The Evolution of the Northern Margin of Tethys in Eastern Switzerland

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The former northern margin of Tethys is being studied in the Alpine chain by IGCP Project 198 ("Evolution of the Northern Margin of the Tethys"). This paper summarizes the present state of knowledge of the opening phase of this Mesozoic to early Paleogene seaway in Eastern Switzerland. Basement rocks and sediments of the previous margin are now exposed here in the nappe stack of the Alps and in their European foreland.

Introduction

The Alpine Tethys is the oceanic basin that opened by extensional and strike-slip tectonics from Triassic time onward, separating the former Pangaea into the Gondwana continent in the south and Laurasia in the north. This marine opening was synchronous with the beginning of the expansion of the North Atlantic basin. However, the Alpine Tethys closed again by orogenic inversion beginning near the end of Early Cretaceous time, some 110 Ma ago. Thus, the former continental margins of the Tethyan basin are now exposed on land, in the outcrops of the Alpine chain (Fig. 1).

On the southern margin of the Alpine Tethys (the Austroalpine realm and Southern Alps of Figs. 1B and 1C), Mesozoic extensional tectonics resulted in tilted blocks and basins, as outlined by Bernoulli and others (1979) and Winterer and Bosellini (1981). The style of this margin has been compared to the tectonic style of the Armorican continental margin of Bay of Biscay, as revealed by reflection seismics (Bally et al., 1981).

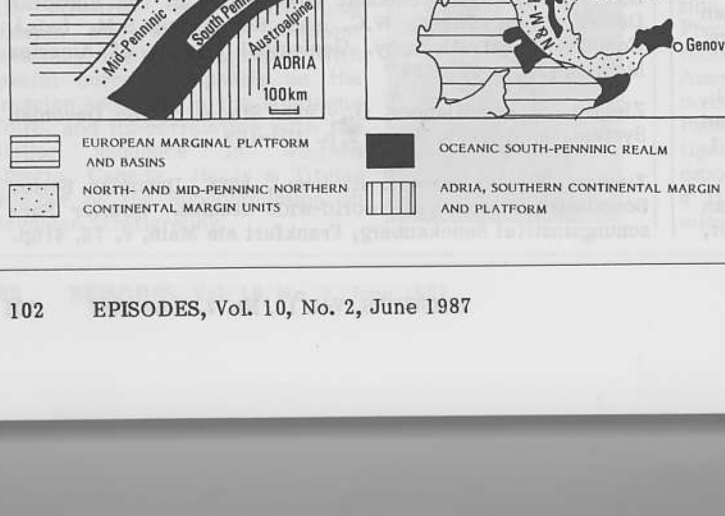

Figure 1: The regional setting and main geological features of the Alps. A: Main trends of the Alpine chain in the Mediterranean realm; B: Simplified geological map of the Western and Central Alps; C: Simplified palinspastic map of the Central and Western Alps in Late Jurassic time.

Within the framework of IGCP Project 198, European geologists are now seeking a better understanding of the evolution of the northern margin of the Tethys from Triassic to early Paleogene times, which must obviously have been quite different from that of the southern margin. A key area for the northern margin is Eastern Switzerland, where the geological history is particularly well studied. Two main problems arise here: what is the most coherent palinspastic reconstruction of the former paleogeographic realm obtainable by restoring the Alpine tectonic history; and which mechanisms of basin subsidence predominated - extensional tectonics, post-Hercynian thermal relaxation, or strike-slip tectonics.

The Mesozoic to early Paleogene margins and basins of Tethys in Eastern Switzerland are found in several geological units, (Fig. 1), which are reviewed from north to south in the following. Figure 2A is a synoptic cross section showing the relative position of the various units discussed in the text.

The European Foreland

The European Foreland is represented by the fold-and-thrust belt of the Jura mountains, composed of Mesozoic sediments and the former intracontinental Jura basin. The sediments are mainly evaporitic and shallow-water Triassic carbonates and Jurassic marls and shallow-water limestones. Below this sedimentary cover, the meso-European crystalline basement is cut by an east-west, late Hercynian intracontinental rift, with continental clastics and coal seams.

To the southeast is the Molasse of the Swiss Plateau, which constitutes the Oligocene-Miocene foreland basin of the Alps. The crystalline basement here is overlain by a Mesozoic sedimentary sequence, which is somewhat thinner than in the Jura mountains. The Molasse sediments are slightly tilted on the Plateau and form a fold and thrust belt at the external margin of the Alps (left side of Fig. 2A, and see cover photo).

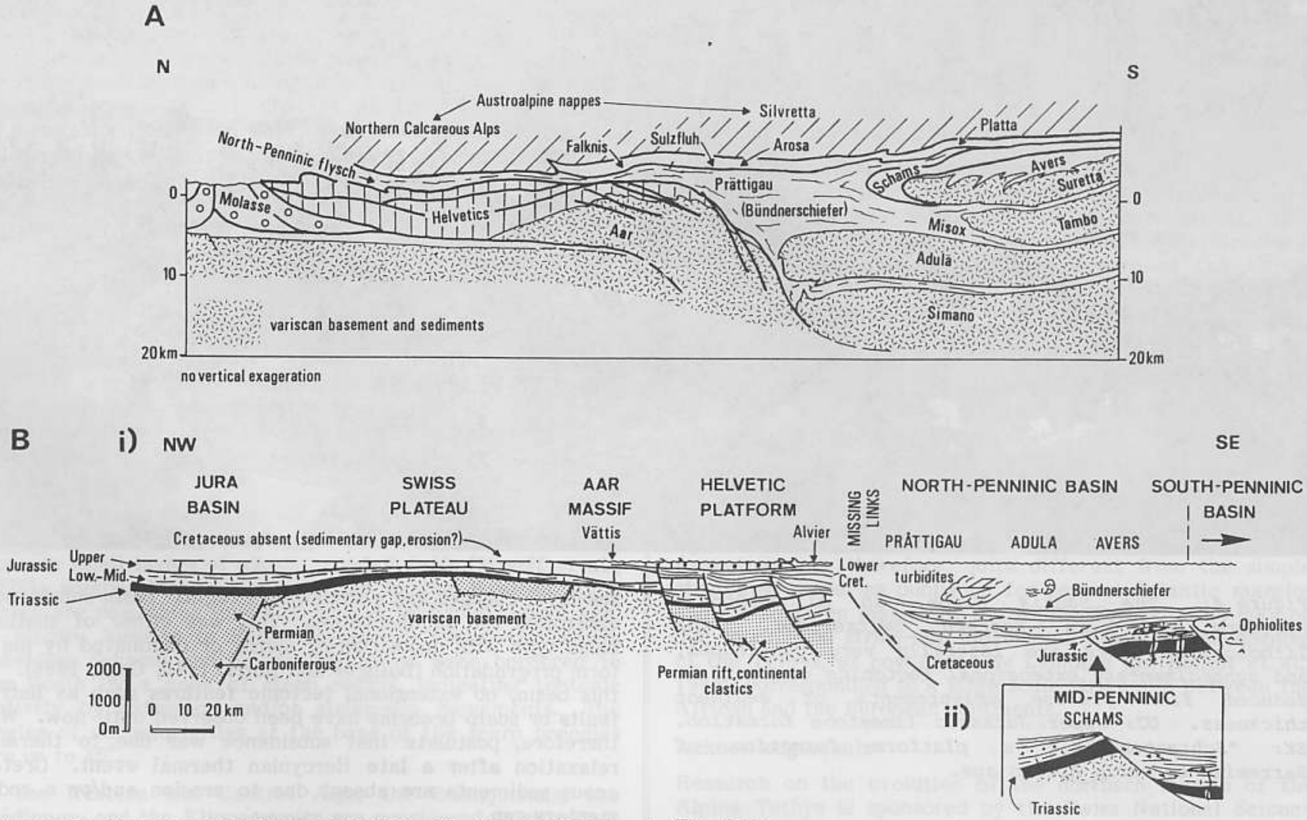

Figure 2: Paleogeographic evolution of the northern margin of the Tethys in Eastern Switzerland along transects shown in Fig. 1B. A: Synoptic cross section, indicating the relative position of the various units discussed in the text. B: Paleogeographic section from the Jura basin to the Penninic basin the Barremian (Lower Cretaceous).

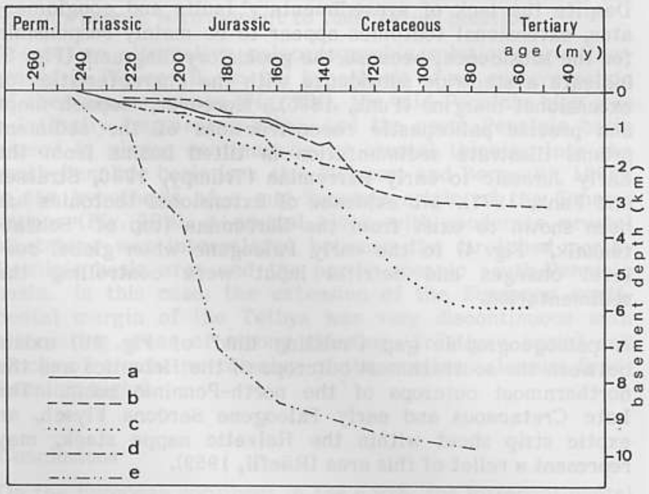

Figure 3: Geohistory diagrams of the continental margin units of Eastern Switzerland, showing total subsidence of pre-Mesozoic basement. (a) Jura basin of Eastern Switzerland. (b) Southern part of the Helvetic platform (Alvier section). (c) Hypothesis for the subsidence of the north-Penninic Prättigau basin. (d) Mid-Penninic Klippen unit in Central Switzerland. e) South-Alpine Generoso basin.

The Alps

The ancient Tethyan basin and continental margin units of Europe (the northern margin) and of Adria (the southern margin) constitute a pile of thrust sheets (Fig. 2A). Within these nappes, the Mesozoic sediments define three geological mega-units, namely the Helvetic, the Penninic and the Austroalpine zones. As demonstrated in the following, the northern margin is preserved in the Helvetic zone and in the northern and middle units of the Penninic zone (Fig. 1B and C). The south-Penninic units are "oceanic" basin relicts, and the Austroalpine zone represents the Mesozoic southern margin of the Tethys, which belongs to the Adriatic promontory of the African continent (Laubscher, 1975, Bernoulli et al., 1979, Dercourt et al., 1985).

In the Helvetic zone, the Hercynian basement of the Aar massif and its sliced-up Mesozoic and Tertiary cover are overlain by the Helvetic nappes (Trümpy, 1969, Milnes and Pfiffner, 1977, Pfiffner, 1978, 1981). In all units, thin epicontinental sediments of Triassic age are followed by Jurassic to Eocene platform units. Compression and thrusting in this zone started in the Late Eocene and continued into Middle Miocene time (Pfiffner, 1986).

The north-Penninic units are composed of Alpine crystalline basement nappes (Gotthard, Lucomagno, Simano, Adula, Tambo and Suretta, see Fig. 2A) and of thick sedimentary sequences. The latter comprise epicontinental and dolomitic sediments of Triassic age, turbiditic Jurassic and Lower Cretaceous shales and arenites (Bündnerschiefer) and shaly, arenitic and conglomeratic deep-water clastics of Late Cretaceous to Early Eocene age (Prättigau Flysch). The sediments are detached from their crystalline basement. Alpine metamorphism in these units is mainly epizonal, with amphibolite facies in the extreme south.

The mid-Penninic units consist of thick platform carbonates of Triassic to lowermost Cretaceous age in the north, and Triassic carbonates and Jurassic to Lower Cretaceous scarp breccias in the south. The Upper Cretaceous to Paleogene deposits are hemipelagic and turbiditic.

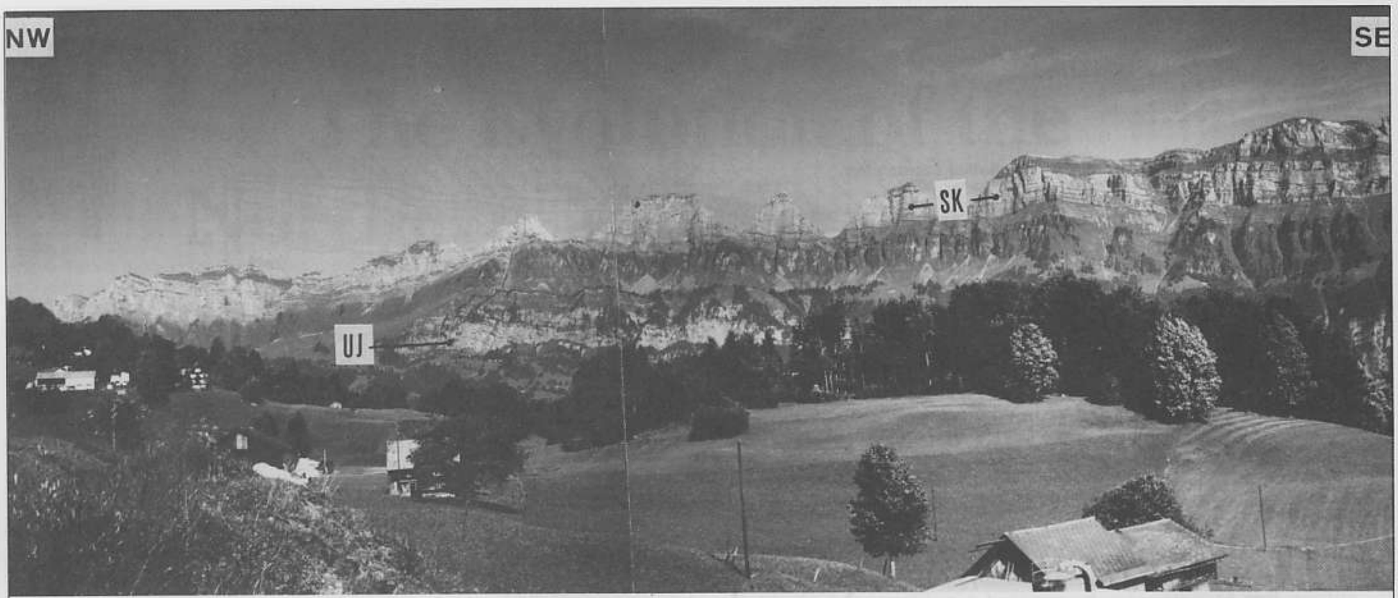

Figure 4: The Säntis nappe, an allochthonous platform unit in Eastern Switzerland. The lithological units are laterally very continuous, and synsedimentary extensional tectonics can only be deduced from precise measurements of sediment thickness. UJ: Upper Jurassic limestone formation. SK: "Schrattenkalk," a platform formation of Barremian to early Aptian age.

It has been suggested that mid-Penninic units exist in two different structural situations (Fig. 2A; Streiff, 1962, Trümpy et al., 1969). In the first, the Falknis-Sulzfluh nappes overlie the north-Penninic units and are themselves overlain by south-Penninic ophiolites. In the second setting, the Schams nappes envelop the front of the Suretta basement nappe and overlie the Avers Bündnerschiefer containing basic volcanics in blueschist facies. However, as north-south and east-west nappe transport is suspected in this area, the debate is still open concerning the paleogeographic origin of the Schams nappes.

The south-Penninic units in this transect of the Alps are slices of the Arosa zone and of the Platta nappe with ophiolites, and pelagic and hemipelagic sediments of Jurassic and Cretaceous age. The Austroalpine zone comprises the Silvretta basement nappe and the Mesozoic cover sediments of the Northern Calcareous Alps (Fig. 2A). Deformation in the Penninic zone and at the southern margin of the Tethys (the Austroalpine realm) started in Early Cretaceous time and continued into the Paleogene.

Triassic to Lower Cretaceous Evolution

The whole area that subsided during the Mesozoic to form the northern margin of the Alpine Tethys was underlain by a Hercynian (Variscan) crystalline basement with east-west and northeast-southwest late Hercynian rifts. Since the opening of the marine basins only began in Triassic to Early Jurassic time, and since orogenic inversion of the basins started in the Early Cretaceous, the discussion here of the evolution of the margin is generally limited to this time interval.

In Early Triassic to Late Jurassic times, the Jura basin (Fig. 2B) was a slowly subsiding trough together with the northern and central part of the Swiss Plateau. The southern part of the Plateau and the area of the Aar massif emerged during early and middle Liassic (the Alemanic land of Trümpy, 1949). In the Middle and Late Jurassic, global sea-level changes and a somewhat irregular basin subsidence controlled the sedimentation. This was either of shallow basin type with deposition of marls, or dominated by platform progradation (Bolliger and Burri, 1970, Gygi, 1986). In this basin, no extensional tectonic features such as listric faults or scarp breccias have been observed until now. We, therefore, postulate that subsidence was due to thermal relaxation after a late Hercynian thermal event. Cretaceous sediments are absent due to erosion and/or a sedimentary gap.

The Helvetic platform of eastern Switzerland existed from the Triassic onward, in part on the top of a late Paleozoic continental basin fill, the "Verrucano" trough (Fig. 2B). Jurassic and Cretaceous sediment sequences are dominated by carbonates, grading into a more marly sequence in the southern part of the shelf. The total thickness of Mesozoic deposits is about 1.5 km in the north and 3 km in the south.

Despite the lack of synsedimentary faults and conglomerates, extensional tectonics appear to be mainly responsible for the subsidence, because the geohistory diagrams (Fig. 3) indicate a stepwide subsidence with the characteristics of extensional margins (Funk, 1985). Moreover, isopach maps and precise palinspastic reconstructions of the sediment prisms illustrate sedimentation in tilted basins from the Early Jurassic to early Barremian (Trümpy, 1980, Strasser and Funk, 1977). No evidence of extensional tectonics has been shown to exist from the Barremian (top of "Schrattenkalk," Fig. 4) to the early Paleogene when global sea-level changes and detrital input were controlling the sedimentation.

A paleogeographic gap ("missing link" of Fig. 2B) exists between the southernmost outcrops of the Helvetics and the northernmost outcrops of the north-Penninic basin. The Late Cretaceous and early Paleogene Sardona Flysch, an exotic strip sheet within the Helvetic nappe stack, may represent a relict of this area (Rüefli, 1959).

The north-Penninic Prättigau basin began with epicontinental and shallow-marine deposits in the Triassic and Early Jurassic, and then subsided rapidly during Jurassic and Early Cretaceous, as indicated by the turbiditic deep-water sedimentation of the Bündnerschiefer (Nänny, 1948, Pantic and Isler, 1978). In the Valais basin, farther west, coarse clastics in the Liassic sediments have most probably been derived from intrabasinal highs (Leu, 1986). We therefore think that strong subsidence and basement topography indicate a regime of extensional tectonics in this area.

When taking into account the presence of helminthoid trace fossils in the Upper Cretaceous flysch sequence of the Prättigau, one can estimate water depth at that time of several hundred metres. In this case, the total pre-orogenic subsidence of the basin is about 5 to 7 km, and the width after stretching is estimated at 80 to 100 km. Lateral sediment input from the west rather than from the east has to be postulated for most of the Cretaceous time; Paleocene and Eocene sediment transport directions are from the north to the south, most probably from an orogenic scarp at the northern margin, to the Prättigau basin in the South (Nänny, 1948, Allemann, 1957).

In the Bündnerschiefer of the Avers area and overlying the Adula basement nappe (Fig. 2A, B), ultrabasic rocks such as prasinites, gabbros, serpentinites and glaucophane schists are intercalated in the sediments, indicating volcanic activity during basin subsidence (Oberhänsli, 1977, 1978, 1986). More complete ophiolitic sequences are only known in the overlying south-Penninic units (Dietrich, 1967). It thus seems that the north-Penninic basement represents thinned continental crust.

As regards the evolution of the presumed mid-Penninic realm, in the Schams nappes the Middle Triassic carbonates contain small layers of alkalic ash-fall tuffs (Streiff et al., 1976), comparable to similar rocks in the Western Alps, which are now being linked to growth faults of Liassic age. In Middle Jurassic to Early Cretaceous times, the slowly subsiding Schams and Falknis platforms were bordered to the South by a zone of steep scarps, indicating tectonic activity by extension and/or strike-slip movements. The angles of unconformities at the base of the scarp breccias are up to 45°.

In the Western and Central Alps, the Briançonnais, the Médianes- and the Klippen-units are considered as remnants of a Mesozoic structural high or "swell" 60 to 100 km wide, south of the north-Penninic basin (Fig. 1C, Boillot et al., 1984A). Nonetheless, it is still possible that these mid-Penninic units may also include the Schams, Falknis and Sulzfluh nappes. For the Falknis nappe, a southern (Austro-alpine) origin has recently been re-stated (Gruner, 1981). However, this hypothesis is not consistent with the tectonic position of this unit. New investigations by St. Schmid and colleagues indicate the possibility of an eastern origin of the Schams nappes with respect to their actual position.

These two alternative paleogeographic solutions are illustrated in Figure 2B. In the hypothesis of an eastern origin of the Schams nappes (Fig. 2Bi), the mid-Penninic high was a laterally fragmented ridge, and the north-Penninic basin passed in places continuously by crustal thinning into the south-Penninic basin (see also Weissert and Bernoulli, 1985). In the hypothesis of a mid-Penninic origin of the Schams nappes (Fig. 2Bii), a crustal block with moderate crustal stretching was intercalated between the stretched north-Penninic basin area and the partly oceanic south-Penninic basin. In this case, the extension of the European continental margin of the Tethys was very discontinuous with alternating areas of strong thinning (Prättigau basin) and blocks of almost no thinning of the continental crust (mid-Penninic highs).

Conclusions

On the European continent in the north, the intracontinental Jura basin and part of the Swiss Plateau were slowly subsiding from Triassic to Late Jurassic time. However, as no extensional features are known in this basin, subsidence was most probably controlled by post-Hercynian thermal relaxation, though this is not yet proven by paleogeothermic data.

To the south of the Plateau, the Helvetic realm, which was a 60 km wide European shelf of the Tethys, subsided by moderate crustal stretching (less than 10%), from Early Jurassic to Early Cretaceous time, as indicated by the sedimentary record. Late Cretaceous to early Paleogene sedimentation was controlled by global sea-level changes and terrigenous sediment input. Strong extensional tectonics with subsidence are indicated in the neighbouring basin to the south, the north-Penninic Prättigau basin, with turbiditic deep-water clastics from Jurassic to Early Eocene time (Bündnerschiefer and flysch sedimentation).

The interpretation of the transition from the extensional part of the European margin to the south-Penninic realm with oceanic crustal characteristics is controversial. One hypothesis suggests that a continuous east-west structural high with platform sedimentation separated the north-Penninic basin from the south-Penninic realm, indicating discontinuous stretching, most probably coupled with strike-slip tectonics. Alternatively, the structural highs formed rather isolated islands, and a continuous transition from one deep basin to the other and from continental crust to oceanic crust may have existed in places. In any case the margin is not a simple Atlantic type stretched margin.

Crustal stretching in the Penninic basins was thus fairly discontinuous, with areas of almost normal crustal thickness in the mid-Penninic structural highs, and strong extensional tectonics in the north-Penninic basin. Continental margin formation was, therefore, quite different from the simple stretching model as published for several Atlantic margins and the southern margin of the Alpine Tethys. This may be due to sinistral strike-slip movements linked to the opening of the Tethys, as postulated by Lemoine (in: Boillot et al., 1984), corresponding to a large scale strike-slip between the African and the European continents.

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