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Swiss National Committee for the International Geodynamics Project
Working Group 8: Past Kinematics and Dynamics of the Alps

Evolution of Continental Margins in the Alps

Report by *D. Bernoulli**), *C. Caron***), *P. Homewood***), *O. Kälin**) and *J. van Stuijvenberg***)

The post-Variscan Mesozoic and Tertiary history of the Alpine-Mediterranean area is closely linked with the evolution of an E-W-trending, Jurassic to Early Cretaceous Tethyan ocean and its partial elimination by subduction and continent/continent collision between Africa and Eurasia from the Late Cretaceous to the Tertiary. The reconstruction of the early evolution of ocean basins and continental margins, the deformed relics of which constitute now the different basement and sedimentary cover nappes in the Alpine belt can be approached from different angles: 1. Whereas in the Dinaride-Hellenide belt Jurassic speading was partly counterbalanced by Late Jurassic and Early Cretaceous subduction, to the west the overall framework is determined by and large by the kinematic evolution of the Atlantic system and the surrounding continents (e.g. LAUBSCHER and BERNOULLI, 1977). 2. Inside the Alpine belt, the ophiolitic associations are interpreted as the remnants of oceanic crust and lithosphere of the Tethyan ocean. Their occurrence and the existence of large facies belts of mainly Mesozoic carbonates to both sides provide a guiding principle for the recognition of former oceanic and continental margin areas. 3. Seismic and deep sea drilling data from the undeformed continental margins and ocean basins of the Atlantic-Tethyan system provide a basis for a comparative anatomy of deformed and undeformed margins (BERNOULLI, 1972; GRACIANSKY et al., in press). It is within this general context, that the working group has formulated a programme that has also been accepted by the International Geological Correlation Programme as Project 105: «Continental Margins in the Alps». Between 1976 and 1979 four international workshops have been held in the Swiss, Italian and French Alps and 16 papers dealing with both earlier and late evolution of the continental margins of the Alpine Tethys have been published or are in press. Some of the main results achieved so far are summarized in Figures 1 and 2.

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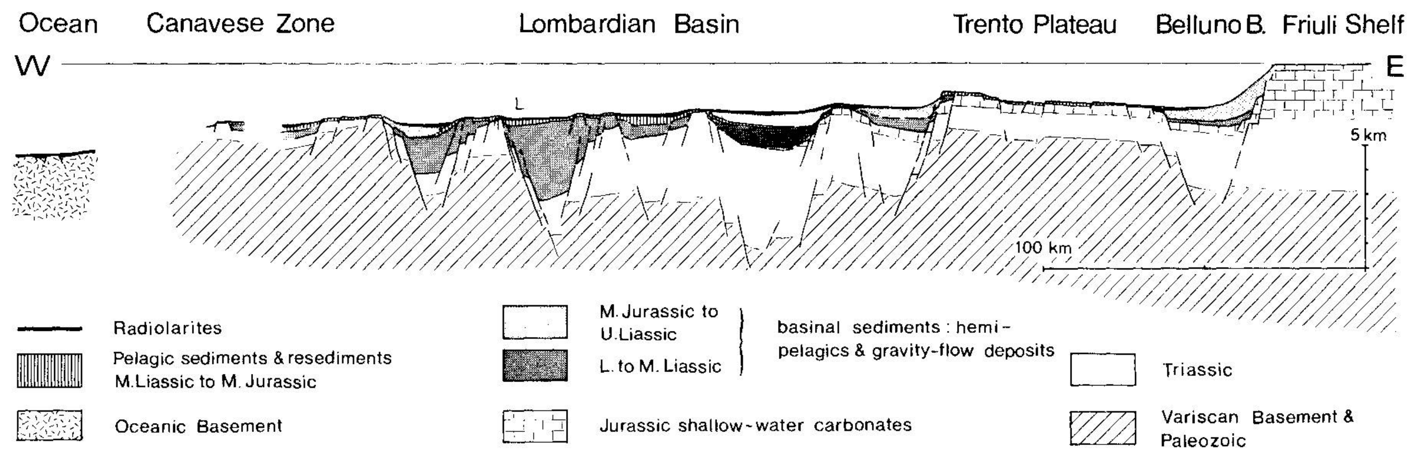

Figure 1 Palinspastic cross-section through the southern continental margin of the Tethys, Southern Alps, Late Jurassic (D. BERNOULLI and O. KÄLIN).

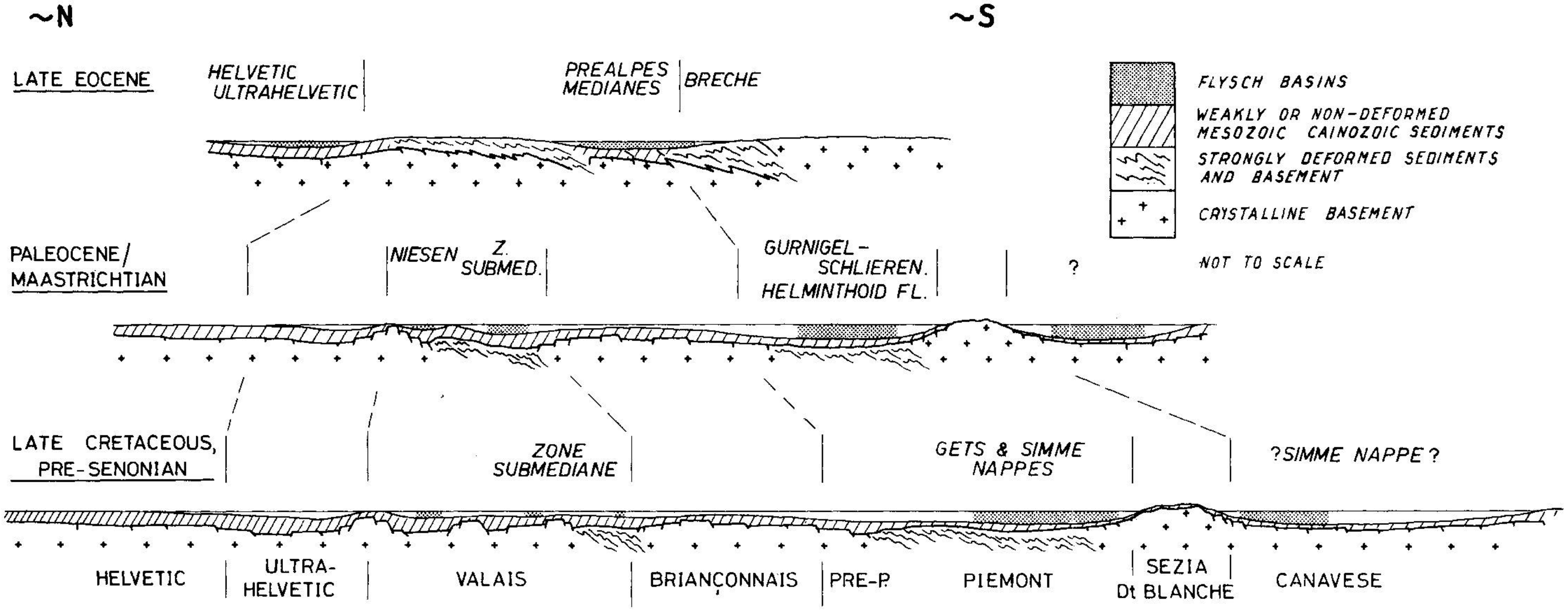

Figure 2 Diagrammatic palinspastic cross-sections illustrating position of flysch basins (gray shading) with relation to basement (crosses), undeformed or weakly deformed Mesozoic sediments (cross hatched), strongly deformed Mesozoic sediments and basement (wavy lines).
(C. CARON, P. HOMEWOOD and J. VAN STUIJVENBERG).

In Figure 1, the early, Jurassic evolution of the southern Tethyan margin has been reconstructed and is shown as a typical example of Tethyan margin evolution. In the western Tethys, early rifting and graben formation were discordantly superimposed on the earlier, Triassic paleogeography (LAUBSCHER and BERNOULLI, 1977), and did not closely follow the sites of Middle Triassic subsidence and volcanicity which are generally interpreted as a phase of aborted rifting. Nevertheless, the thicknesses of the latest Triassic to early Jurassic appear to thin out towards the zone of later rupture (TRÜMPY, 1975) and to anticipate the presence of later basement highs near the edge of the continental margins.

During the early Jurassic, the areas which were to become the continental margins were affected by block-faulting. As a consequence, shallow-water sedimentation was interrupted over large areas and only a number of platforms surrounded by deeper throughs and plateaux persisted throughout the Jurassic. Whereas along the northern margin fine terrigenous material was trapped in a large intermediate basin (Dauphiné-Valais trough, GRACIANSKY et al., in press) the southern margin was dominated by shallow-water and pelagic carbonate sedimentation. The analogies between the carbonate platforms of the southern Tethys and those of the Recent Bahamian margin with its irregular belts of shallow and deep water comprise general facies distribution, size and morphology of the platforms, rates of subsidence and many other parameters and go far beyond the limits of chance. In the basins bordering the platforms coarse platform-derived debris and grain-flow deposits as well as carbonate turbidites and peri-platform oozes were deposited. Off the platforms the resediments comprise pelagic sediments and peri-platform oozes (Figure 1).

Subsidence rates were highest during this early phase of disintegration of the margin and varied widely between the different fault blocks. Some of the former platforms and uplifted blocks (BAUD et al., 1979) became submarine highs and seamounts on which only limited amounts of pelagic sediments accumulated (Trento high, Briançonnais platform). The asymmetry of certain of these highs and the marked unconformities at the base of the pelagic sequences suggest crustal attenuation in connection with listric faulting (e.g. GRACIANSKY et al., in press).

With the onset of spreading and the formation of oceanic crust during the late Early (?) to Middle Jurassic, subsidence rates decreased and were more evenly distributed over the margins. Through time, the submerged distal continental margins (Lombardian and Prépiemontais Zones) became increasingly starved and only pelagic sediments whose facies were mainly determined by synsedimentary faulting and prolonged subsidence were deposited. Throughout the Jurassic, increasing water depth is reflected by increased carbonate solution, culminating in the deposition of radiolarites below the calcite compensation depth (BOSELLINI and WINTERER, 1975; BERNOULLI et al., 1979).

Only in the latest Jurassic, an evolutionary bloom of the calcareous nannoplankton and/or a change in the paleo-current system led to a depression of the carbonate compensation depth (WEISSERT, 1979).

Local uplifted blocks and long-lived active fault scarps associated with marine breccia formations (Falknis Nappe, Breccia Nappe) point to the interference of transverse movements, particularly along the northern (transform) margin of the Liguria-Piemont ocean.

Although the general tectonic evolution of the Tethyan margins closely parallels that of «passive» Atlantic-type and more specifically that of starved margins like the Blake Plateau or the northwest Australian margin, there are differences in the sedimentary evolution: whereas on the present-day spreading ridges and on the deeply submerged margins pelagic carbonates only are deposited, the sea floors of the juvenile Jurassic oceans and margins were below or close to the carbonate compensation depth. This shows that exogenous conditions were quite different in this narrow east-west trending Jurassic ocean (WEISSERT, 1979). The interplay between endogenous and exogenous factors are most prominent along the proximal parts of the margins, e.g. in the Helvetic facies belt where global sea level changes superimposed on the general subsidence led to shoaling-upward sedimentary cycles (workshop 1977).

The turn from «passive» Atlantic-type continental margins to margins governed by compression and/or large strike-slip movements occurs with the opening of the North Atlantic, the Bay of Biscay and the South Atlantic, and sinistral movements in the Tethyan system were replaced by dextral ones.

During mid-Cretaceous times, the pelagic sedimentation prevailing over the distal continental margins and in the deeper basins was modified by a considerable detrital influx. The subsequent terrigenous clastic deposits, which appear to correlate well with the mid-Cretaceous orogenic events (e.g. Gosau phase), built up turbidite sequences in both the South-Pennine ocean and the North-Pennine Valais Trough.

Abundant chromite mineral grains (Simme nappe, FLÜCK 1973) mixed with the relatively immature terrigenous clastics, suggest multiple sources for the South-Pennine ocean deposits. This, together with the ophiolite blocks (olistolithes) of the Gets nappe (e.g. CARON 1972) indicate that oceanic crust also contributed some of the detritus. General simultaneity of radiometric dates of high-pressure, low-temperature metamorphism in South-Pennine units of the Alps (HUNZIKER 1974) inevitably suggests that the former flysch deposits were related to an active subduction arc-trench environment in the Southern part of the oceanic area (CARON et al. 1979).

Coeval deposits of the North-Pennine Valais Trough are not so well documented, but have been considered in the light of transform movements parallel to the W-E trend of the basin (HOMEWOOD 1977).

Senonian sequences of the South-Pennine ocean are characteristically abundant in basinal lime-mud turbidites. Helminthoid trace fossils are frequent, particularly in beds of Maastrichtian age, and this facies is widely known in the Alps as «Helminthoid Flysch» (topic of the fourth I.G.C.P. 105 workshop). Chromite is not to be found in these flysch, which show monotonous and fairly constant facies along the trend of the Alpine belt, and general sedimentation controls are taken to be exogenous in a fairly tranquil oceanic basin.

Very coarse, upper Senonian terrigenous turbidite sequences of the North-Pennine Valais Trough (e.g. Niesen Flysch, see CARON et al. 1979) once again suggest strike-slip or oblique-slip control of sedimentation, together with some evidence for crustal collision during Late Cretaceous to Early Tertiary orogenic events.

Deep-marine sedimentation of clastics whose source was probably related to this phase took place in the South-Pennine ocean during the early Tertiary (Paleocene-Eocene). Here, the predominantly sandy Gurnigel and Schlieren Flysch deposits were controlled by sea-level changes and long-term growth of depositional systems in an apparently tranquil «oceanic» basin (STUIJVENBERG 1979).

Crustal collision, followed by obduction of slivers of oceanic crust and «décollement» of the overlying sedimentary pile mainly occurred from Eocene to Oligocene times. During this phase flysch was first accumulated on the submarine highs (e.g. Briançonnais and Ultrahelvetic) but later over the more proximal part of the North-Alpine margin (Helvetic facies belt). The deep-marine basins of the Alpine belt were thus definitely closed and the clastic depocenters were moved to the shallow seas of the Alpine foreland.

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