Zeitschrift: Eclogae Geologicae Helvetiae

Herausgeber: Schweizerische Geologische Gesellschaft

Band: 70 (1977)

Heft: 1

Artikel: Structural development of the infrahelvetic complex, eastern Switzerland

Autor: Milnes, Alan G. / Pfiffner, O. Adrian

DOI: https://doi.org/10.5169/seals-164615

Eclogae geol. Helv.	Vol. 70/1	Pages 83-95	3 figures in the text and 1 table	Basle, March 1977

Structural development of the Infrahelvetic complex, eastern Switzerland

By ALAN G. MILNES and O. ADRIAN PFIFFNER[1])

ABSTRACT

The Infrahelvetic complex encompasses all units which underly the basal thrust of the Helvetic nappes in eastern Switzerland (Cantons Graubünden, Glarus and St. Gallen). Four phases of deformation can be distinguished: 1. *Pizol:* emplacement of the exotic Ultrahelvetic units; 2. *Cavestrau:* emplacement of the allochthonous Subhelvetic units; 3. *Calanda:* ductile penetrative deformation of these together with the underlying autochthonous-parautochthonous Flysch, Mesozoic cover and pre-Mesozoic basement (Aar massif); 4. *Ruchi:* development of crenulation cleavage associated with movements on the basal Helvetic thrust (Glarus overthrust). Stratigraphic and radiometric data indicate that this deformational history started in mid-Oligocene times and ended during the Miocene, although late stage movements (gravitational) continued into the Pliocene. The Calanda and Ruchi phases were probably the early and late stages of a continuous process. Strain analysis has enabled strain rates to be estimated for the Calanda phase, giving long-time average values between 2×10^{-14} sec^{-1} (in highly deformed zones) and 5×10^{-15} sec^{-1} (bulk regional strain).

An evolutionary sequence for the whole area shows, at first, overthrusting from the south driven by gravitational spreading (Pizol and Cavestrau phases), followed by a period of intra-plate thickening, at a site not connected with a former plate boundary (Calanda and Ruchi phases). Final stages, up to the present, were dominated by differential uplift, causing northward tilting.

ZUSAMMENFASSUNG

Das Infrahelvetikum umfasst alle tektonischen Einheiten unter der basalen Überschiebung der helvetischen Decken in der Ostschweiz («Glarner Hauptüberschiebung»). Vier Deformationsphasen können unterschieden werden: 1. *Pizol-Phase:* Platznahme der exotischen (ultrahelvetischen) Einheiten; 2. *Cavestrau-Phase:* Bewegung der allochthonen (subhelvetischen) Einheiten; 3. *Calanda-Phase:* durchdringende Verformung mit gleichzeitig duktilem Verhalten der Gesteine dieser sowie der darunterliegenden, autochthon-parautochthonen Einheiten (Aarmassiv mit seiner mesozoisch-tertiären Hülle); 4. *Ruchi-Phase:* Ausbildung einer Runzelschieferung (crenulation cleavage) in Zusammenhang mit Bewegungen an der «Glarner Hauptüberschiebung». Stratigraphische und radiometrische Argumente sprechen dafür, dass diese Verformungsgeschichte post-unteroligozän ist und im Miozän ihren Abschluss fand, obschon späte Bewegungen (vielleicht Schweregleitung) bis ins Pliozän reichten. Die Calanda- und die Ruchi-Phase waren wahrscheinlich frühe und späte Teile eines kontinuierlichen Prozesses. Für die Calanda-Phase konnte durch Bestimmung des Verformungszustandes die Verformungsgeschwindigkeit berechnet werden; die Werte dafür bewegen sich - örtlich und zeitlich gemittelt - zwischen 2×10^{-14} sec^{-1} (stark verformte Bereiche) und 5×10^{-15} sec^{-1} (mittlere regionale Verformung).

Über das ganze Untersuchungsgebiet betrachtet, beginnt die Abfolge der tektonischen Prozesse mit Überschiebungen aus dem Süden infolge von Schwereausbreitung (Pizol- und Cavestrau-Phase), gefolgt von einer Periode von platteninterner Verdickung (Calanda- und Ruchi-Phase) an einem Ort, der in keinem direkten Zusammenhang mit einer früheren Plattengrenze steht. Die Abfolge schliesst mit einer Episode von differenzieller Hebung, welche eine Kippung bewirkte (relative Senkung der Molassebecken gegenüber den Alpen) und heute noch nicht ganz ausgeklungen ist.

[1]) Geological Institute, Swiss Federal Institute of Technology, CH-8092 Zurich.

Introduction

The Infrahelvetic complex[2]) in eastern Switzerland, that is, the Aar massif with its parautochthonous, allochthonous and exotic cover sediments, is one of the classical areas in the Alps (ALB. HEIM 1878, OBERHOLZER 1933). Recently, the area has gained new interest from fundamental work in various directions. An attempt has been made at a palinspastic reconstruction of the Helvetic belt (TRÜMPY 1969), and the mechanical aspects of the famous Glarus overthrust, separating the Helvetic nappes from the underlying Infrahelvetic complex, have been considered from theoretical and field geological points of view (HSÜ 1969, SCHMID 1975). We have been engaged in detailed structural investigations and strain analysis in the Infrahelvetic complex over the past five years. The aim of this paper is to give a short description of the structural relations there and to integrate this into a coherent picture of the tectonic evolution of the whole region.

Geologic setting

A generalized tectonic map of the area under consideration (Fig. 1, see also SPICHER 1972) shows a series of major units lying one above the other in the form of a broad arch, plunging eastwards. In the present eroded stumps of this arch, the highest unit outcrops to the east, the Austroalpine zone, followed by the underlying Penninic zone and the still lower Helvetic zone towards the west (see TRÜMPY 1960). The Helvetic zone is subdivided into the overlying Helvetic nappe complex and the underlying Infrahelvetic complex by the Glarus overthrust, as mentioned above. The generally accepted schematic picture of this sequence of units is that they were juxtaposed by successive overthrusting from the south, so that usually the higher the unit the more southerly its situation was in the pre-orogenic set-up. The actual sequence of events leading to this juxtaposition, however, was extremely intricate (see, for instance, TRÜMPY 1973, MILNES 1974*a*, AYRTON & RAMSAY 1974) and often difficult to unravel. The importance of the Infrahelvetic complex is that the structural events can be fitted into a fairly well-known stratigraphic framework and that the picture that emerges provides some boundary conditions in interpreting the evolution of the other units, where the relations are not so clear.

The term Infrahelvetic complex is used here to cover all the units below the Glarus overthrust. It is mainly made up of Aar massif basement and its parautochthonous, Mesozoic to lower Tertiary cover. The basement consists of granitic and high-grade metamorphic rocks of Hercynian age, together with narrow zones of Carboniferous sediments and volcanics (HÜGI 1941, WIDMER 1948, FRANKS 1968). The cover ranges from Triassic to Oligocene in age, but mainly consists of Upper Jurassic (Malm) and Cretaceous limestones and Eocene marls which grade up into flysch-type sandstones. The stratigraphy of these rocks has been subject of many detailed investigations (for example, Trias - BRUNNSCHWEILER 1948; Lias - TRÜMPY 1949; Dogger - DOLLFUS 1965; Malm - PFIFFNER 1972*a*, *b;* Cretaceous -

[2]) The Infrahelvetic complex is defined here in a purely geometrical sense and covers all the units below the Glarus overthrust, whatever their origin may be.

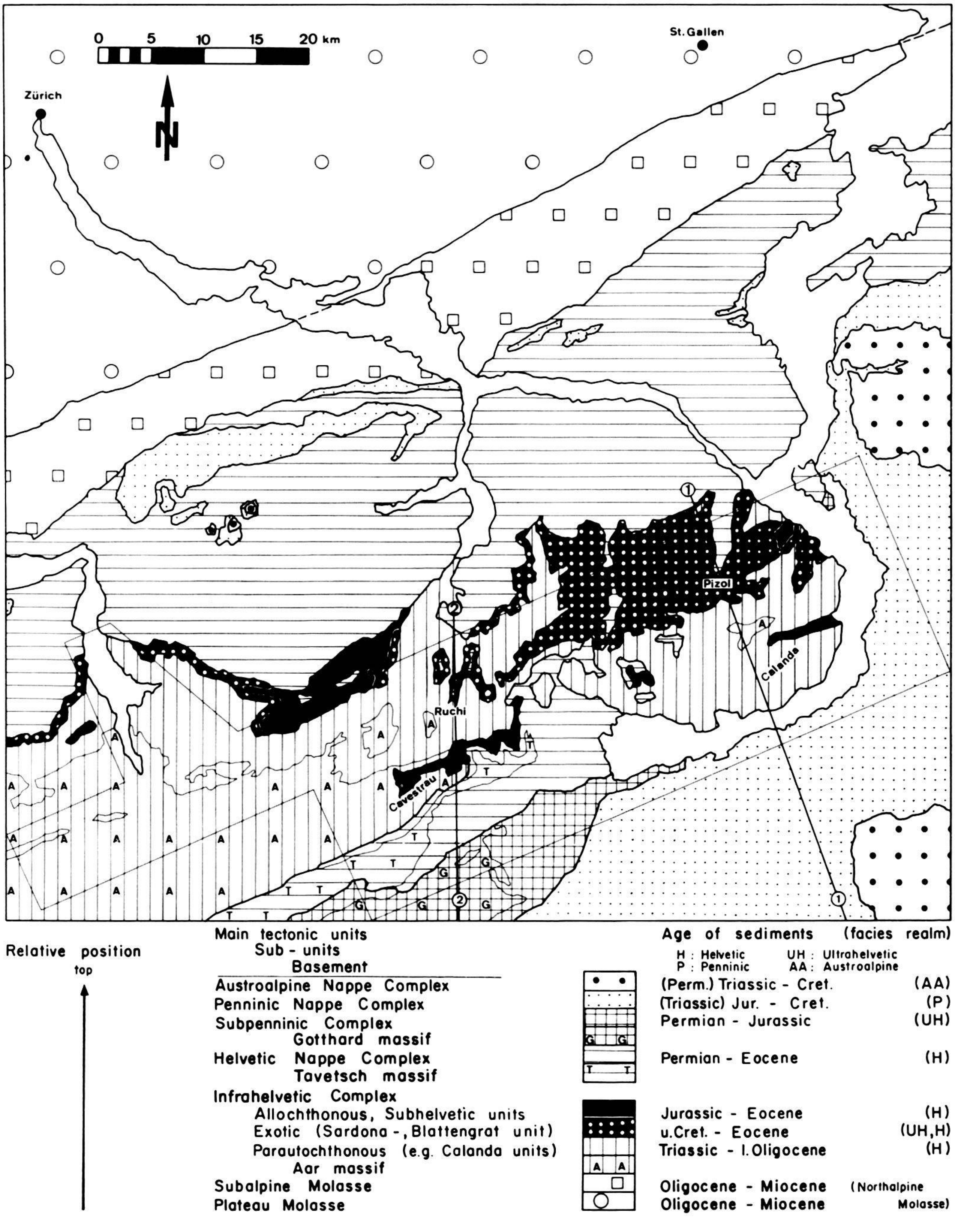

Fig. 1. Tectonic map of the region between Reuss and Rhine valleys (eastern Switzerland) showing the area investigated. Traces 1 and 2 show the location of the cross sections of Figure 2.

ARN. HEIM 1916, OBERHOLZER 1933; Tertiary - STYGER 1961, SIEGENTHALER 1974). The youngest sediments are dated as lower Oligocene by their abundant and well-known fish fossils (WETTSTEIN 1887, FRÖHLICHER & WEILER 1952). On top of this succession, often separating it from the Glarus overthrust, lie various masses of stripped off cover which have been subdivided into allochthonous and exotic according to their origin (i.e. facies belt affiliation). The allochthonous units (the Subhelvetic nappes, cf. F. FREI 1965, TRÜMPY 1969) contain Mesozoic sediments similar in facies to the Helvetic nappes and the cover of the very southernmost part of the Aar massif. The exotic strip sheets are derived from further south (southernmost Helvetic and Ultrahelvetic, and perhaps even Penninic realms, cf. BISIG 1957, RÜEFLI 1959, WEGMANN 1961) and underly the allochthonous units when the two types occur together.

Structural relations

The rocks in the area under investigation show four phases of deformation, two of which resulted in widespread foliations (see Table), and these have been named after type localities, much like in stratigraphy, in order to facilitate correlation (cf. TOBISCH et al. 1970, MILNES 1974*b*). These phases are as follows (see also Table):

1. *Pizol* (emplacement of exotic units),
2. *Cavestrau* (early large scale folds and initiation of movement of allochthonous units),
3. *Calanda* (penetrative ductile deformation),
4. *Ruchi* (ductile deformation associated with continued movement on the Glarus overthrust).

The structural relations are summarized in two cross sections through the type localities (Fig. 2) and will be described in detail elsewhere (PFIFFNER, in prep.); in the following only the main features will be discussed.

Table: *Correlation of the main phases of deformation in the Infrahelvetic complex with those recognized by earlier authors*

TRÜMPY 1969	SCHMID 1975	this paper
Späthelvetische Stauch- und Gleitphasen	—	(phase not named)
Helvetische Hauptphasen	phase 3 phase 2	Ruchi phase Calanda phase
Frühhelvetische Überfaltungsphase	—	Cavestrau phase
Oligozäne Divertikel	phase 1	Pizol phase

1. Pizol phase structures

This phase of deformation, named after the Pizol mountain (Fig. 1 and 2), involved the emplacement of the exotic strip sheets (Sardona and Blattengrat units), which has long been recognized as the earliest major act of the orogenic history of the region (ARN. HEIM 1911, LEUPOLD 1937). This interpretation is based on stratigraphic evidence (Upper Cretaceous of the exotic strip sheets rests on Oli-

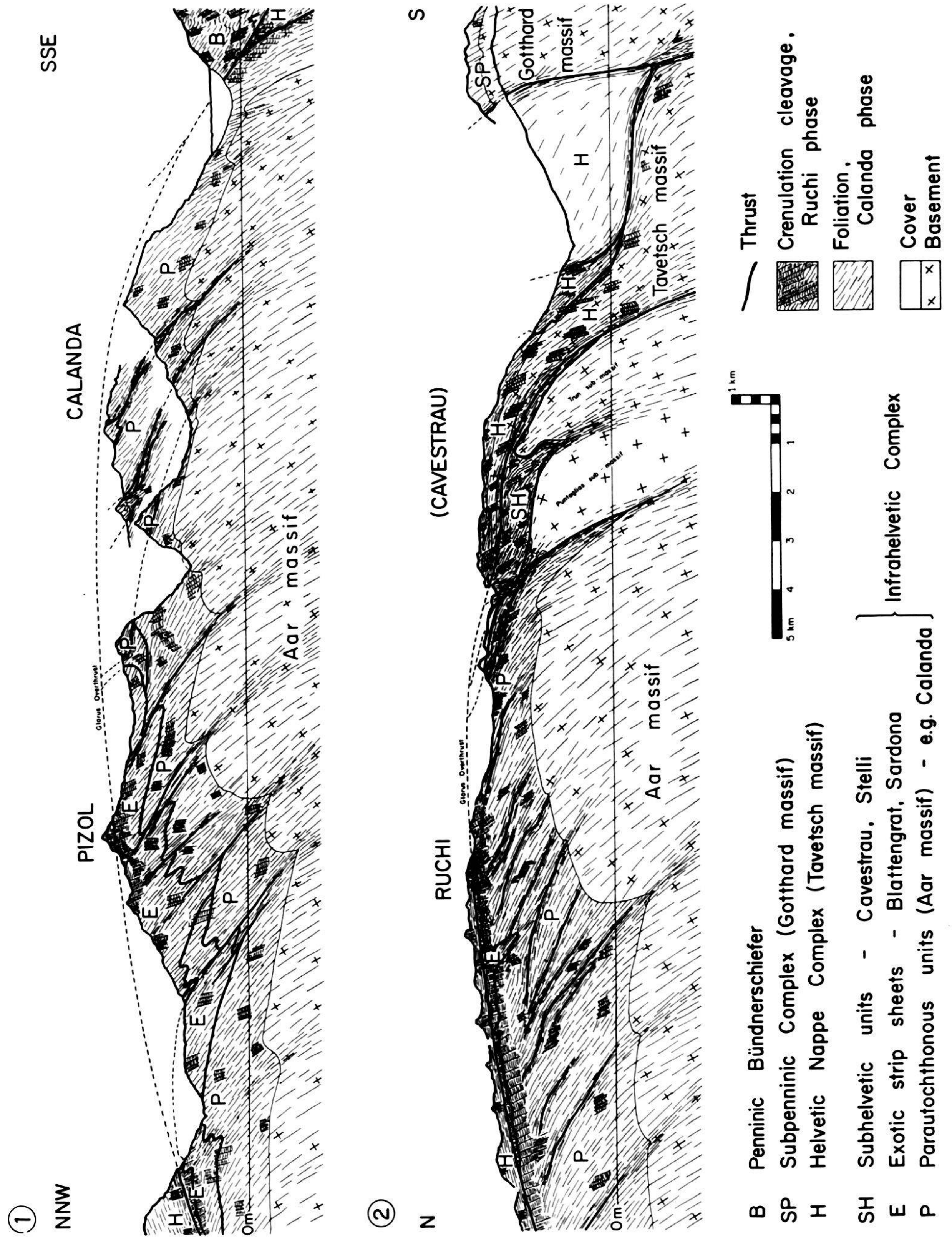

Fig. 2. Structural cross sections through the Infrahelvetic complex (for location, see Fig. 1).

gocene of the Aar massif cover). Structural evidence is lacking; any penetrative structures which may have been produced must have been obliterated by later events, especially during the Calanda phase (see also SCHMID 1975). However, much of the chaotic folding visible within the exotic strip sheets (e.g. RÜEFLI 1959, Pl. II) and some of the folding and thrusting in the Tertiary rocks underlying them (e.g. SIEGENTHALER 1974, photograph 1) may have been initiated at this time.

2. *Cavestrau phase structures*

The phase in which a first emplacement of the allochthonous (Subhelvetic) units occurred is named after the mountain Cavestrau (Fig. 1). Penetrative deformation in this phase was strongly localized in this and a few other areas (e.g. Stelli, north of Calanda) and did not result in a regional cleavage. In the Cavestrau chain, the southernmost part of the Aar massif (Punteglias and Trun sub-massifs, Fig. 2) has been stripped of its cover (which most probably now lies further north as the allochthonous Grießstock unit) and an inverted sequence, presumably the lower limb of a large, north-facing recumbent anticline, has taken its place (cf. KÄCH 1969, 1972). In the Cavestrau as well as in the Stelli area, parts of these lower limbs were affected by subsequent folding during the Calanda phase, producing antiformal synclines and synformal anticlines.

3. *Calanda phase structures*

The main penetrative deformation throughout the whole of the Infrahelvetic complex is distinguished as the Calanda phase (Fig. 1 and 2). Although there is no indication that the Calanda and Cavestrau phases are separated by a static interval, the bedding/cleavage relations in the inverted limb of the Cavestrau fold clearly show a change in conditions. The Calanda phase is characterized by a very penetrative deformation, with ductile behaviour of most of the rock types producing a pronounced cleavage (dipping 25-30° to the SSE) and stretching lineation (see also PFIFFNER 1972*a*). The foliation is axial planar to major and minor folds and varies in style according to lithology. The stretching lineation in the foliation plane, and the corresponding elongation direction of the numerous strain markers, has a rather constant down-dip orientation. In contrast, the minor fold axes often show girdle distributions, and the major folds have variable axes with a tendency to be subhorizontal (see also SCHMID 1975, Fig. 4 A/B). Numerous small thrusts developed in the parautochthonous series, producing a large number of small tectonic units (see e.g. HELBLING 1938, Pl. 22; STYGER 1961, Table 1; BÜRGISSER & FELDER 1974, Table 1). These thrusts are parallel to the foliation and accompanied by a zone of a few meters thickness in which the rocks are more intensely foliated and strained, as indicated, for example, by deformed oolites. It is therefore concluded that the foliation and thrusts formed at the same time. Basement was involved in the folding and thrusting processes of the Calanda phase at an early stage and led in some instances to the arcuate shape of thrust surfaces (cf. Fig. 2).

The time bracket for the Calanda phase deformation can be given as Upper Oligocene. The youngest sediments affected are Lower Oligocene (Engi-Dachschiefer member, see above), but since the Pizol and Cavestrau phases also post-date their deposition, the Calanda phase must be considerably later.

The upper limit is given by a metamorphic event which marks the end of the Calanda phase. Rosette-shaped clusters of chloritoid porphyroblasts grew in certain lithologies across the Calanda phase foliation but were subsequently somewhat rotated whilst flattening in the matrix continued. Metamorphism was highest in the south of the Infrahelvetic complex where it reached greenschist facies conditions (see also M. FREY et al. 1974; M. Frey, pers. comm., 1976). The acme of this metamorphism lies probably in the time around the Oligocene-Miocene boundary (18–24 my, according to K/Ar dates on illites, see M. FREY et al. 1974; M. Frey, pers. comm., 1976). A similar relation between porphyroblast growth and main penetrative deformation has been reported from the cover of the Gotthard massif (CHADWICK 1968, AYRTON & RAMSAY 1974).

Strain produced by the Calanda phase was very heterogeneous. There were narrow zones near thrust surfaces where the strain ellipsoid, as calculated from deformed pebbles and ooids, attained axial ratios of up to 4.5:1:0.33, whereas bulk regional axial ratios were more in the region of 2:1:0.5. Long and intermediate axes of the strain ellipsoid are subparallel to the foliation, the long axis being parallel to a stretching lineation. The time available for this deformation was 5–10 million years (Fig. 3), so slowest time-averaged strain rates in zones of high strain were in the order of 2×10^{-14} sec^{-1}, assuming a coaxial deformation path and a constant strain rate over this time interval. Time-averaging the estimated bulk regional strain rate yields values around 5×10^{-15} sec^{-1}.

4. *Ruchi phase structures*

The Calanda phase foliation is affected in irregular patches by small scale crenulations often accompanied by a well-developed crenulation cleavage (Fig. 2). This deformation is particularly concentrated in – but by no means restricted to – the vicinity of the Glarus overthrust and the shear direction indicated by it (anticlockwise rotation as one looks eastwards, cf. Fig. 2) is the same as the one that the movements along the thrust surface indicate (overthrusting from the south), We conclude – in agreement with SCHMID (1975, p. 255–257) – that this crenulation cleavage is related to movements along the overthrust (SCHMID phase 3, cf. Table). Ruchi phase structures not only occur below and above the Glarus overthrust but also up in the Penninic Bündnerschiefer (cf. Fig. 2). The thrust plane truncates Calanda phase structures (e.g. thrust surfaces in Fig. 2), but there is no argument for a specific time of non-deformation between the Calanda and Ruchi phases.

In the south, the thrust surface is parallel to the Calanda phase foliation in both the underlying Infrahelvetic complex and the overlying Helvetic nappes; this relation is modified as one goes progressively northwards. On the flat top of the arch formed by the thrust surface, for example, only the foliation of the Helvetic nappes retains this parallelism, while in the Infrahelvetic complex the two features subtend a progressively increasing angle (cf. Fig. 2). From this we conclude that the Glarus overthrust developed out of a major Calanda phase structure. In contrast to the Calanda phase foliation, the crenulation cleavage of the Ruchi phase is always oriented at a high angle to the thrust surface, except for the uppermost two meters of the footwall. Its development depends strongly on the lithology and pre-existing anisotropies (e.g. bedding, Calanda phase foliation); thus one finds a crenulation cleavage particularly in slates and other rocks containing an appreciable amount of layer-silicates. When lithological discontinuities dominate, the Ruchi phase produced folds of various styles (cf. SCHMID 1975, Fig. 6) and in relatively massive rocks there are usually no signs of deformation detectable macroscopically. Similarly, the structures produced during the Calanda phase also depend on the lithology and in some places a Calanda phase crenulation cleavage occurs. Thus, structural correlation on the basis of style is a hazardous procedure in this region.

In the Infrahelvetic complex, movements later than those of the Ruchi phase are represented by strike slip and reverse slip faults associated with kakirites (see PFIFFNER 1972*a*, *b*); similar structures have been reported from the Helvetic nappes (Späthelvetische Stauch- und Gleitungsphasen, see SCHINDLER 1959, TRÜMPY 1969).

Tectonic evolution and discussion

Combining our own data with those of others makes it possible to attempt a synthesis of the tectonic evolution, as illustrated in Figure 3. In addition to the structural and stratigraphic arguments (see also TRÜMPY 1969, SCHMID 1975) we have used various other lines of evidence, in particular, from the metamorphic history and radiometric age dating (M. FREY et al. 1974), from the geology of the Penninic and Austroalpine zones south of the area (TRÜMPY et al. 1969, MILNES 1974*a*) and from component analyses of the synorogenic Molasse conglomerates (SPECK 1953, DIETRICH 1969). The following remarks indicate the simplest possible interpretation of this large body of data and of other information from the voluminous literature.

As far as the Infrahelvetic complex is concerned, the story can be started during the Upper Eocene (around 40 my ago), when the Aar massif was the site of rapid flysch-type sedimentation with detritus originating in an area of andesitic volcanism. No sediments of this age are known from the south, i.e. on the south side of the Tavetsch massif and on the Gotthard massif, and throughout the Penninic-Austroalpine region, the youngest desposits found in units derived from these areas are of Middle Eocene age. Some time later - at the Eocene-Oligocene boundary - the first signs of tectonic movements appear in the Aar massif area in the form of widespread slumping (SIEGENTHALER 1974), and volcanic detritus is no longer being supplied, so the situation in earliest Oligocene times may have been roughly as in sketch *A* (Fig. 3). An active collision zone is sited to the south - the ocean which once separated the Austroalpine and Penninic continental masses has closed and the Austroalpine nappe complex is overriding northwards, accreting large quantities of Penninic Flysch in the process. The latter now forms a cordillera-like coastal region, simultaneously shedding debris into and encroaching upon the now quite narrow arm of the sea. There, the youngest formation in the cover of the Aar massif is being deposited - the Engi-Dachschiefer member with its famous fossil fish - a sequence of turbidites devoid of calcareous, volcanic or coarse clastic material.

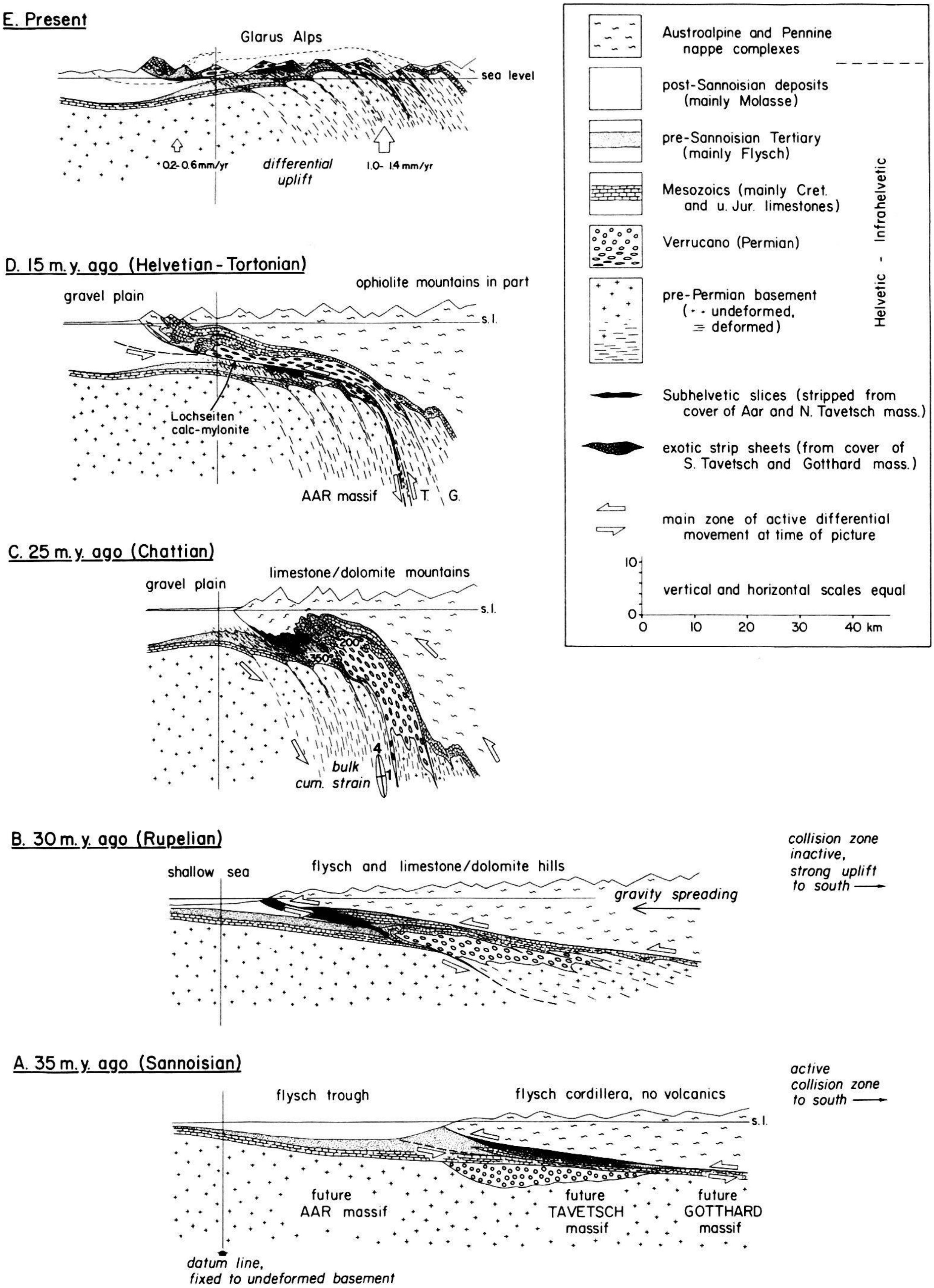

Fig. 3. Sketches showing the tectonic evolution of the Infrahelvetic complex and the overlying Helvetic nappes.

This marks the beginning of the period during which first the exotic and then the allochthonous units were emplaced. It is difficult to deduce the actual conditions at this time, due to the intensity of later movements. Hovewever, it seems unlikely that these units were emplaced by gravity sliding down northward dipping slopes, as envisaged by TRÜMPY (1969). The successively more ductile nature of the deformation, culminating in the Calanda phase, strongly suggests a progressive increase in the depth of burial of the future Infrahelvetic and Helvetic crustal segments during this period. This increase in depth is also indicated by the fact that the sea to the north became steadily shallower without the advent of coarse clastic sedimentation, suggesting a southward tilting of this segment (compare sketches *A* and *B*, Fig. 3). We envisage a northward advancing, overrriding mass of Penninic Flysch driven by a process of gravity spreading (cf. ELLIOTT 1976) due to a regional northward surface slope. This is supported by evidence indicating that isostatic uplift replaced active differential movement in the collision zone to the south during this time (MILNES, in press). The emplacement of the exotic strip sheets was not "avalanche-like" (LEUPOLD 1943, p. 286; TRÜMPY 1969, p. 127) but rather "glacier-like", by dragging up-slope at the base of the northward flowing Penninic-Austroalpine tongue. By Middle Oligocene times (sketch *B*, Fig. 3), the zone of main differential movement has widened and now involves parts of the hitherto rigid Tavetsch-Gotthard basement block. The period of crustal shortening which is to culminate in the succeeding Calanda phase (between sketches *B* and *C*, Fig. 3) has begun.

The Calanda phase movements, in Upper Oligocene times, resulted in an estimated shortening of the Infrahelvetic and Helvetic basement to about half its original width (sketch *C*, Fig. 3). This was coupled with extension in a subvertical direction which resulted, on the one hand, in active uplift and high relief, and on the other, in crustal thickening. The effects of the former are seen in the onset of coarse clastic Molasse sedimentation (Nagelfluh) to the north, with huge fans and debris cones in which the components are mainly of Austroalpine derivation. The latter is indicated by the effects of Calanda phase deformation in the basement (folding, foliation, cf. Fig. 2) and by the fact that temperatures should be rising during this time (see below). The "root" of crustal material which now developed initiated isostatic uplift of the whole region and is probably the cause of the present day movements (sketch *E*, Fig. 3, see also SCHAER & JEANRICHARD 1974). Depths postulated in sketch *C* (Fig. 3) are partly based on estimated temperatures of metamorphism (M. Frey, pers. comm., 1976), which were highest at the close of the Calanda phase. It is constructed assuming a "normal" average geothermal gradient of 30 °/km, based on the general dynamic situation, which does not seem favourable for postulating large-scale disturbance of the isotherms at the time under consideration (simultaneous uplift and root formation), and on the lack of evidence for a supplementary heat source.

Although we take sketch *C* as illustrating the situation at the end of the Calanda phase, it should be emphasized particularly in this context that it is merely a single frame from a continuously changing sequence. The phase of slow deformation of the order of 5×10^{-15} sec^{-1} over a broad crustal segment (Calanda phase) grades imperceptibly into one of very rapid deformation concentrated in a narrow zone - the Lochsiten calc-mylonite, marking the Glarus overthrust. In the latter, average strain rates of 10^{-10} sec^{-1} have been estimated (SCHMID 1975). In the Infrahelvetic complex, the Ruchi phase structures seem to be related to these late stage movements on this thrust. We envisage the complexes on both sides of the thrust as continuing to deform very slowly at this stage (Ruchi phase crenulation cleavage and, possibly, in some zones, continued development of the Calanda phase foliation).

Sketch *D* (Fig. 3) shows a reconstruction for mid-Miocene times. Movements on the Glarus overthrust are probably in progress, although the dating of this is rather imprecise (see also TRÜMPY 1973, p. 243), so the picture illustrates conditions at some time in our Ruchi phase. Thrusting along the north margin of the Alps probably continued long afterwards, however, since the youngest Molasse deposits which are disturbed are of Messinian age. These very late stage effects may have been partly gravitational since differential uplift (northward tilting) became an important process by then. Some minor faulting may have been associated with this differential uplift, but there is no evidence for a horst-like lifting of the Aar massif alone or for a major fault along the Rhine valley which could be associated with it (cf. TRÜMPY 1973).

Conclusions

The deformational history of the Infrahelvetic complex which underlies the Glarus overthrust in eastern Switzerland started in mid-Oligocene and ended in Miocene times, during which time four main phases can be distinguished. The first phases (Pizol and Cavestrau) seem to be caused by gravity spreading from a regional topographic high resulting from a continent-continent collision to the south (the suturing of the Penninic and Austroalpine zones). The other phases (Calanda and Ruchi) represent an episode of considerable intra-plate thickening in a zone not coincident with former plate boundaries. During these phases the Infrahelvetic and adjacent Helvetic complexes lay continuously within the ductile field of most rock types (p-T-$\dot{\varepsilon}$-conditions), although the deformation was often strongly heterogeneous. They were deformed and juxtaposed by crustal compression, with gravity sliding playing a subordinate role only at a very late stage.

Acknowledgements

This work was made possible by financial support from the "Schweizerischer Nationalfonds" (project 2.436.71). R. Trümpy, S. Schmid and D. Elliott helped us by criticizing an early draft of the manuscript, R. Trümpy also by his constant interest in our work and by many useful discussions. We are, of course, alone responsible for the interpretations presented.

REFERENCES

AYRTON, S. N., & RAMSAY, J. G. (1974): *Tectonic and metamorphic events in the Alps.* - Schweiz. mineral. petrogr. Mitt. *54,* 609-639.

BISIG, W. (1957): *Blattengratflysch und Sardonaflysch im Sernftal nördlich der Linie Richtelipass - Elm - Ramintal - Grosse Scheibe.* - PhD. thesis, ETH Zürich.

BRUNNSCHWEILER, R. O. (1948): *Beiträge zur Kenntnis der Helvetischen Trias östlich des Klausenpasses.* - PhD. thesis, Univ. Zürich.

BÜRGISSER, H., & FELDER, T. (1974): *Zur Geologie der Südabdachung der Segnas-Ringel-Gruppe (Vorderrhein, Graubünden).* - Eclogae geol. Helv. *67,* 457-468.

CHADWICK, B. (1968): *Deformation and metamorphism in the Lukmanier region, Central Switzerland.* - Bull. geol. Soc. Amer. *79,* 1123-1150.

DIETRICH, V.J. (1969): *Die Ophiolithe des Oberhalbsteins (Graubünden) und das Ophiolithmaterial der ostschweizerischen Molasseablagerungen, ein petrographischer Vergleich.* - Lang, Bern.

DOLLFUS, S. (1965): *Über den Helvetischen Dogger zwischen Linth und Rhein.* - Eclogae geol. Helv. *58,* 453-554.

ELLIOTT, D. (1976): *The motion of thrust sheets.* - J. geophys. Res. *81,* 949-963.

FRANKS, G.D. (1968): *A study of upper Paleozoic sediments and volcanics in the northern part of the eastern Aar massif.* - Eclogae geol. Helv. *61,* 49-140.

FREY, F. (1965): *Geologie der östlichen Claridenkette.* - Vjschr. natf. Ges. Zürich *110,* 1-277.

FREY, M., HUNZIKER, J.C., FRANK, W., BOCQUET, J., DAL PIAZ, G.V., JÄGER, E., & NIGGLI, E. (1974): *Alpine metamorphism of the Alps: a review.* - Schweiz. mineral. petrogr. Mitt. *54,* 247-290.

FRÖHLICHER, H., & WEILER, W. (1952): *Die Fischfauna der unterstampischen Molasse des Entlebuchs (Kt. Luzern).* - Eclogae geol. Helv. *44,* 353-359.

HEIM, ALB. (1878): *Untersuchungen über den Mechanismus der Gebirgsbildung im Anschluss an die geologische Monographie der Tödi-Windgällen-Gruppe* (Bd. I/II). - Schwabe, Basel.

HEIM, ARN. (1911): *Zur Tektonik des Flysches in den östlichen Schweizeralpen.* - Beitr. geol. Karte Schweiz [N.F.] *31,* 37-48.

— (1916): *Über Abwicklung und Fazieszusammenhang in den Decken der nördlichen Schweizer-Alpen.* - Vjschr. natf. Ges. Zürich *61,* 474-487.

HELBLING, R. (1938): *I. Die Anwendung der Photogrammetrie bei geologischen Kartierungen. - II. Zur Tektonik des St. Galler Oberlandes und der Glarneralpen.* - Beitr. geol. Karte Schweiz [N.F.] *76.*

HSÜ, K.J. (1969): *A preliminary analysis of the statics and kinetics of the Glarus overthrust.* - Eclogae geol. Helv. *62,* 143-154.

HÜGI, T. (1941): *Zur Petrographie des östlichen Aarmassivs (Bifertengletscher, Limmenboden, Vättis) und des Kristallins von Tamins.* - Schweiz. mineral. petrogr. Mitt. *21,* 1-120.

KÄCH, P. (1969): *Zur Tektonik der Brigelserhörner.* - Eclogae geol. Helv. *62,* 173-183.

— (1972): *Geologie der Brigelserhörner (Bündnerisches Vorderrheintal).* - PhD. thesis, Univ. Zürich.

LEUPOLD, W. (1937): *Zur Stratigraphie der Flyschbildungen zwischen Linth und Rhein.* - Eclogae geol. Helv. *30,* 1-23.

— (1943): *Neue Beobachtungen zur Gliederung der Flyschbildungen der Alpen zwischen Reuss und Rhein.* - Eclogae geol. Helv. *35* (1942), 247-291.

MILNES, A.G. (1974a): *Structure of the Pennine zone (Central Alps): a new working hypothesis.* - Bull. geol. Soc. Amer. *85,* 1727-1732.

— (1974b): *Post-nappe folding in the Western Lepontine Alps.* - Eclogae geol. Helv. *67,* 333-348.

— (in press): *Structural zones and continental collison, Central Alps.* - Tectonophysics.

OBERHOLZER, J. (1933): *Geologie der Glarneralpen.* - Beitr. geol. Karte Schweiz [N.F.] *28.*

PFIFFNER, O.A. (1972a): *Neue Kenntnisse zur Geologie östlich und westlich des Kunkelspasses.* - Eclogae geol. Helv. *65,* 555-562.

— (1972b): *Geologische Untersuchungen beidseits des Kunkelspasses zwischen Trin und Felsberg.* - Diplom thesis, ETH Zürich.

— (in prep.): *Tektonische Untersuchungen im Infrahelvetikum.* - PhD. thesis, ETH Zürich.

RÜEFLI, W.H. (1959): *Stratigraphie und Tektonik des eingeschlossenen Glarner Flysches im Weisstannental (St. Galler Oberland).* - PhD. thesis, ETH Zürich.

SCHAER, J.-P., & JEANRICHARD, F. (1974): *Mouvements verticaux anciens et actuels dans les Alpes suisses.* - Eclogae geol. Helv. *67,* 101-120.

SCHINDLER, C.M. (1959): *Zur Geologie des Glärnisch.* - Beitr. geol. Karte Schweiz [N.F.] *107.*

SCHMID, S.M. (1975): *The Glarus overthrust: field evidence and mechanical model.* - Eclogae geol. Helv. *68,* 247-280.

SIEGENTHALER, C. (1974): *Die Nordhelvetische Flysch-Gruppe im Sernftal (Kt. Glarus).* - PhD. thesis, Univ. Zürich.

SPECK, J. (1953): *Geröllstudien in der subalpinen Molasse am Zugersee und Versuch einer paläogeographischen Auswertung.* - PhD. thesis, Univ Zürich.

SPICHER, A. (1972): *Tektonische Karte der Schweiz 1:500000.* - Schweiz. geol. Komm.

STYGER, G.A. (1961): *Bau und Stratigraphie der nordhelvetischen Tertiärbildung in der Hausstock- und westlichen Kärpfgruppe.* - PhD. thesis, Univ. Zürich.

TOBISCH, O.T., FLEUTY, M.J., MERH, S.S., MUKHOPADHYAY, D., & RAMSAY, J.G. (1970): *Deformational and metamorphic history of Moinian and Lewisian rocks between Strathconon and Glen Affric.* - Scott. J. Geol. *6*, 243-265.

TRÜMPY, R. (1949): *Der Lias der Glarner Alpen.* - Denkschr. schweiz. natf. Ges. *79*, 1-193.

— (1960): *Paleotectonic evolution of the Central and Western Alps.* - Bull. geol. Soc. Amer. *7á*, 843-908.

— (1969): *Die helvetischen Decken der Ostschweiz. Versuch einer palinspastischen Korrelation und Ansätze zu einer kinematischen Analyse.* - Eclogae geol. Helv. *62*, 105-142.

— (1973): *The timing of orogenic events in the Central Alps.* In: DE JONG, K.A., & SCHOLTEN, R. (Ed.): *Gravity and Tectonics* (p. 229-251). - Wiley, New York etc.

TRÜMPY, R., FUMASOLI, M., HÄNNY, R., KLEMENZ, W., NEHER, J., & STREIFF, V. (1969): *Aperçu général sur la géologie des Grisons.* - C.R. Soc. géol. France *1969/9*, 330-364, 391-394.

WEGMANN, R. (1961): *Zur Geologie der Flyschgebiete südlich Elm (Kanton Glarus).* - PhD. thesis, Univ. Zürich.

WETTSTEIN, A. (1887): *Über die Fischfauna des Tertiären Glarnerschiefers.* - Abh. schweiz. paläont. Ges. *13*, 1-103.

WIDMER, H. (1948): *Zur Geologie der Tödigruppe.* - PhD. thesis, Univ. Zürich.

WYSSLING, L. (1950): *Zur Geologie der Vorabgruppe.* - PhD. thesis, Univ. Zürich.