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Klippen of Giswil (Briançonnais s.l.) and associated Helvetic - Ultrahelvetic nappe system (Central Swiss Alps)

with 8 figures and 3 plates

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Zusammenfassung

Die jährliche VSP - Tagung 1998 in Sörenberg war nicht nur der lokalen und der regionalen Geologie der Giswiler Klippen in den zentralen Schweizer Voralpen gewidmet, sondern auch Fragen der angewandten Geologie. Besonderes Augenmerk lag dabei auch auf der historischen Felsrutschung am Nünalpstock und den damit verbundenen besonderen Anforderungen für die Neuverlegung der Transitgas - Pipeline, die aus Gründen des Hochmoorschutzes neu unter der Rutschmasse durchgeführt wird. In der Zwischenzeit ist die Rutschung wieder in Bewegung geraten und Anfang 1999 durch starke Murgangaktivität zu einer ernsthaften Bedrohung eines Teils der Ortschaft geworden.

Es wird versucht, die paläogeographische Herkunft der Giswiler Exoten und ihrer Unterlage aus dem Briançonnais s.l. respektive aus dem Süd - bis Ultrahelvetikum zusammenfassend darzustellen und die gegenwärtigen Kenntnisse auf den Stand der neueren alpinen und plattentektonischen Literatur zu bringen. Dabei werden auch die subtilen und bis anhin wenig untersuchten Manifestationen von neotektonischer Bewegungen berücksichtigt, weil diese u.U. entscheidend an Massenbewegungen beteiligt sein können und sicher auch ein lohnendes zukünftiges Forschungsgebiet darstellen.

1. **Introduction** (figs. 1a, 1b, plate 1)

The 1998 annual symposium and field trips of the Swiss Association of Petroleum Geologists were held on June 21^{st} and 22^{nd} 1998 in Sörenberg, Canton of Lucerne, Central Switzerland. It was dedicated to the "Klippen of Giwsil" ("Klippen" = cliffs), which are built up by a variety of well defined dismembered sedimentary sequences of Middle Penninic Briançonnais palaeogeographical origin. In addition the underlying complexly deformed nappes of N - to S - Helvetic, Utrahelvetic and Ultrapenninic / Pre - Piemontese origin were studied (border chain Pilatus - Niederhorn / Drusberg, Habkern - Wildflysch nappes and Schlierenflysch - Simme nappe s.l.). This stack of rootless decollement nappes, which today measures approximately 25 km along its dip trajectory, was detached during the polyphase Alpine orogeny from an original sedimentary Mesozoic crustal cover extending from the passive S European to the active Sub - Piemontese margins, and which orginally covered some 500 km.

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1a

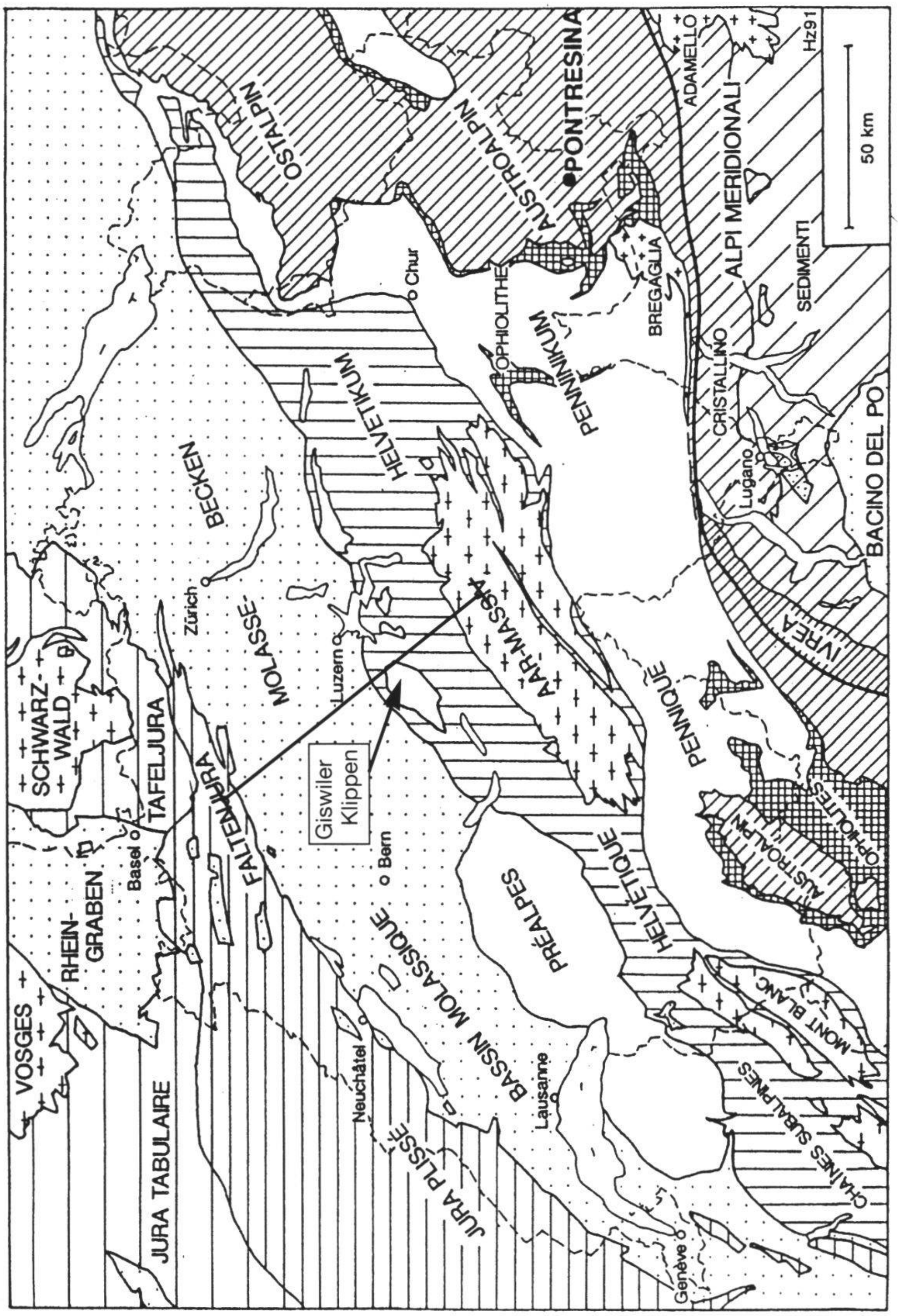

Fig. 1a: Tectonic sketch map of Switzerland with location of Giswiler Klippen (Heitzmann 1991). Bar indicates location of fig 1b.

1b

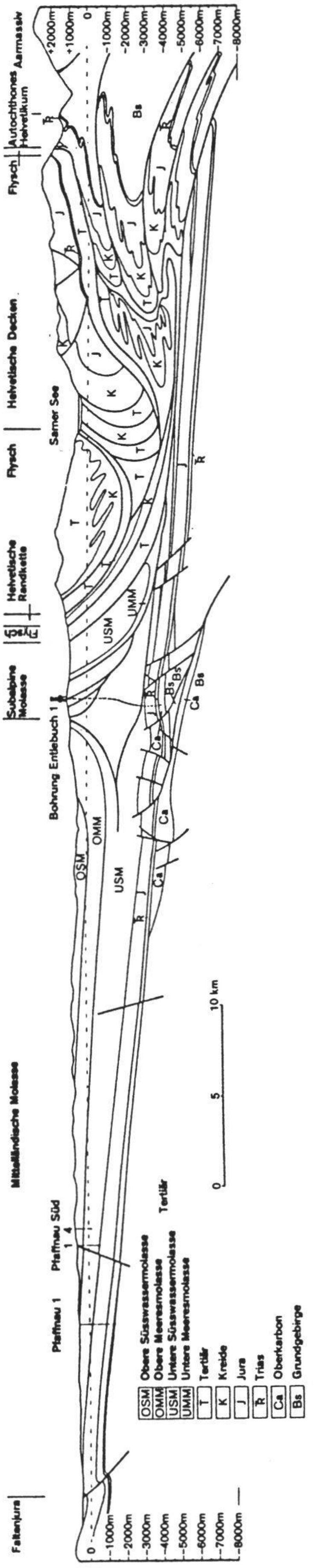

Fig. 1b: Cross section from the Jura to the Aar massif (Vollmayr & Wendt 1987) with tectonic position of Giswiler Klippen.

Part of the excursion was dedicated to the spectacular rock slide of on the W face of the Nünalpstock, which is overlooking the tourist resort of Sörenberg. The mass movements devastated the outskirts of the village in 1910. The block debris fan requires monitoring to this day on a regular basis. The glided mass extends up to the break - off outcrop amphitheatre. It has come to rest mostly on a steep slope and still is experiencing minor creep. Part of it has recenlty threatened to turn unstable again in the wake of the late 1989 and early 1999 heavy snow and rain precipitations. Presently construction of a tunnel below the slided rock mass is planned, which will serve for part of the ongoing upgrading of the N - to S European Transitgas pipeline. It is recalled that the existing right of way for the existing pipeline W of Sörenberg was not renewed for the new construction. The mountain moor habitats, which are affected by the old have trajectory in the mean time have become protected by new environmental legislation.

In the Schlierenflysch nappe W of the peak of the Nünalpstock the land slide has created what can be considered the most spectacular Flysch outcrop of the Swiss Alps. During the inspection of the land slide small scale post - nappe emplacement neotectonic movements were observed and their potential impact on geological hazard assessment were discussed by participating engineering geologists, who are experienced in many parts of the Swiss Alps.

The present article presents a brief sketch of the state of structural understanding of the rootless pile of nappes of the area and their regional palinspastic restoration. The structural interpretation is almost exclusively based on field mapping at a scale of 1 : 25'000 and smaller i.e. in the virtual absence of seismic data. As an afterthought to the mentioned visit to the land slide some emphasis is put on little investigated Neotectonic phenomena. In the wider area pioneering work has been carried out in recent years notably by the late speleo - geologist Thomas Bitterli of Basel, and by several workers of the University of Neuchâtel school of hydrogeology and speleology. Large parts of the giant cave systems of the N Helvetic border chain of the Sieben Hengste and Schrattenflue have been or are being explored and studied.

Following this new approach this article also attempts to define objectives of potentially rewarding further structural, and in particular of Neotectonic research.

2. **Stratigraphy and Structure** (figs. 2, 3, 4)

The Klippen of Giswil comprise four clearly differentiated main units, i.e. overthrusted fragments derived from the Briançonnais microcontinent of Late Jurassic - Early Tertiary age. A minor remnant of the same Briançonnais origin is encountered between the S overturned margin of the Schlierenflysch nappe and the northernmost Klippen unit of the Rotspitz (see fig. 2, "St", "A", "G", "R", fig. 3 and Mohler 1966).

The southernmost and largest Klippe, i.e. the Giswilerstöcke s.l. consist of massive Middle Triassic shallow platform carbonates of Anisian - Ladinian age, which are overlain by Late Triassic Carnian evaporitic cornieules and minor marls and dolomites. The sequence is clearly correlatable with the "Préalpes Médianes Rigides" or with the Briançonnais s.s of W Switzerland, where the Médianes are present as a laterally more or less continuous decollement nappe (e.g. Stampfli et al. 1998). The Giswilerstöcke unit is overthrusted over the frontal overturned folds

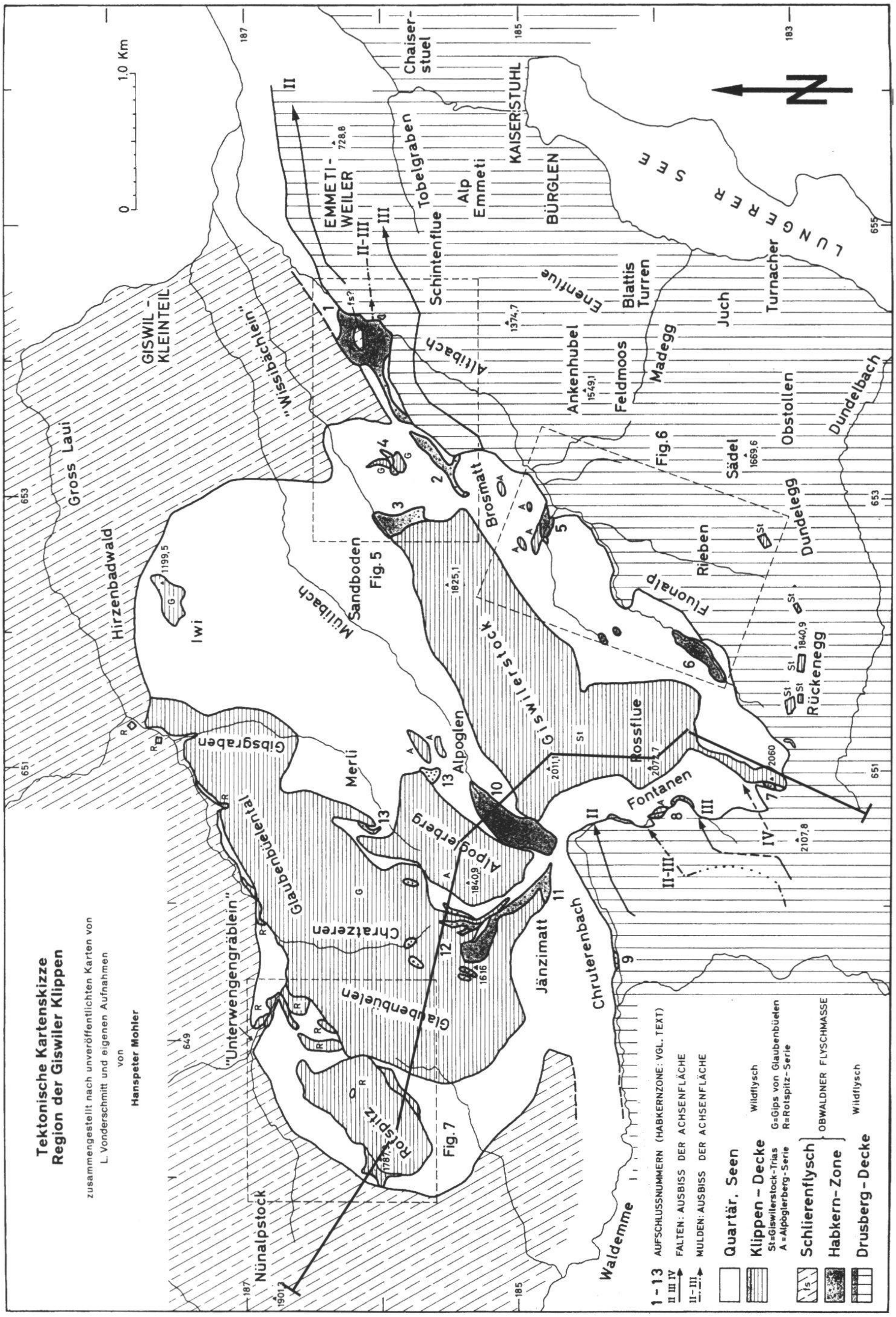

Fig. 2: Tectonic sketch map of Giswiler Klippen region (Mohler 1966). Bar indicates location of fig. 3.

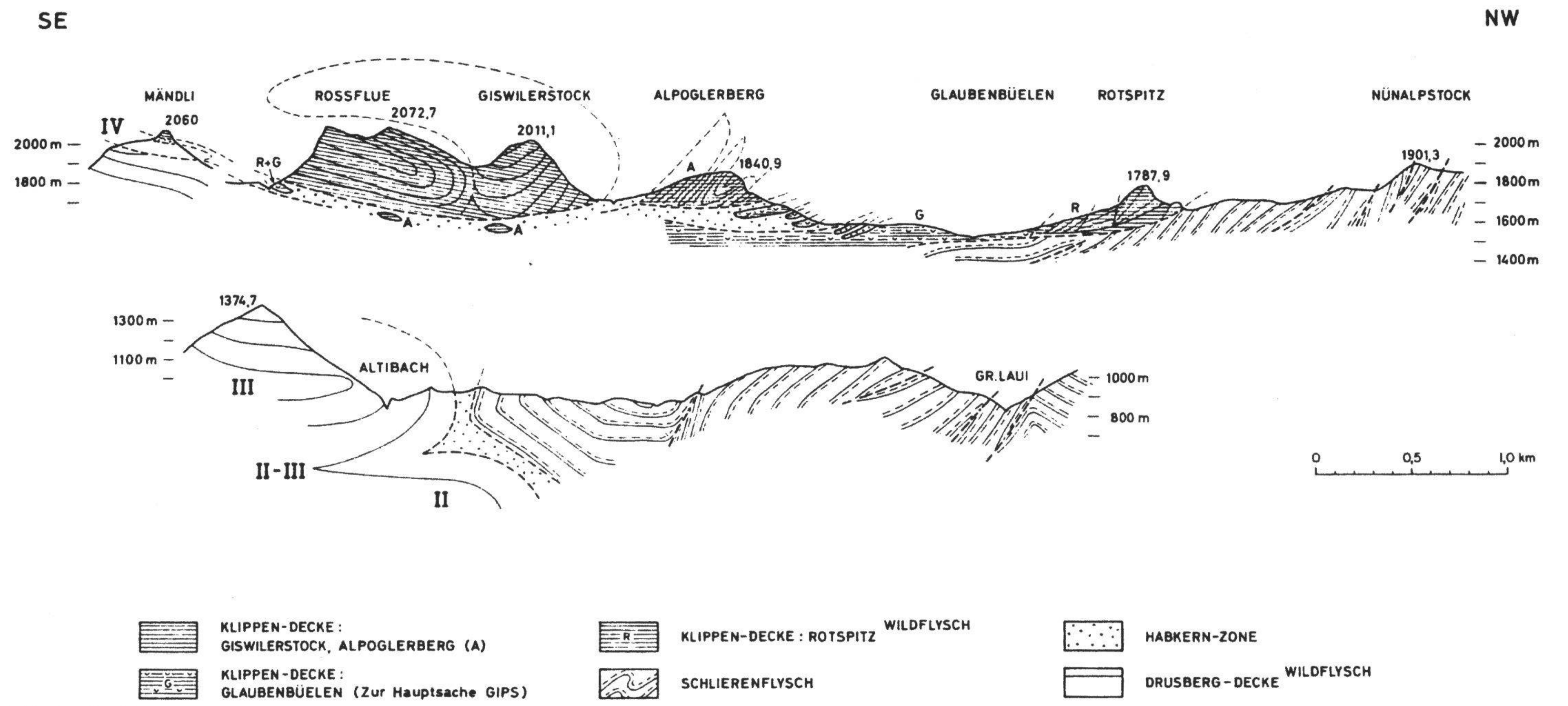

Fig. 3: Cross section through the Giswiler Klippen region (Mohler 1966). Location see fig. 2.

and local thrusts of the S Helvetic Drusberg nappe. A beautiful recumbent N vergent anticline is exposed on the W face of the Giswilerstöcke (Rossflue), with overturned limbs to the S and N, the latter one completely detached (Mändli and Schafnase respectively).

The remaining three klippen elements correspond to the "Préalpes Médianes Plastiques", or Sub - Briançonnais. From S to N:

"A": *Alpoglerberg:* Late Triassic "blond" dolomite with hard ground at top, minor cornieule and coaly plant bearing marls and sands (?Norian - Carnian), reduced phospatic Ammonite and Belemnite bearing Early - Middle Liassic of Carixian - Domerian and "Cancellophycus -Dogger" of Aalénian - Callovian ages.

"Gl": *Glaubenbüelen:* thick Late Triassic evaporites (gypsum), minor " blond" dolomites and variegated marls of Carnian - Norian? age.

"R": *Rotspitz* (plates 2 a + b, 3 a – d): sequence with reduced thicknesses, exhibiting several important stratigraphic gaps. Late Triassic continental - lagoonal marls and "blond" dolomites of Carnian - Norian? age, Middle - Late Jurassic shallow carbonate platform with a sandy - cherty lower unit, deeper marine Tintinnid bearing Latest Jurassic - Earliest Cretaceous white - grey, cherty Tithonian and "Neocomian" limestones and interbedded shales, followed by red - greenish Late Cretaceous - Early Eocene deposits with rich planktonic foraminifera and Nannoplankton assemblages of deep marine, bathyal - pelagic origin (Couches Rouges). The latter grade into a greenish sand - siltstone bearing Wildflysch of Early Eocene age, and containing older resedimented Rotspitz sediments in breccias and blocks.

A small tectonic relict of "Rotalipora - Marls" consisting of dark green deep marine shales and containing a well preserved very rich fauna of planktonic foraminifera of Late Albian - Cenomanian age occurs below the Rotspitz. They correspond to the *Intyamon Formation* of the Préalpes Médianes (old name "Complexe Schisteux Intermédiaire"; see also above).

The various Sub - Briançonnais units exhibit intensive trusting and imbrication internally and a predominance of overturned positions. From S to N they overly the South - to Ultrahelvetic Wildflysch and the overturned imbricate zone of the S margin of the Schlierenflysch nappe respectively.

The frontal *Drusberg* - nappe exhibits steeply piled up N vergent recumbent folds, which are modified locally by thrusting. The fold axes of the Drusberg nappe dip towards the E. The regional position and physical extent of the klippes of Giswil mark the area of steepest dips of these axes. This area also coincides with a pronounced change of regional strike of the Drusberg nappe from NNW - SSW to E - W.

The youngest member of the Drusberg nappe is a Wildflysch of Late Eocene (Priabonian) age, which stratigraphically grades from the underlying Globigerina Marls of the same age, and which latter contain larger foraminiferal "Heterostegina" / algal calciturbidites near the top. The lithology of the Drusberg nappe Wildflysch is comparable with the Habkern Wildflysch. It also contains minor sand - siltstones and exotic blocks in the form of resedimented "Leimern" beds, pelagic limestones of Late Cretaceous age (plate 2 c + d, see also below).

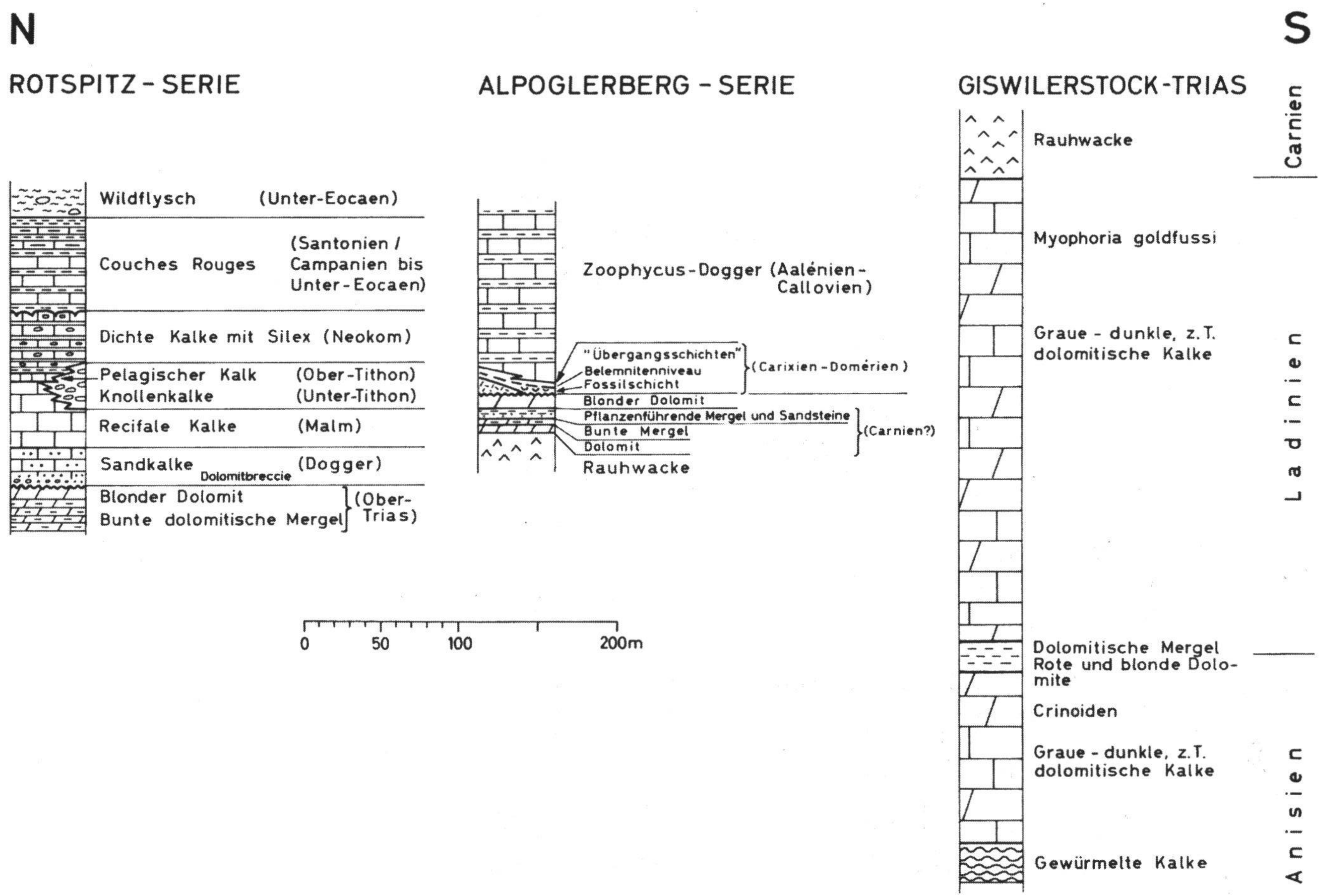

Fig. 4: Stratigraphic profiles through the Klippen series at Giswiler Stöcke, Alpoglerberg and Rotspitz (Mohler 1966).

The highly tectonized *Habkern Wildflysch* zone regionally occurs at three different tectonic levels (Vonderschmitt & Schaub 1943):

- at the base of the overthrust of the Klippen of Giswil (Giswilerstöcke, Alpoglerberg, and possibly Glaubenbüelen),
- below the Schlierenflysch nappe (including the type area), and
- as Subalpine Flysch below the overthrust of the N Helvetic Pilatus - Niederhorn nappe, which builds up the border chain (e.g. Schrattenflue).

The Wildflysch is characterized by a chaotic mélange of dark and light shales containing Schlierenflysch turbidite type breccias and sand - siltstones and a variety of exotic blocks (Kaufmann 1886 and Bayer 1982). The light coloured (calcareous) shales often consist of Late Eocene Globigerina Marls, similar to the ones present in the Drusberg nappe and represent the youngest members of both units. A major part of the exotic blocks shows affinity to an Ultrahelvetic Late Cretaceous - Palaeogene facies belt originally forming the deeper shelf - slope extension S of the Drusberg deeper marine platfom ("Leimern" beds). The Leimern type locality, however, provides a notable exception and cannot clearly be correlated with either the Ultrahelvetic nor the Penninic facies belt (Bayer 1983 and Mohler 1983). It is postulated that the Habkern zone represents a zone of cannibalization during the process of Late Eocene tectono - sedimentary Wildflysch formation (see also below). The ubiquitous turbiditic sand - siltstones on the other hand show affinity with Schlierenflysch material while the most notable other exotic blocks are represented by gypsum, baryte nodules and the famous mostly reddish and fresh Habkern granite. The latter also commonly occurs as a component of the Schlierenflysch breccias and sandstones.

The *Schlierenflysch* nappe is overlying the Habkern Wildflysch zone. It exhibits two large scale synclines, which are separated from each other by a highly squeezed and thrusted anticlinal zone (Schaub 1966 and Winkler 1983). Its S overturned margin is locally overthrusted by the Rotspitz klippe and N of the latter in one locality by a fragment of Intyiamon Formation.

The northernmost element visited during the excursion consists of the inclined and fractured slab of the *Schrattenflue border chain,* which represents the N Helvetic Pilatus - Niederhorn nappe (Soder 1949). This unit is overthrusted over the Subalpine Flysch of Habkern Wildflysch origin, which separates it from the underlying Molasse imbricates, which themselves are overthrusted over the S flat lying *Molasse foredeep*. From facies reconstruction of the Helvetic shelf it seems plausible that at depth a suture may exist between the Pilatus and the Drusberg nappes, caused by important overthrusting. However, this feature - in analogy with structure at depth in general - remains still to be defined by seismic.

3. Tectonic - Palinspastic Framework

The Préalpes Médianes nappe was detached from its basement during Alpine orogeny (Pontis and Siviez Mischabel nappes). Figures 1a, b schematically illustrate the Alpine context of the rootless nappe edifice of central Switzerland in general, and of the Klippen of Giswil. Figure 1a also highlights the tectonic position of the Préalpes Médianes of W Switzerland, which is identical with the several klippen fragments of Central Switzerland as well as its Briançonnais or middle Penninic palaeogeographical origin (Trümpy 1960, 1980).

In general the present - day arrangement of the Giswiler Klippen units reflects the distribution of their relative original palaeogeographical positions within the Briançonnais depositional belts albeit with important lateral gaps, which are presumably of erosional origin (Mosar et al. 1996: fig. 4). However, the palaeo - geographical position of the Glaubenbüelen evaporites defies unambiguous definition. Their S portions are intensely imbricated with the Habkern Wildflysch below the Alpoglerberg overthrust. Gypsum is also omnipresent e.g. in the Ultrahelvetic of the wider Habkern - Wildflysch zone below the Schlierenflysch nappe, in its equivalent of the Subalpine Flysch, in the Zone des Cols of W Switzerland as well as in the Briançonnais of the French Alps. In addition another exception is present in the form of a small ocurrence of Intyamon Formation mentioned above. This in all probability is derived from a more internal Briançonnais facies belt than the Rotspitz series, which itself represents the N bounding high of the Sub - Briançonnais, i.e. of the Cancellophycus - Trough (Mythen - Moléson - Brasses palaeo - high; Boller 1963).

4. Plate Tectonic and Geodynamic Aspects (figs. 5, 6)

Mosar, Stampfli & Girod (1996) and Stampfli, Mosar, Marquer, Marchant, Baudin & Borel (1998) describe a continental collisional model between the active N Adriatic margin representing African crust and the European crust of the passive S Helvetic margin. The Briançonnais was originally located as an E prolongation of the Iberian plate at the N margin of the Tethys since the opening of the Liguro - Piemontese ocean during Early - Middle Jurassic times. It evolved as a rim basin until the Eocene.

Eoalpine Phase: Subduction of the Adriatic plate was initiated in Late Jurassic - Early Creataceous. It was coeval with the closure of the alpine Tethys and the opening of the N Atlantic, of the Gulf of Biscay and of the Valais ocean. As a result of the latter the Briançonnais microcontinent was severed from the Iberian plate by Late Cretaceous. Subsequently the Briançonnais microcontinent was incorporated as an exotic terrane into the acrretionary complex only by Middle Eocene times (meso - alpine subduction of Trümpy 1980). Earlier collision of the Briançonnais microcontinent with either the S Helvetic realm or N Adria is ruled out by Stampfli et al. based on cooling temperatures of the Briançonnais basement of Middle - Late Eocene age and on deep marine "anorogenic" deposition of the Couches Rouges lasting until Middle Eocene times.

Mesoalpine Phase: The Briançonnais was detached from its basement and was incorporated into the advancing accretionary prism of the closing Piemont ocean marking the incipient Mesoalpine orogeny during Bartonian - Priabonian times as recorded in the Briançonnais and Helvetic Flysch / Wildflysch sequences. Only relatively small parts were obducted, however, while the major portions of the crust and of the lithosphere were subducted. The obducted portions were thrusted over the foreland, underwent thin - skinned tectonics and led to the development of the typical present - day foreland fold - and thrust - belt of the Préalpes Médianes.

Neoalpine Phase: Collision started when the unthinned Helvetic crust began to subduct during Late Eocene - Early Oligocene times. Detachment and obduction of large part of the Helvetic basement allowed further subduction, together with rearrangement of the prism due to the Piemont slab detachment around the Eocene -

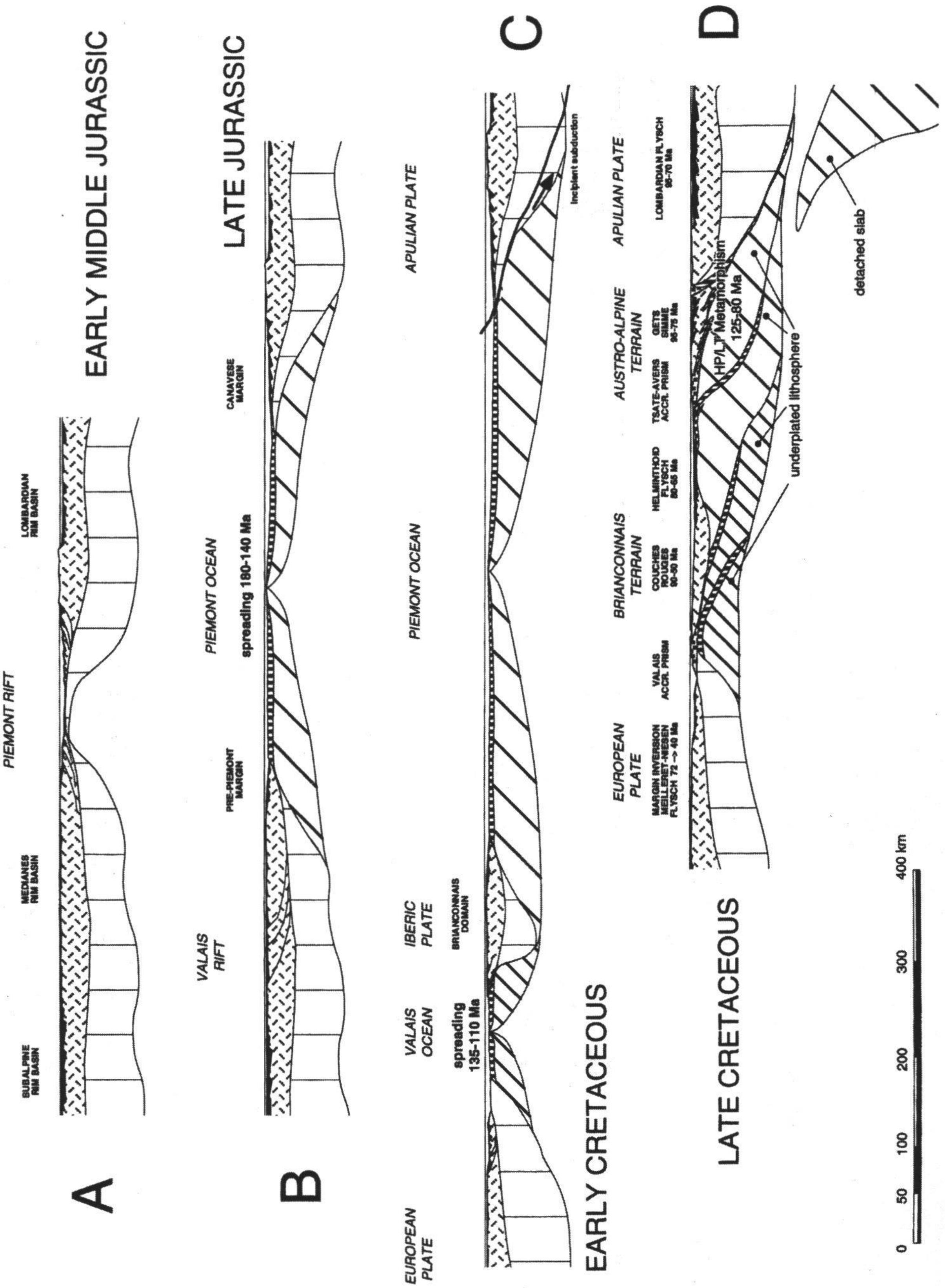

Fig. 5: Middle Jurassic to Middle Eocene evolution of the Alpine continental margins (Stampfli & Marchant 1997). The Briançonnais domain is kept fixed in this reconstruction. In Late Jurassic it is drifting away from the Provençal portion of the European crust. The Tertiary it is obducted into a more E part thereof. This drifting opens the Valais ocean s. str. and closes the Piemont ocean. The subduction of the Piemont ocean results in the Tsaté – Avers accretionary prism and in HP/LT metamorphism. Large crustal mélanges of elements of the westernmost portions of the Austroalpine plate occur deeper in the prism (Sesia and internal massifs).

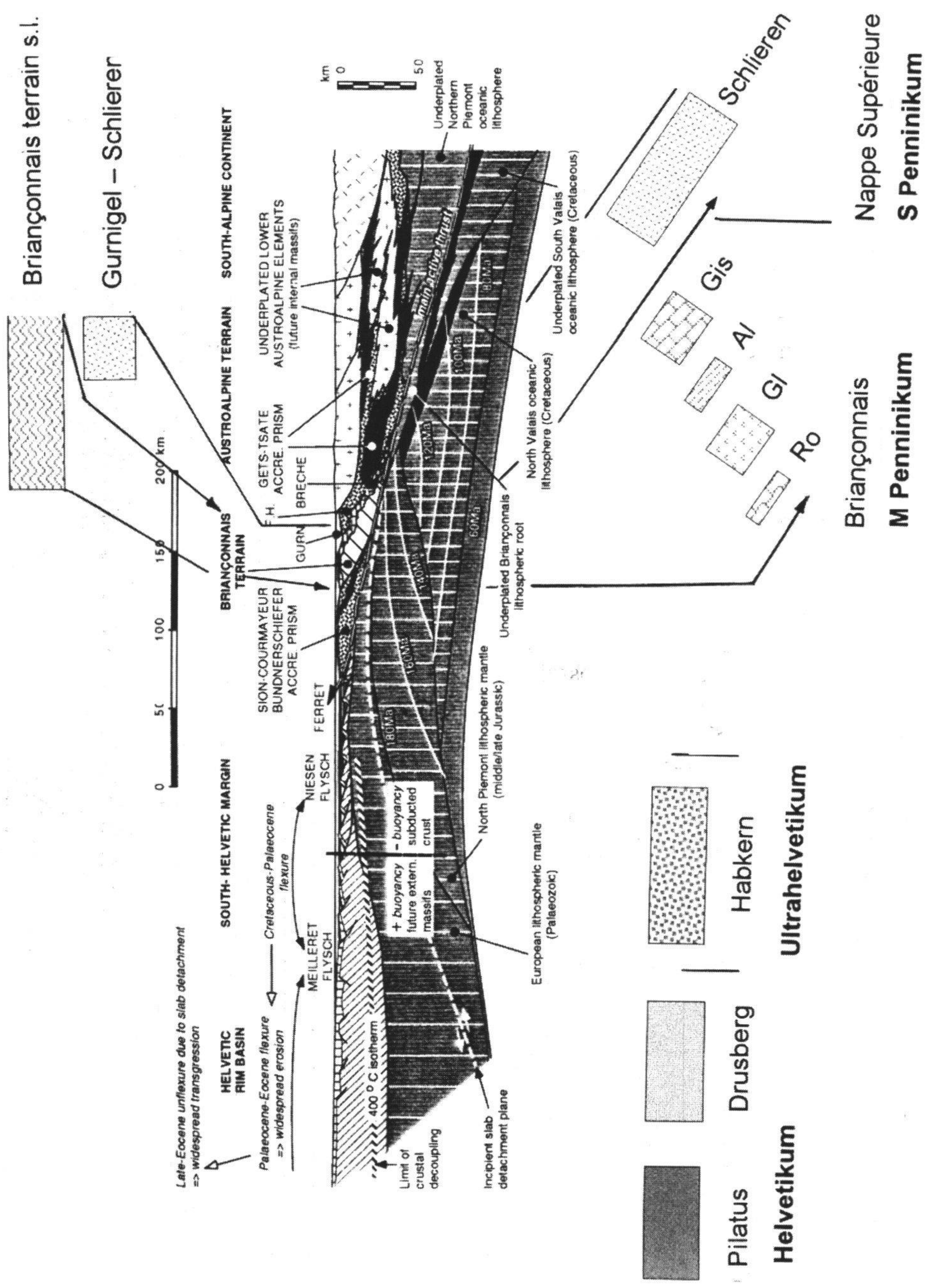

Fig. 6: Middle to Late Eocene Reconstruction: Pre collisional Alpine Orogen (Mosar et al. 1996). Ro: Rotspitz, Gl: Glaubenbüelen, Al: Alpoglerberg, Gis: Giswilerstock

Oligocene boundary. After the early thrusting on top of the evolving Helvetic nappes the Préalpes were emplaced In their present - day position in front of the Alpine mountain belt during Early Oligocene times as evidenced by the Molasse foredeep sedimentary record contained in the internal overthrusted Molasse units.

The larger picture exhibits striking similarity to the above sketched evolution of the Briançonnais: Closure in the W Tethys had started with the eastward subduction of the Meliata Ocean during the Early Jurassic, which was coeval with the opening of the Central Atlantic and Alpine Tethys. During Cretaceous the Austroalpine - inner Carpathian domain accreted as terranes. This was followed by a propagation of the subduction zone to the N margin of the Adria, and to the N margin of Iberia, resulting in the Pyrenean - Provençal orogenic belt. In this reconstruction there is no room for the existence of a separate Cretaceous subduction zone in the Austro - Carpathian Penninic ocean. - The model, however, does allow for the exception of the partial closure of the Valais trough during the Late Cretaceous.

As a consequence it is proposed that a single subduction suture of Palaeogene age gave rise to the formation of the Alpine arc from N Spain to the E Carpathians. It had jumped from the Meliata ocean in Jurassic times to the Alpine Tethys by Early Cretaceous, and finally to the Pyrenees - Gulf of Biscay ocean by the Middle Eocene. This mainly south directed subduction was then replaced by a mainly north directed one, which is still active today and giving rise to the Magrhebides, Apennines, Dinarides and Hellenides.

Neotectonics: On a regional scale likely post - nappe emplacement Neotectonic movements, i.e. including postglacial activity are thought to be present in the form of strong changes in fold axial dips / fold directions, of marked changes in the depth to the basal thrust, of W vergent thrusting and of the thrusting of the internal S Molasse basin rim. These follow in the wake of the development of new basement nappes and by thrusting and uplift in the external crystalline massifs, triggered by a typical "in - sequence deformation mode" terminating with the folding and thrusting of the Jura foreland belt and the subsequent movements.

In a much larger context the ongoing present - day uplift of the Central Alps and the Molasse basin and right lateral movements alonge the Rhone - Simplon line are well documented (e.g. Schaer & Jeanrichard 1974, Laubscher 1974, Schaer 1992, Pfiffner 1986, Maurer, Burkhard, Deichmann & Grenn 1997 and Eckardt, Funk & Labhart 1983).

More recently, Sue & Tricart (1999) described post - nappe emplacement, i.e. Late Alpine - recent brittle extension of the Frontal Pennine Thrust of the Western Alps near Briançon.

5. Nappe Emplacement and Mountain Building Processes (fig. 7)

The following attempt rests on the regional, palinspastic and geodynamic framework as outlinded above in conjunction with the local knowledge of the sedimentary records and surface structure. In addition the in - sequence mode of compressional mountain building is used as an indispensable guide line. This model proposes that in general - and with only few exceptions - propagation of deformation preferentially proceeds from internal to external zones, i.e. from shallow to deeper

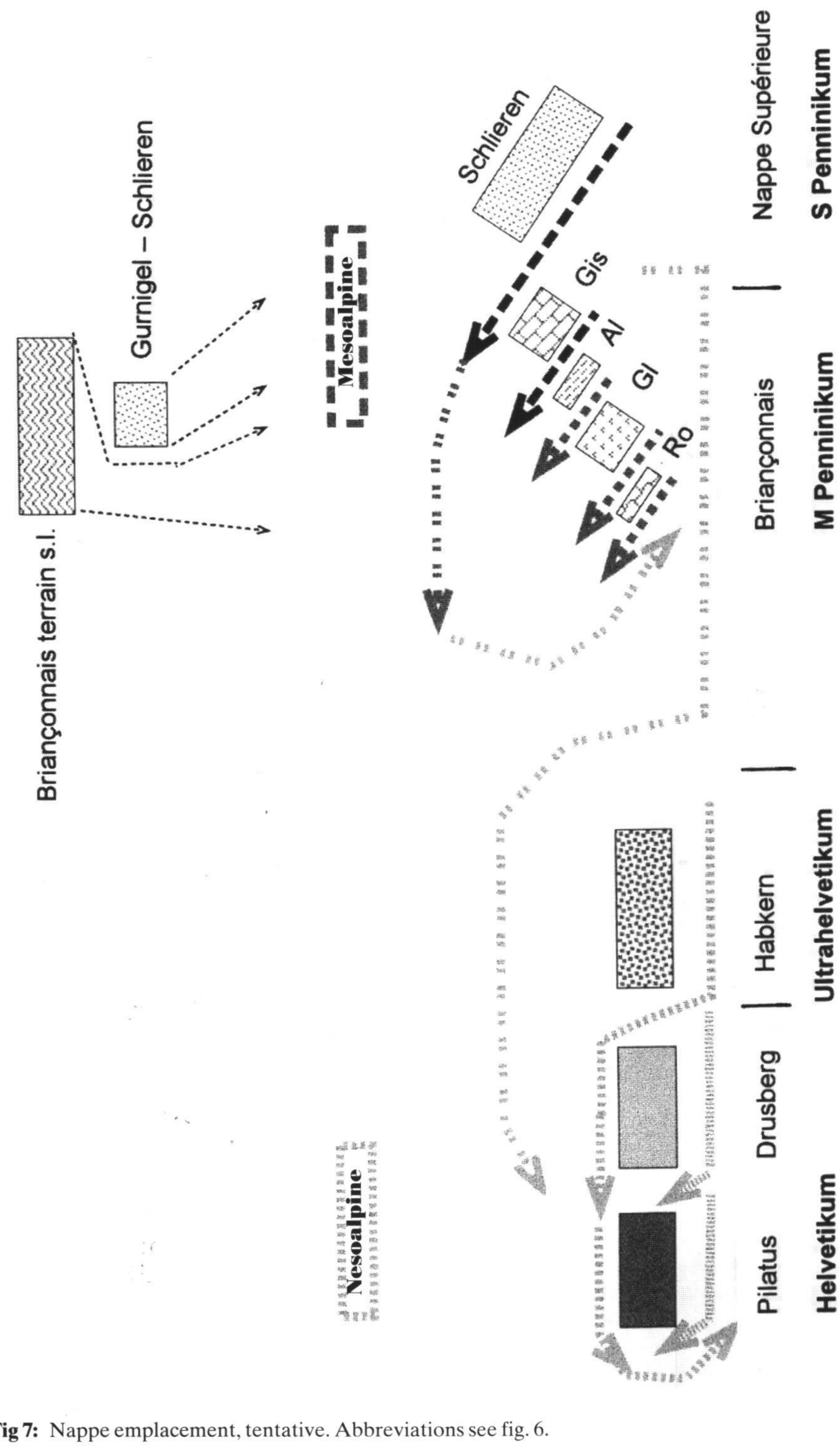

Fig 7: Nappe emplacement, tentative. Abbreviations see fig. 6.

crustal levels. Clearly only a first order working hypothesis can be presented at this time, which requires updating / revision by a.o. radiometric geochronology, perhaps palaeo - magnetometry, which to date have hardly been addressed.

Recently, Claudel & Dumont (1999) have proposed a multistage model respectively of Early and Middle - Late Jurassic continental break - up of the Briançonnais of the W Alps. These results put some limitations, for this area at least, on both the applicability of the in - sequence mode of contraction in mountain belts, and on the simplistic assumption that only negligible rotation of the nappe units has taken place.

The most internal unit of the wider Giswiler Klippen area is formed by the Schlierenflysch nappe of South - to Ultra - Penninic origin. It is assumed to be the first unit to be displaced during Mesoalpine deformation and thus originally came to rest on the S Briançonnais margin, which started to develop into the nappe stack of the Préalpes Médianes. Subsequently the Schlierenflysch nappe was displaced by an important out of sequence detachment fault, possibly towards the end of Mesoalpine or during early Neoalpine movements. As a result the unit became positioned in front of the Préalpes Médianes.

The entire re - arranged Briançonnais - Schlieren complex was then transported onto the evolving S and N Helvetic Drusberg and Pilatus - Niederhorn nappes during Neoalpine times. After this latest emplacement the Schlierenflysch was partly overridden by the Briançonnais Klippen, i.e. its former tectonic substratum. This is evidenced by the overturned and imbricated structural style of the S margin of the Schlierenflysch, and possibly by the largely overturned nature of the individual Klippen units. The S margin is also locally folded into the frontal Drusberg nappe and overlying Wildflysch, which may represent a slightly earlier movement.

The evolution of the Habkern Zone during Neoalpine times is thought to show striking analogy with the multi - phase Schlierenflysch emplacement, which began earlier. The Wildflysch mass was severed from and thrusted over the S margin of the evolving Drusberg and possibly also Niederhorn nappes shortly after deposition in a trough, which was located very likely adjacent to the already emplaced Schlierenflysch nappe

This is evidenced by the polymict and exotic composition of the Habkern - Wildflysch consisting of both South - to - Ultrahelvetic as well as of South - to - Ultrapenninic elements. It consists of respectively pelagic Late Cretacous "Leimern" limestones / marls cum Eocene Globigerina marls of likely S South - to - Ultrahelvetic origin, versus Schlierenflysch type turbidite breccias - sand / siltstones and Habkern granite of much more internal, i.e. South - to - Ultrapenninic origin.

The Habkern - zone could be either interpreted as of purely tectonic or alternatively of sedimentary origin with an intense tectonic overprint. Following the sedimentary model the exotic components have to be considered reworked in an olisthostrome mode of deposition in front of the advancing or emplaced Schlierenflysch nappe.

This latter model is favoured. It rests on the observations

a) that the Late Eocene Globigerina of the Drusberg nappe grade into Wildflysch sedimentation as described above (Mohler 1966) and

b) on the presence of a thick analogous Globigerina Marl - Wildflysch type sequence ("Fleckenmergel") on the Pilatus nappe, which was transported together with the Ultrahelvetic complex (Soder 1949, Mohler 1966).

The notion is supported by the occurrence of a Habkern granite block, which has been resedimented with a basal conglomerates into the Wildflysch matrix ("Murchison block", Gigon 1952).

Finally an out of sequence thrust displaced the Habkern Wildflysch nappe partly to the front of both the Drusberg and Pilatus nappes in which position it was finally overridden and strongly tectonized by these respective units. These last movements may possibly also have given rise to the imbrication and thrusting of the underlying S margin of the Subalpine Molasse over its foreland.

In the internal imbricated thrust sheets of the Subalpine Molasse Gasser, 1968 described a transition from Flysch - into Molasse sedimentation. The presence of reworked Ultrahelvetic and Préalpes derived conglomerates and heavy minerals, signals that by Early Oligocene time the final positioning of these nappes had been completed.

6. Post - Nappe Development: Neotectonics

We owe the first attempt to Neotectonic including Holocene glacial morphological restoration to the speleo - geologist Th. Bitterli (1988), who established that successive karst levels of the Sieben Hengste - Schrattenflue karst systems tend to descend in jumps of 200m to 300m albeit without clear understanding of the underlying history of valley incision. While the deeper levels are likely to correpsond to glacial erosion processes, higher and older ones are located in excess of 1 km above and can only be explained by phased uplift of the karst system, i.e. with the regional relative lowering of the adjacent imbricate Molasse zone. A central difficulty lies in the fact that owing to glacial erosion fossil valley terraces and older alluvial pebbles have not been preserved in general. As a consequence practically the only witnesses for these pre - glacial movements are to be found in karst systems. It follows that without correlation to the surface absolute age dating remains a serious hurdle and for the time being the more thorough exploration of the karst systems and the study of their respective relative sequence of origin remains a very promising objective for some time to come.

Bitterli's pupblication was paralleled by a joint paper with his colleague Jeannin (Bitterli & Jeannin 1988) and by the latter's diploma thesis at the University of Neuchâtel (Jeannin 1989). In addition the Schrattenflue system was investigated by the diploma thesis of Blant (1989).

Jeannin introduced the first attempt to correlate Neotectonic karst development of the Sieben Hengst area with local structural surface and regional seismic criteria. He demonstrated that definition of relative age of deformation is greatly aided by combining surface fault and fracture analysis with morphological subsurface manifestations and hydrodyamic behaviour of faults. In addition he notably included detailed documentation and measurement of post - karst deformation such as fault planes, displaced fault gauge stalagmite material and deformed or displaced stalactite - stalagmite pairs. On the basis of the integration of all of these data he proposes three phases of Neotectonic deformation, corresponding to three coeval superimposed karst systems. The first and last phases are of compressive and the intermediate one of extensive nature.

Blant deployed a similar methodology to the Schrattenflue. In contrast to the Siebenhengst area sinistral stripe - slip mode of Neotectonic deformation seems to dominate the Schrattenflue segment. Follow - up investigations should shed light on this discrepancy.

Finally, in his Ph.D. thesis Jeannin (1998) investigated and applied deterministic modelling of both hydrodynamics and networks of karst systems in space and time. While primarily of technical application, improved and more thorough understanding of the 3D complexity of karst system will ultimately at the same time constitue an invaluable aid for the better understanding of Neotectonic Alpine development in general.

7. Rockslide Laui - Sörenberg

Apart from the quoted publications (Heim 1910, 1932; Kopp 1950) the diploma thesis by Manser (1991) on the rock slide of Sörenberg contains information of interest. Additionally unpublished reports exist, prepared by consulting geologists working for the geological engineering firms von Moos, Geotest and others (e.g. Wildberger, Liniger).

Since 1880 rock movements were observed on the SW slope of the Nünalpstock, which overlooks Sörenberg from the E. The movements accelerated at the turn of the century climbing to maximum rate in 1910. During Spring of this year a slide displaced the entire alp of Satz by several tens of m and caused the frontal parts of the mass to break apart. In the wake of this disintegration process several pulses of debris flows were triggered and eventually came to rest only at the Waldemme river some 750 m below break - off level (Heim, 1910). This author estimated the missing, i.e. displaced rock mass to be of the order of magnitude of 4 Mio m^3. Renewed flows were experienced in 1922, which yet again reached the Waldemme river, and minor ones in 1986. The break - off niche measures in the order of 400 m length and 100 m height and displays a subvertical outcrop of steeply dipping to overturned Schlierenflysch sequence, mostly in a beautiful amphitheatre shaped form (see also chapter 1. Introduction above).

In 1999, only one year after the VSP excursion, big debris flows yet again began threatening, following a wet autumn during the preceding year, and an exceptionally snowy winter and intensive Spring melting period, which was accompanied by long and intensive rain falls.

The nature of the movements are either more or less continuous small scale creeping at a rate of some cm to dm per year as measured by the Cantonal Geodetic Survey of Lucerne since 1975, or debris flows breaking away from the frontal part of the mass during periods of exceptionally heavy snow fall cum melting and / or rainy periods.

Newer studies, independently carried out by Wildberger (von Moos) and Liniger (Geotest) estimated the volume of the entire destabilized rock mass to measure in

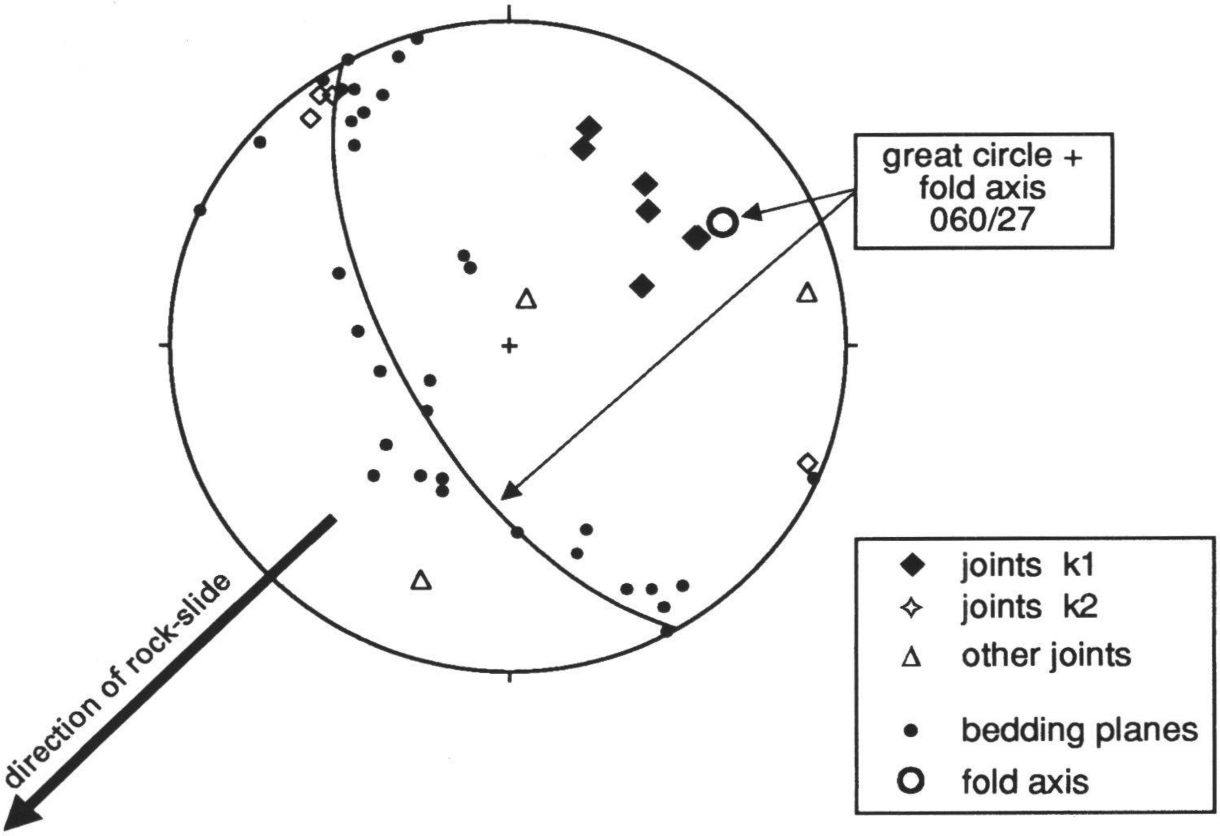

Fig. 8: Stereopraphic projection (lower hemisphere) of joints and bedding planes in the stable area above and behind the rock slide if Nünalpstock-Sörenberg (data be Geotest and von Moos).

the order of magnitude of 15 - 20 Mio cum. In the absence of drilling data these estimates are based on morphological, hydrological and geotechnical criteria.

The question of the primary reason of the movements is a complex one:

Manser describes a system of open, slope - subparallel fractures, which are superimposed on the fold - thrust geometry inherited from the emplacement of the Schlierenflysch nappe. They are a determining factor in weakening the material, may have caused the historical land slide and potentially represent the prime risk for inducing further rock mass movements. It remains an open question whether they were induced by Neotectonic faulting (Winkler 1983) or simply by gravity movements.

During the excursion sub - horizontal slickensides were observed on the Schlierenflysch outcrop of the Nünalpstock, which may provide at least partial support for the interpretation by Winkler.

Some structural data consisting of measurements of bedding planes and joints are available from Wildberger and Liniger and tend to support the above mentioned observations made by Manser. They are plotted in figure 8 as plane poles and fit well into a great circle oriented 060/27. The upper onset of the gliding plane of the moving rock mass is nearly perpendicular to the bedding. This is possible due to the prominent steep joints k1, relating to the fold axis perpendicular to the joints. Occasionally, however, the gliding plane jumps to joints with lower angles.

For geometrical reasons the steep joints k1 cannot represent the only effective gliding / detachment plane. Below the lower, unexposed parts of the moving rock mass low angle planes are extrapolated to exist in addtion to the k1 - system and in fact prevail, which must have functioned as gliding / detachment surfaces, either alone or in combination with other planes.

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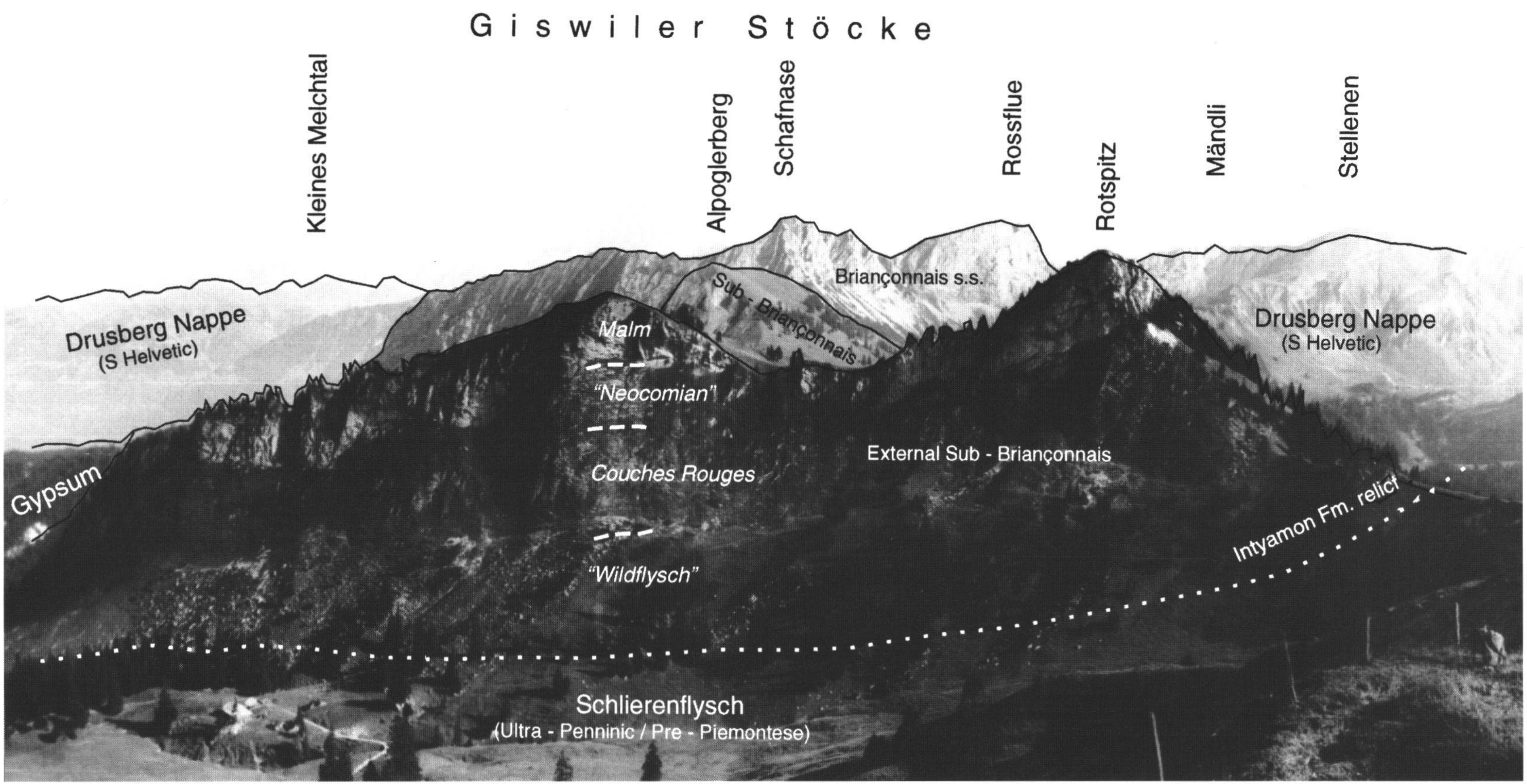


Plate 1: Panoramic overview on the Giswiler Klippen from N (Nünalpstock) to S.

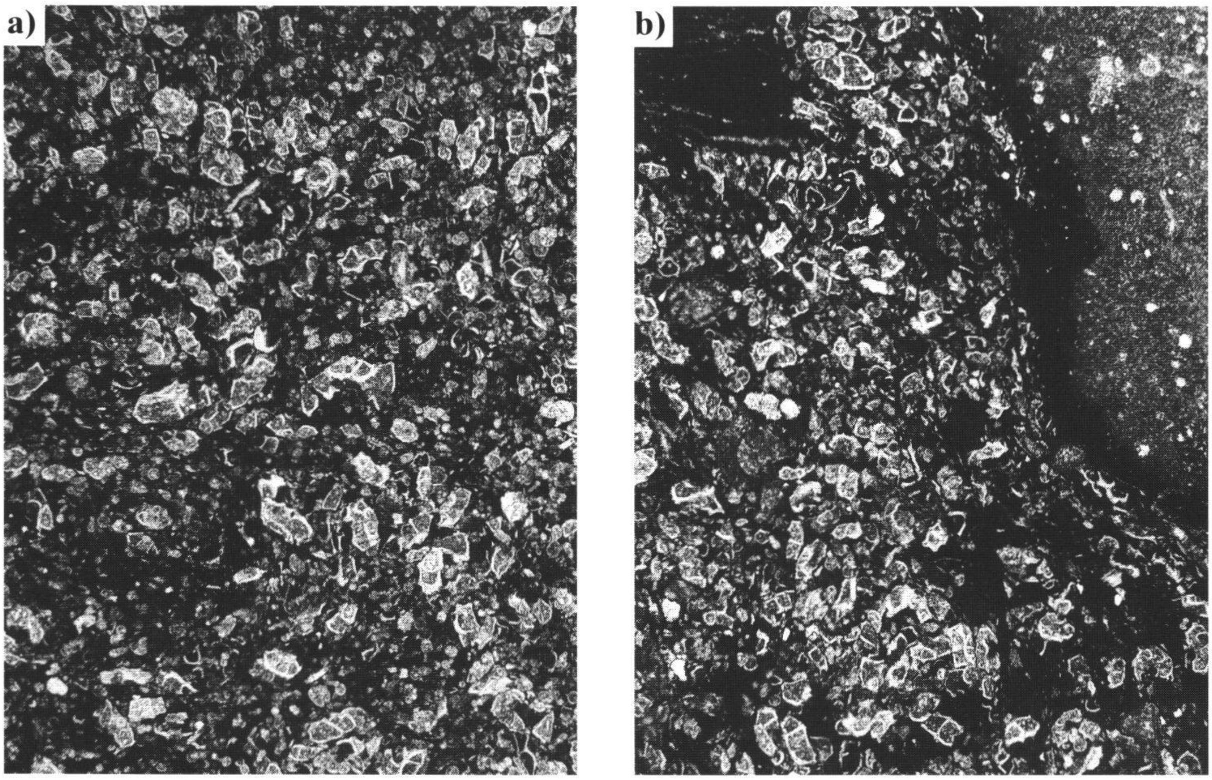
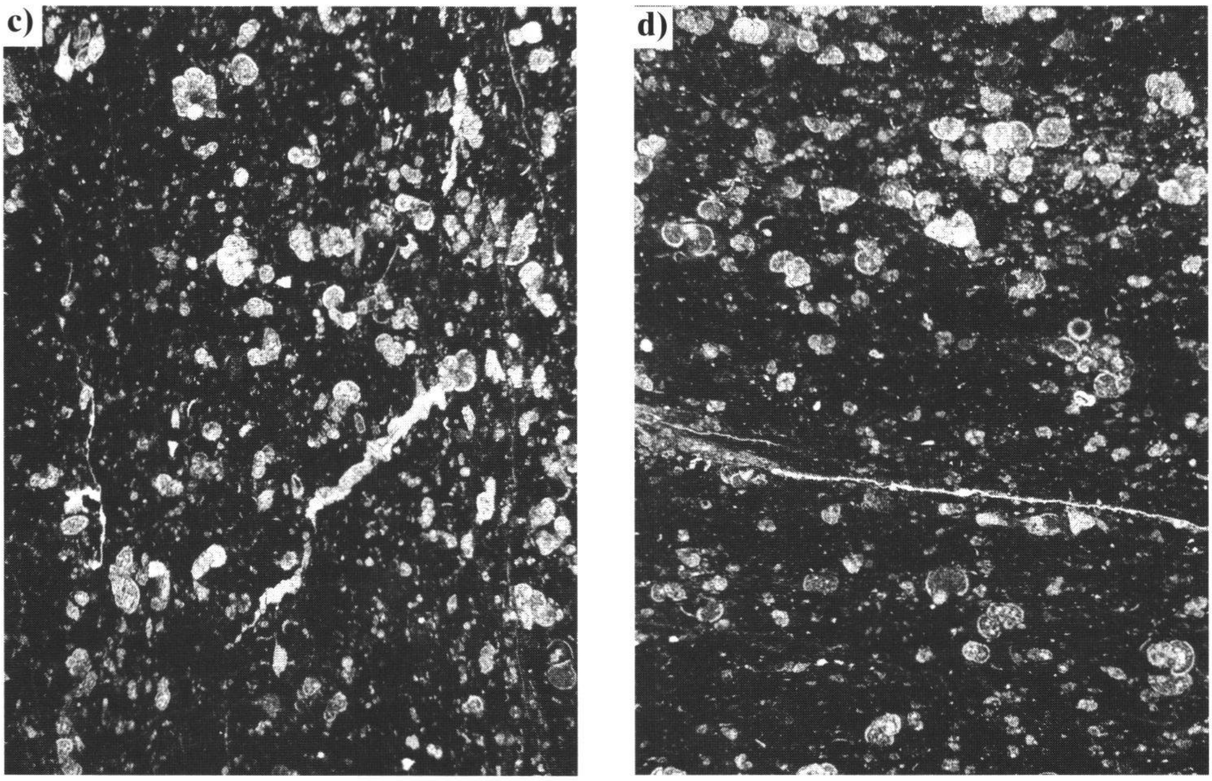


Plate 2: a) Microfacies of basal Couches Rouges, Rotspitz, Klippen.
b) Microfacies of Couches Rouges with reworked Neocomian components.
c) Microfacies of Leimern beds with *Globotruncana helvetica*.
d) Microfacies of Leimern beds with Globigerinids and Globorotalides.
For further explanations see Mohler 1966.



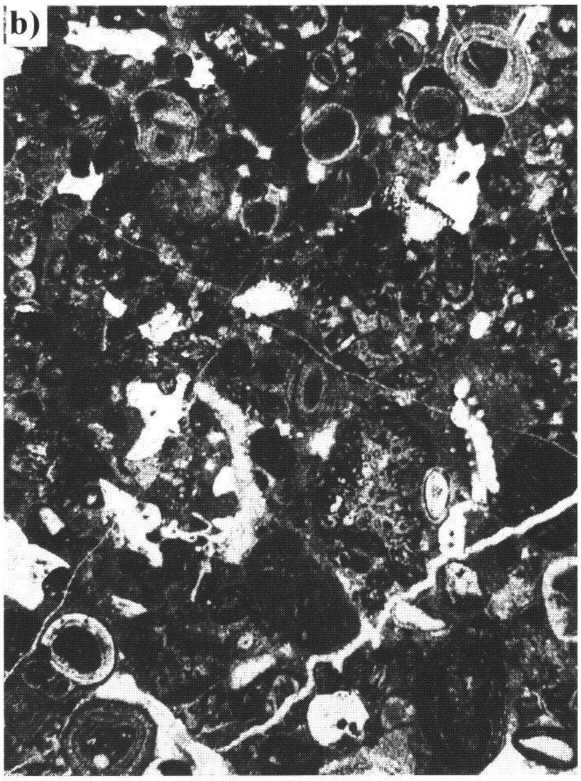


Plate 3: a) Microfacies of Middle – Late Jurassic "Knollenkalke" with *Saccocoma*, Rotspitz, Klippen.
b) Microfacies of Middle – Late Jurassic "Knollenkalke" with oolites, Rotspitz, Klippen.
c) Microfacies of "Wildflysch" (Early Eocene): breccia with components of Malm age, Rotspitz, Klippen.
d) Microfacies of "Wildflysch" (Early Eocene): sandstone with Globigerinids and Globorotalia, Rotspitz, Klippen.
For further explanations see Mohler 1966.