supérieur);

– la complémentarité des séries stratigraphiques décollées (bien datées dans les Préalpes) et des téguments;

– la présence de séries témoins restées solidaires des socles.

Ce fil conducteur se perd au passage pennique moyen / pennique supérieur (nappes du Mont-

Fort et du Tsaté). Le niveau de décollement préférentiel des couvertures mésozoïques devient la base des quartzites du Trias inférieur, à l'exception de la couverture autochtone de la nappe du Mont Fort formant un tégument de Trias moyen qui pourrait constituer la patrie de la nappe de la Brèche. Les autres unités en position internes ne trouvent plus d'équivalents dans les Préalpes et leur stratigraphie n'est que partiellement élucidée.

Pour ces lambeaux très étirés de couverture mésozoïques associés intimement aux schistes lustrés de la nappe du Tsaté (nappes des Cimes Blanches et du Frilihorn (ESCHER et al., 1993) à l'est; unités de La Meina et de Berthé (ALLIMANN, 1990) à l'ouest) la trajectoire des déformations alpines semble bien plus complexe. Elle comprendrait:

– le décollement, la translation et la mise en place (synsédimentaire?) dans un bassin de flysch en cours de tectonisation au Crétacé;

– l'implication dans une structure d'extension majeure qui aurait affecté ce premier bâti alpin crétacé au Crétacé-supérieur-Paléocène (MERLE et BALLÈVRE, 1992);

– la translation principale et la mise en place de cet ensemble «Tsaté» en substitution de couverture sur les unités du pennique moyen a l'Eocène-Oligocène (ESCHER et al., 1993);

– la déformation polyphasée ductile à cassante des contacts de nappes durant le Néogène (SARTORI, 1987).

Les socles susceptibles d'avoir porté ces couvertures (p. ex. Mont-Rose, Sesia-Dent Blanche) ont pour leur part subi un enfouissement considérable pendant le Crétacé et évolue très loin et très différemment d'elles. L'utilisation des critères simples de reconnaissance des relations socle-couverture devient donc hasardeux.

L'existence de filons basaltiques recoupant certaines de ces séries sédimentaires (unité du Gornergrat, unité du Monte de la Preja (JABOYEDOFF, 1986) offre néanmoins la perspective d'exploiter un autre type de critères permettant une filiation socle-couverture.

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SARTORI, M. (1987): Structure de la Zone du Combin entre les Diablons et Zermatt (Valais). Eclogae geol. Helv. 80/3, 789–814.

Gregor Schönborn (Neuchâtel):

Different basement-cover relationships in the southern Alps: faulted, detached, or undisturbed (see p. 421–436 this issue).

Marc Schürch (Basel):

Strukturelle Entwicklung der Dent-Blanche-Decke bei Zinal (Wallis).

Structural evolution of the Dent-Blanche nappe at Zinal (Valais).

Die Arolla-Serie der Dent Blanche-Decke bei Zinal zeigt keine prä-alpine Deformationsstrukturen. Die Gneise, Granodiorite und Gabbros der Arolla-Serie zeigen aber oft primärmagmatische Relikte (Stoffbänderung, Mingling), die im Zusammenhang mit der Entstehung der einzelnen Intrusionskörper stehen (Mont-Collon-Gabbro 248 Mio. J.).

Als eo-alpine Bildungen werden die Kalifeldspat-Muskowit-Quarz-Aplite angesehen, die in einer frühen, alpinen Extensionstektonik in das Kristallin der Arolla-Serie eingedrungen sind. Die Aplite können nicht während der Decken-Überschiebungsphase D_1 entstanden sein, da sie von D_1 überprägt werden.

Die Deckenüberschiebungsphase D1 bildet eine penetrative, schichtparallele Stoffbänderung S_0 (helle Quarz-Hellglimmer-Bänder einerseits und dunkelgrüne Chlorit-Epidot-Hellglimmer-Quarz-Bänder andererseits), die nahe der Basisüberschiebung der Dent-Blanche-Decke subparallel zur letzteren ist. Die Stoffbänderung S_0 charakterisiert sowohl die Gneise der Dent-Blanche-Decke als auch die Bündnerschiefer der Tsaté-Decke. Die Faltenachsen FA_1 sind ca. 180/15 orientiert. In den isoklinalen, flachliegenden Falten (cm-Bereich) entsteht eine Achsenebenenschieferung AE_1. In den nicht verfalteten Zonen sind S_1 und AE_1 identisch und subparallel zur Stoffbänderung S_0. Die Einregelungs- und Streckungslineationen fallen flach nach S oder flach nach SSE ein. D_1 ist mit der ersten alpinen Deformationsphase von MAZUREK (1986) und SARTORI (1987) vergleichbar.

D_2 verfaltet durch Grossfalten die Basisüberschiebung der Dent-Blanche-Decke, die Stoffbänderung S_0, die Lineationen L_1 und die D_1-Mylonite an der Basis der Dent-Blanche-Decke. Die Faltenachsen FA_2 der NW-vergenten Grossfalten fallen im Arbeitsgebiet und am Les Diablons (SATORI, 1987) mit 30 Grad nach SW ein. Im Gebiet von Zinal werden die Augengneise durch eine Kalifeldspat-Einregelungslineation L_2 und durch ein s-c-Gefüge charakterisiert. MAZUREK (1986) beobachtete bei Hohenbalmen (bei Zermatt) E–W streichende N-vergente Grossfalten. Nach seiner Beschreibung muss es sich bei jenen E–W streichenden Grossfalten ebenfalls um D_2 handeln.

D_3 bildet einerseits Grossfalten und andererseits Krenulationsfalten. Die Faltenachsen FA_3 der S-vergenten Falten sind ca. 270/35 orientiert. Die millimetergrossen Krenulationsfalten sind innerhalb der Gesteine der Arolla-Serie auf chlorit-, hellglimmerreiche Zonen konzentriert. D_3 steht im Zusammenhang mit der Rückfaltungsphase, die unter anderem auch die Mischabelfalte ausbildet. MÜLLER (1983) erklärt D_3 mit dem Block-Scherungskonzept.

Die letzte, alpine Phase D_4 wird durch spröde Deformationen gekennzeichnet. Dabei bilden sich Brüche und Klüfte. Bei den Brüchen sind E–W streichende, steil gegen Norden einfallende, dominant. Es handelt sich dabei um Auf- und Abschiebungen. Sie können auch als konjugiertes Bruchsystem auftreten. Die Klüfte lassen sich in drei verschiedene Kluftsysteme unterteilen: a) mit Chlorit, Quarz oder Stilbit verheilte Klüfte, b) eine penetrative, engscharige, dominante Klüftung, c) eine «en echelon»-Kluftschar in lokalen Zonen.

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Sergei A. Sergeev, Martin Meier and Rudolf H. Steiger (Zürich):

Emplacement of Variscan granitoids in the Gotthard massif – a coherent process?

The composition, nature and emplacement sequence of the granitoid units in the pre-Alpine basement relics can be of use in the study as significant indicator for geodynamic interpretations of the plates involved in the evolution of the Central Alps. In distinction from other lithologies which may have been generated in various places and brought together tectonically, the granitoid intrusives reflect the geodynamic development of relatively conservative, already existing segments of the crust. Thus, the geochronological study of the granitoid bodies can provide both a time-frame for tectonic and metamorphic episodes and information about the age of the granitoid protolith.

The Variscan granitoid magmatism in the Gotthard massif is fairly extensive and displays a range of structural and compositional properties. It comprises the partly isometrical *gneissic granite/granodiorite stocks* (Fibbia, Gamsboden, Medels, Cristallina), and the more acidic, *massive granite intrusives* (Rotondo, Tremola, Cacciola, Winterhorn, Mt. Prosa) at their margins, and dikes (example Saedelhorn). Field observations show the absence of clear intrusive contacts along the gneissic granite/granodiorite stocks and their originally magmatic nature assumed on the basis of their internal textures and the occurrence of country rocks xenoliths within them.

The *gneissic granitoid stocks* exhibit most of the diagnostic features of S-type granites, derived from a source within the continental crust. These are: (1) the concentric planar fabric concordant with the fabric of enveloping rocks and decreasing in intensity inwards from the stock's margins, similar to diapiric bodies, (2) the lack of the contact metamorphic aureoles, (3) the presence of paragneiss inclusions oriented parallel to the granitoid fabric, (4) the occurrence of irregularly distributed muscovite and garnet accumulation, (5) relatively clear peraluminous affinities (A/CNK $\geq$ 1), (6) development of Fsp-megacrysts with prograde history, (7) high $^{87}Sr/^{86}Sr$; (0.707–0.711) as well as negative $\varepsilon Nd(t)$ (–3 to –5), (8) abundance of zircon populations much older than those of magmatic origin. It is important to note the apparent progression and amplification of some of these features from SW to NE along the axis of the Gotthard massif, i.e., from the Gamsboden/Fibbia to the Medels/Cristallina stocks that as a assumption may indicate different crustal levels of the Gotthard massif are exposed at present time.

In contrast, the *massive granite intrusives* outcropping mainly in the SW part of the Gotthard massif are homogeneous leucocratic rocks. They can be considered as a more mobile, silica-rich melt forming the marginal phase or apical part of the gneissic granitoid stocks.

Precise determinations by U/Pb single-zircon method indicate an extrapolated intrusive age of 300 ±1 Ma for the SW granitoid stocks, only ca. 4–6 Ma higher than that of the massive marginal granites based on exactly concordant analytical data points at 294 ± 1 Ma. The lack of zircon data points older than 294 Ma on the 300 Ma-discordia line for the gneissic granitoids may be due to the presence in the single grains of a minor pre-magmatic zircon phase. This concurs with the increasing proportion of pre-magmatic zircon grains found in the granitoids as the leucocratic affinity of these rocks decreases from SW to NE.

Thus, if the Variscan magmatism in the Gotthard is the result of partial melting of a poly-component rock complex (including metasediments), which, e.g., occurred during a continental collision event, this process could be rather continuous. The observed compositional progression may simply reflect protolith melting of different degree and at different crustal levels. Whereas only pre-Caledonian rocks can be consider as a source for first generation of the Gotthard granitoids (Caledonian ortho-Streifengneiss), the Caledonian and later rocks may be also involved in the anatectic mechanism of the second, Variscan, granite magma generation.

Peter Spillmann (Zürich):

Das Margna-Bernina-Deckensystem: Die Struktur eines alpin überprägten passiven Kontinentalrandes.

The Margna-Bernina nappe system: Alpine imprint on a passive continental margin.

Der südpenninisch-unterostalpine Deckenstapel des Berninamassivs repräsentiert einen Abschnitt des adriatischen passiven Kontinentalrandes. Basierend auf der Untersuchung der Struktur, der Stratigraphie und der Kinematik des Dekkenbaus, wird die folgende paläotektonische Rekonstruktion der tektonischen Elemente des Margna-Bernina-Deckensystems vorgeschlagen:

Die Profile schematisieren die ursprüngliche Lage der Margnadecke am distalen adriatischen Kontinentalrand. Die distale Lage der kontinentalen Kruste der Margnadecke bezüglich des Kontinentalrandes ist angezeigt durch die Integration adriatischer Unterkruste in ihre alpine Deckenstruktur. Entsprechend der alpin-tektonischen Lage der südlichsten Platta-Ophiolithe zwischen Decken kontinentalen Ursprungs ist die Margnakruste in Profil B durch einen Ast des südpenninischen Ozeans vom Bernina-Julier-Bereich getrennt. Durch das Auskeilen der Platta-

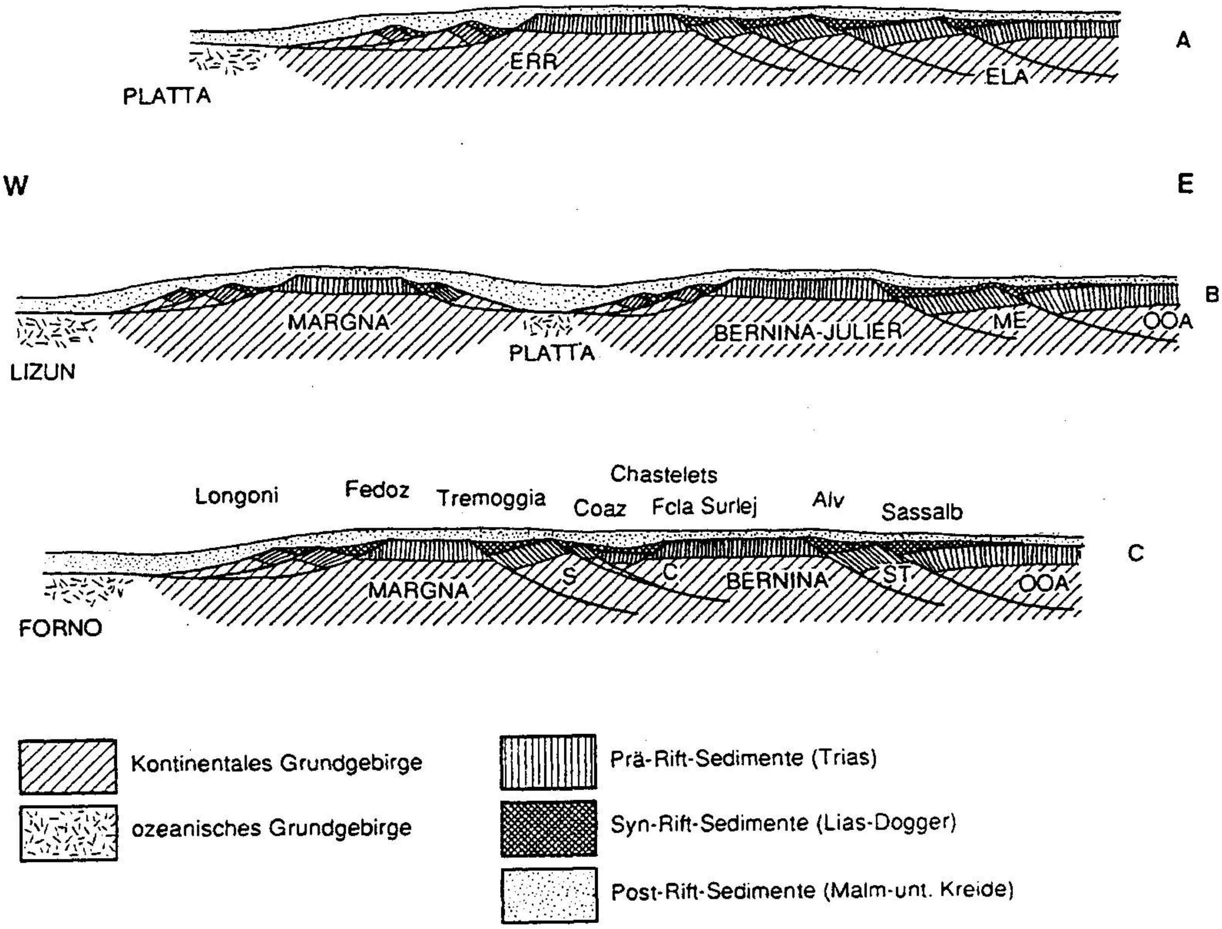

Fig. 1 Die Lage der tektonischen Einheiten des Margna-Bernina-Deckensystems am passiven adriatischen Kontinentalrand (ME: Mezzaun, OOA: Oberostalpin, S: Sella-Teildecke, C: Corvatsch-Teildecke, ST: Stretta-Teildecke).

Ophiolithe in der tieferen Berninadecke s.l. (auf dem tektonischen Niveau der Coaz-Sedimente) repräsentiert die Deckenstruktur des südlichen Berninamassivs einen kontinuierlichen Bereich kontinentaler Kruste (Profil C). Die präalpine Zergliederung der kontinentalen Kruste leitet sich aus den Sedimentbedeckungen der Margnadecke und der Berninadecke s.l. ab:

Jurassische Extensionstektonik, gebunden an ostfallende Bruchstufen, ist gut dokumentierbar in der höheren Berninadecke s.l. (Sassalb, Alv) (vgl. BERNOULLI et al., 1993, mit Ref.). Die Sedimente, welche die Teildecken der tieferen Berninadecke s.l. (Sella, Corvatsch) definieren, sind tektonisch, aber auch stratigraphisch reduziert. Jurassische Schichtlücken (Chastelets, Fuorcla Surlej) sowie chaotische Megabrekzien (Coaz) belegen jurassische Extensionstektonik in diesem Bereich. Aus der Struktur der Tremoggiamulde, welche die Grundgebirge von Margna- und Berninadecke s.l. verbindet, kann ein jurassisches Extensionsbecken, das an eine ostfallende Bruchstufe gebunden war, rekonstruiert werden. Äquivalente der Allgäu-Fm im Verkehrtschenkel der Margnadecke (Longoni) belegen jurassische Extensionstektonik am distalsten Kontinentalrand.

In der Fortsetzung der Platta-Ophiolithe wird in Profil C eine intrakontinentale Grabenstruktur im Bereich der Coaz-Sedimente postuliert. Eine Fortsetzung der Platta-Ophiolithe im Deckenbau des südlichen Berninamassivs wurde nicht beobachtet. Die Fortsetzung der ozeanischen, südpenninischen Sutur verlagert sich daher in die Malenco-Forno-Lizun-Einheit im Liegenden der unterostalpinen Margnadecke. Aus dieser Struktur resultiert eine lokale Komplizierung des räumlichen Verlaufs des Kontinentalrandes.

Im Zuge der westgerichteten, eoalpinen Dekkenbildung wurde die Berninadecke s.str. als intern wenig deformierter, starrer Block auf die Teildecken der tieferen Berninadecke s.l. (Corvatsch, Sella) überschoben. Die Sedimente der Tremoggiamulde wurden in einer Synklinale unter die Berninadecke s.l. eingefaltet. Die homogen alpin mylonitisierte Margnadecke schliesslich zeigt einen liegenden, antiklinalen Deckfaltenbau.

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Gérard M. Stampfli (Lausanne):

Exotic terrains in the Alps: a solution for a one ocean model (see p. 449–452 this issue).

Rudolf H. Steiger, Martin Meier, Shigeru Iizumil and Ruth A. Bickel (Zürich, Matsue):

The polyorogenic nature of the Simano Nappe as derived from single-zircon U/Pb data

Terrane analysis in the Penninic realm to allow reconstruction of the Paleozoic tectonic setting is fraught with difficulties because most of the pre-Alpine structures and correlations have been destroyed during Alpine deformation and metamorphism. For the definition and comparison of terranes we must therefore resort to geochemical, isotopic and geochronological characterization of the constituted rock units.

The lower Penninic Simano basement-nappe represents a terrane whose composition was essentially established and consolidated by the end of the Variscan orogenic cycle. It consists of a variety of orthogneisses, and of more massive granitoid units and migmatites that may be separated from each other by mesocratic gneisses and schists of sedimentary origin. Whereas Alpine deformation led to involved tectonic deformation, and possibly to some internal disruption and thrusting, the accompanying metamorphic conditions of upper amphibolite-facies resulted in recrystallization and in the resetting of mineral ages, but not in melting or remobilization.

An effort is currently under way to determine the isotopic signatures of some of the typical gneiss units of the Simano nappe, to study their zircon typology and to assign the respective protolith, intrusive and metamorphic ages by the use of high-resolution/high-precision single zircon U/Pb dating techniques. This latter method, in particular is well-suited to penetrate the veil of high-grade Alpine metamorphism. The general age pattern of zircons from the Simano nappe was first established by KÖPPEL et al. (1980). Despite the observed discordance, they suggested Caledonian affinities for the Malvaglia gneiss zircons but remained ambiguous in assigning a Hercynian or Caledonian zircon age to the Verzasca gneiss from Brione.

Improvements in analytical blanks, in precision of analysis and its application to single grains or to single fragments of zircon have since greatly enhanced the resolving power of conventional U/Pb dating. We are thus able to attribute an unequivocally Caledonian and concordant zircon age of 445 ± 5 Ma to the Verzasca gneiss from the Soriöö quarry W of Brione, and to precisely determine the intrusive age of the leucocratic trondhjemitic Verzasca core gneiss from Motta (Rozzera) at 280 ± 6 Ma. The nebulous migmatites from the abandoned quarry N of Ponte di Corippo yield a more complex picture which suggests that migmatization presumably occurred during the Variscan cycle. While discordant, those morphological types (G1 and P3) from Molta and Corippo that are indicative of late crystallizates show $^{206}Pb/^{238}U$ ages of at least 235 Ma. None of the selected grains has a $^{206}Pb/^{238}U$ age lower than 200 Ma and there is little if any indication of an Alpine overprint although the sampling localities are situated in the sillimanite zone of Alpine metamorphism.

This and the importance of the Caledonian event was also confirmed for the Malvaglia augen gneiss from the quarry at Ponte Lesgiuna. Single fragments of core and rims of zircon grains gave identical $^{206}Pb/^{238}U$ ages between 441 and 447 Ma. There, some of the rim material is probably of metamorphic origin because of the observed low Th/U ratios. On the other hand, the zircon populations from both the Malvaglia augen gneiss and the Corippo migmatites contain grains with old components that date back to about 600 Ma and 800 Ma, respectively. Since both of these rocks are S-type granitoids, the observed zircon cores may be of detrital origin and be attributed to the Panafrican or Pan-Gondwanan orogenic cycle. This supports the idea that the Penninic basement is part of or does at least contain (possibly recycled) components derived from the Gondwana supercontinent (GEBAUER, 1992).

It thus appears that the Simano basement nappe preserves records of involvement in at least three orogenic cycles. Contrary to the Alpine orogeny, the Variscan and Caledonian cycle led to anatectic melting and remobilization. The oldest components found so far do not exceed a late Proterozoic age, in stark contrast to the infra-Penninic Gotthard terrane.

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KÖPPEL, V., GÜNTHERT, A. and GRÜNENFELDER, M. (1980): Patterns of U–Pb zircon and monazite ages in polymetamorphic units of the Swiss Central Alps. Schweiz. Mineral. Petrogr. Mitt. 61, 97–119.

Jürgen von Raumer and Franz Neubauer (Fribourg, Graz):

The Palaeozoic evolution of the Alps (see p. 459–467 this issue).

Roger Zurbriggen (Bern):

A reinterpretation of the Cenerigneiss, its importance as a structural marker and a comparison of the Strona-Ceneri zone (SCZ) with the Silvretta nappe.

After the first field sommer in the northern SCZ, between Cannobio (Italy) and Brissago (Switzerland), I represent herewith the first field results and the actual working hypothesis.

The Cenerigneiss (SCZ) is a homogeneous Ms-Bt tonalitic gneiss which, due to its calc-silicate nodules and greywacky-like composition, was interpreted by most authors as a metasediment ("paragneiss"). The following features lead to a new interpretation of the Cenerigneiss as a Caledonian S-type granitoid:

1) The internally folded gneiss and granulite to amphibolite facies metamorphic calc-silicate xenoliths,

2) the mafic metasedimentary restites,

3) the lack of Cenerigneiss xenoliths in the adjacent metagranitoids ("orthogneisses") and vice versa

4) the absence of metapegmatites which are typical for SCZ-metasediments (especially near metaigneous rocks),

5) the plutonic zircon population and microtextures (e.g., zoned plagioclase),

6) the lack of pre-Ordovician S_0 and S_1 structures,

7) the geochemical affinity to the Ordovician metagranitoids (WENGER, 1983),

8) the tonalitic (greywacky-like) composition, and

9) the concordant U–Pb zircon and monazite ages around 450 Ma (KÖPPEL and GRÜNENFELDER, 1971; RAGETTLI, 1993).

Around 450 Ma, after attainment of the Caledonian amphibolite to granulite facies metamorphic peak (D_1), anatexis (T ~ 800 °C) of metagreywackes produced tonalitic melts. These acted as potential crustal components, contaminating the simultaneously intruding, mantle-derived magmas, and evolving into the Ordovician calcalkaline granitic suite ("orthogneisses"). Some of these tonalitic melts intruded as unmixed S-type granitoids and formed the protolith of the Cenerigneiss. In this reinterpretation, the Cenerigneiss becomes an important structural marker for distinguishing preintrusive S_0 and S_1 structures (in xenoliths and host rocks) from syn- to post-magmatic S_2 structures (regional "main schistosity").

The Silvretta nappe is composed of similar lithologies showing exactly the same pre-Variscan evolution (MAGGETTI et al., 1990).

In both the SCZ and the Silvretta nappe (MAGGETTI et al., 1990), the E–W trending "Schlingen" (subvertical, kilometer scale folds) fold older N–S striking, subvertical planar structures (S_2) and develop a new axial plane schistosity (S_3).

The Permian dyke swarm which is associated with the CMB line indicates N–S extensions. On the other hand, N–S compression tectonics are needed to produce the "Schlingen". Therefore, the CMB line can not be related with the "Schlingen" event (D_3). Both, the CMB line and the (younger?) Pogallo line are not folded by the "Schlingen", but they probably cut the "Schlingen" foliation (S_3), and might therefore be younger than the "Schlingen" event.

In both, the SCZ and the Silvretta nappe, the still subvertically oriented Permian dyke swarms and the horizontally overlying Mesozoic sediments are not consistent with the, by many authors proclaimed, post-Permian strong tilting (> 60°) of these basement units.

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