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SHORT COMMUNICATION

The Palaeozoic evolution of the Alps*

by *Jürgen F. von Raumer*[1] and *Franz Neubauer*[2]

Abstract

It is tried to reconstruct the puzzle of pre-Mesozoic basement areas in the Alps and to present the geological history from Proterozoic to Permian times, including the Proterozoic to Early Palaeozoic rifting history by the stepwise crustal shortening and the final collision during the Late Variscan.

Keywords: palaeotectonics, pre-Mesozoic basement, Variscan fold belt, Alpine evolution.

Introduction

Pre-Mesozoic basement covers almost fifty percent of the Alpine domain and its evolution should be consistent with the former adjacent areas outside the Alps. In palaeotectonic reconstructions it occupies only a small sector in the pre-Permian framework (e.g., RAST and SKEHAN, 1988), more or less in the continuation of the Appalachian and Atlas mountain chains and, certainly, basement-cover relations of very different ages have existed. Here, we summarize shortly main stages of tectonic evolution of the Alpine basement, and a detailed discussion is given in VON RAUMER and NEUBAUER (1993a).

Our discussion is based on tectonic reconstructions of the final stages of the Variscan orogen (Figs 1, 2), where Alpine shortening was restored (PFIFFNER, 1993; RATSCHBACHER and FRISCH, 1993; DE GRACIANSKY, 1993). The general effects of Alpine extension pre-dating Alpine shortening are difficult to evaluate. We suppose major strike-slip displacement along strike of later nappe complexes. These effects are not restored in figure 2. Several stages may be differentiated in the basement of the Alps (VON RAUMER and NEUBAUER, 1993b), which may correspond to an early extensional period followed, at least since the Ordovician, by crustal shortening. Silurian-Devonian times are represented by contrasting settings – extension vs contraction – thus preserving the occurrence of terranes and, after the Early Carboniferous, the entire area suffers final collision.

Proterozoic-Cambrian rifting period

Earliest tectonic elements may have existed as fracture zones of Late Proterozoic or Early Cambrian age in an older continental crust, comparable to those which influenced the formation of sedimentary troughs in Germany (ZEMAN, 1980; FREYER and SUHR, 1987) and in the Bohemian Massif (HIRSCHMANN, 1988), where they were the place of Late Proterozoic rifting and subduction. In the African shield BUGGISCH and FLÜGEL (1988), RAHMAN et al. (1990) and HARMS (oral comm.), and in the North American shield STANLEY and RATCLIFFE (1985) and SKEHAN (1988) observe a regular pattern of late Proterozoic rift zones. Taking in account such observations and regarding the Precambrian evolution in the Alpine domain, we may, in consequence, envisage large areas with deposits of a continental-margin environment or the existence of intra-

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continental sedimentary troughs guided by major fracture zones where oceanic crust may appear. In fact, the most important lithologic association comprises metagreywackes, metapelites, a few quartzites, very few carbonates, and locally metavolcanics. This association is found in the Helvetic domain, in the basement of the Eastern Alps, in parts of the Penninic zone, and in the Southern Alps, implying the existence of such sedimentological environments (Fig. 2).

The crustal extension during the Late Precambrian / Early Ordovician is accompanied by formation of ultrabasic, basic and acidic rocks emplaced in oceanic and/or continental extensional environments (MÉNOT et al., 1988; GUILLOT et al., 1991; NEUBAUER, 1991; SANTINI, 1991; MÉNOT and PAQUETTE, 1993; NEUBAUER and VON RAUMER, 1993; PFEIFER et al., 1993). A candidate for such a major pre-Variscan, complex suture are probably the basement units preserved in the Alpine Penninic domain and adjacent areas like the Gotthard Massif (Helvetic domain; BIINO, 1992) and parts of the Middle Austroalpine units (NEUBAUER et al., 1989). This suture zone is likely to represent a special type of palaeotectonic environment, influenced by a large zone of thinned crust already since the Proterozoic (VON RAUMER and NEUBAUER, 1993). It should be comparable to those Precambrian rift-zones observed from the African shield (RAHMAN et al., 1990; HARMS, oral comm.), and was called the Penninic-Austroalpine mobile belt by the authors. This large suture zone, situated on the Gondwana-shelf, separated the Moldanubian domain, comprising the polymetamorphic basement areas of the Helvetic domain, and representing a Gondwana directed active margin during the Palaeozoic, from the passive margin of the main "African" bloc (Southern Alps, Austroalpine), where Pan-African/Cadomian elements are better preserved. Rifting and formation of oceanic crust, in this large zone, occurred during different time periods since the Proterozoic and at different places.

Ordovician – beginning of crustal shortening

After the earliest period of rifting mentioned above, distinct tectonostratigraphic units underwent a different evolution during the following time-periods since the Ordovician. Parts of the External domain (Helvetic units) underwent

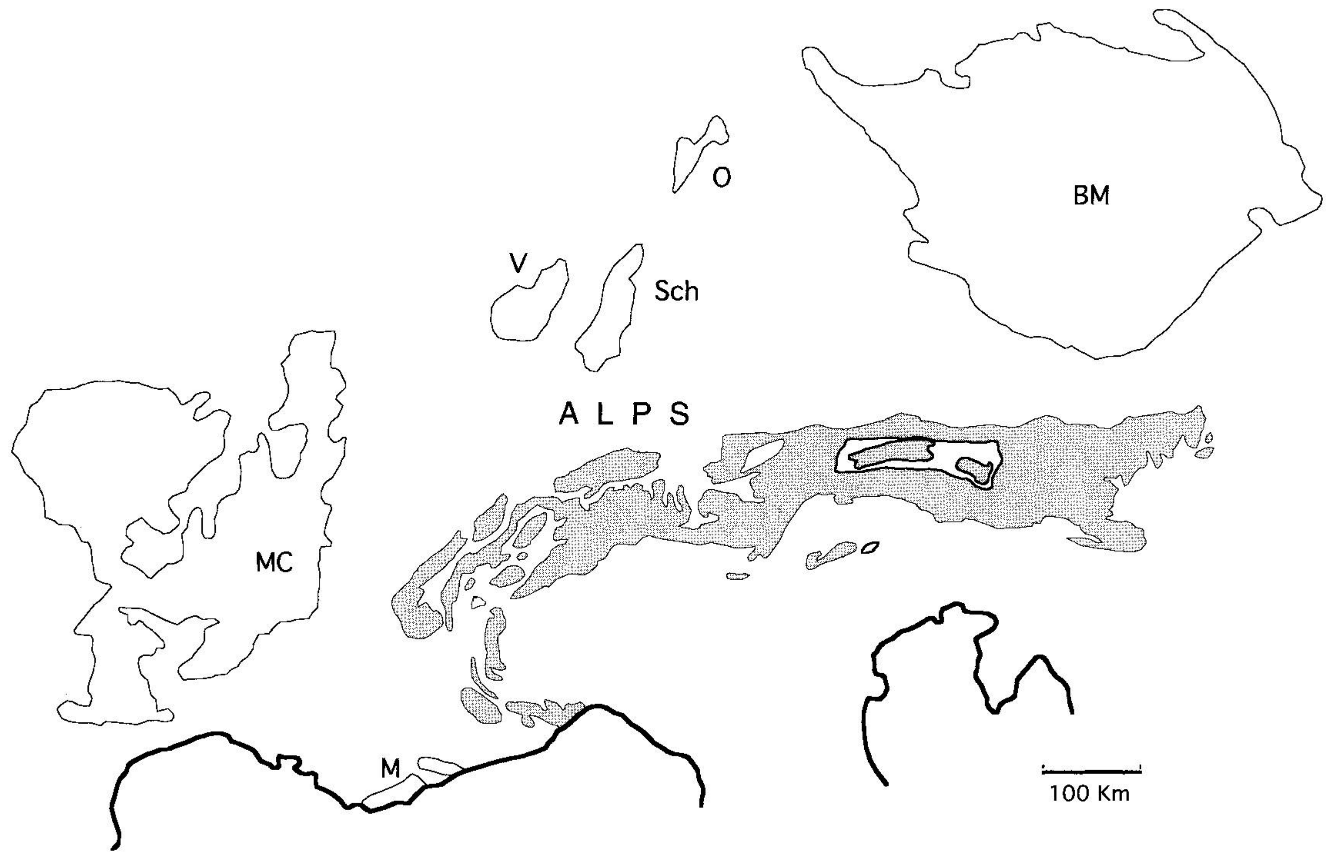


Fig. 1 The Alpine pre-Mesozoic basement and its extra-Alpine Variscan framework. BM = Bohemian Massif; M = Maures Massif; MC = French Central Massif; O = Odenwald-Spessart regions; Sch = Schwarzwald; V = Vosges.

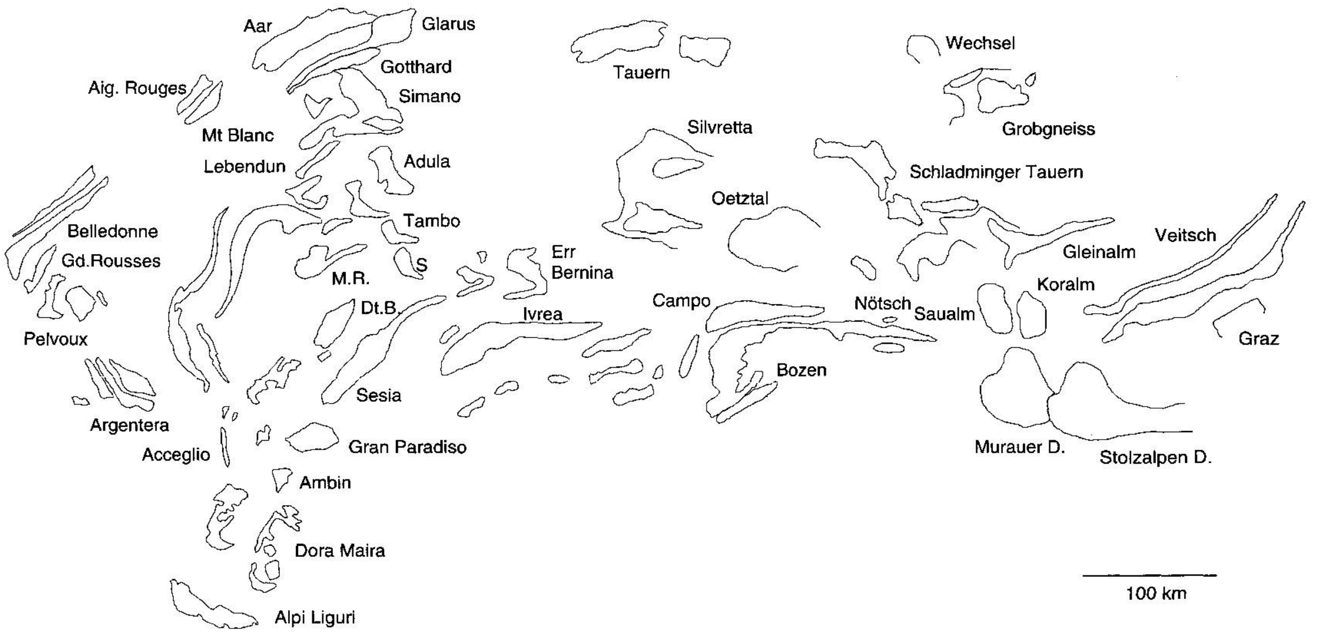
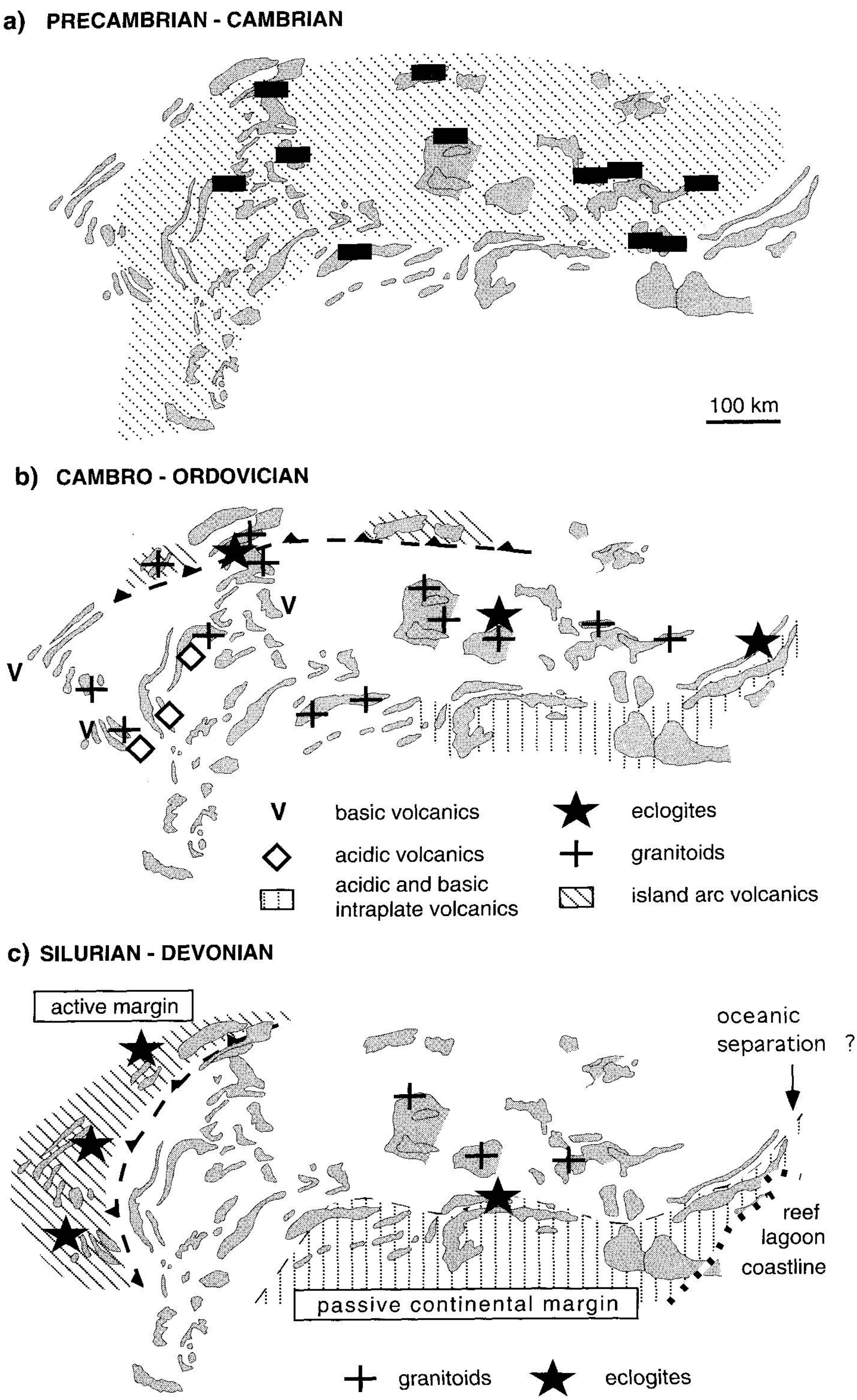


Fig. 2 Pre-Mesozoic palinspastic reconstruction of the pre-Mesozoic basement in the Alps after figure 2 in VON RAUMER and NEUBAUER (1993) and based on the reconstructions of NEUBAUER (1988); DE GRACIANSKY (1993); PFIFFNER (1993); RATSCHBACHER and FRISCH (1993), with indication of names of the different units.

crustal shortening accompanied by formation of eclogites (GEBAUER, 1993) and/or granulite facies corresponding to the Ordovician. Some of the eclogites of the polymetamorphic basement yield Silurian-Early Devonian eclogite formation ages (Belledonne, Aiguilles Rouges, PAQUETTE, 1987, PAQUETTE et al., 1989), but the corresponding data might be the result of the Ordovician thermal event and the following collision (for full discussion: ABRECHT et al., 1991).

Granitoids are widespread and were correlated to the so-called Ordovician "thermal event" (SCHMIDT, 1977). The regional comparative study of Late Palaeozoic granitoids (BONIN, 1988) shows, that evolution of granites changes rapidly through time and space and, in consequence, much more data are needed, to give a sense to the widespread distribution of Ordovician granitoids of apparently very different ages, which might represent an evolution going from early convergence to collision, followed by post-collisional magmatism. For the Early Palaeozoic period, first geochemical data indicate an intraplate to arc-situation for the granitoid rocks from the Aiguilles Rouges (External Massifs, CHIARADIA, 1992), and corresponding granitoids from the Mont-Blanc area have an Ordovician age (460 Ma, U/Pb zircon, BUSSY and VON RAUMER, 1993). FRISCH et al. (1993) consider the island-arc and back-arc situation of the Tauern domain through the Ordovician. A volcanic-arc to syn-collisional situation is discussed for the Silvretta granitoids (LIEBETRAU and NÄGLER, 1993; POLLER, 1993), and a subduction-type of metamorphism and calc-alkaline granites followed by post-orogenic granitoids are observed in the Southern Alps (BORIANI et al., 1991), a general situation which, after SCHMID (1993), may correspond to an Early Palaeozoic underplating accompanied by formation of Ordovician granitoids. Ordovician anatexis is dated in the Aar massif (SCHALTEGGER, 1991) and discussed for the Ötztal region (SÖLLNER and HANSEN, 1987), and collisional granitoids, postdating high-pressure metamorphism and anatexis, are mentioned for the Austroalpine domain (THÖNI, 1986). BIINO (1994) and OBERLI and MEIER (1994), for the Gotthard-Tavetsch areas (external massifs at the boundary to the Penninic area) propose the consumption of a rather large oean during the Caledonian cycle comprising subduction, arc evolution, collision and uplift during the time span of 30 Ma.

Such evolution has to be reconciled with that of the Austroalpine and Southalpine quartz-phyllite and other sedimentary sequences, which resulted from Ordovician subsidence (LOESCHKE and HEINISCH, 1993; NEUBAUER and SASSI, 1993), most probably in a back arc basin (LOESCHKE, 1989; NEUBAUER and FRISCH, 1988). The observations lead to very contrasting plate tectonic interpretations for the different domains, including collisional and extensional regimes and it be-


a) PRECAMBRIAN - CAMBRIAN
100 km
b) CAMBRO - ORDOVICIAN
V
basic volcanics
acidic volcanics
acidic and basic intraplate volcanics
eclogites
granitoids
island arc volcanics
c) SILURIAN - DEVONIAN
active margin
oceanic separation ?
reef
lagoon
coastline
passive continental margin
granitoids
eclogites

d) EARLY CARBONIFEROUS

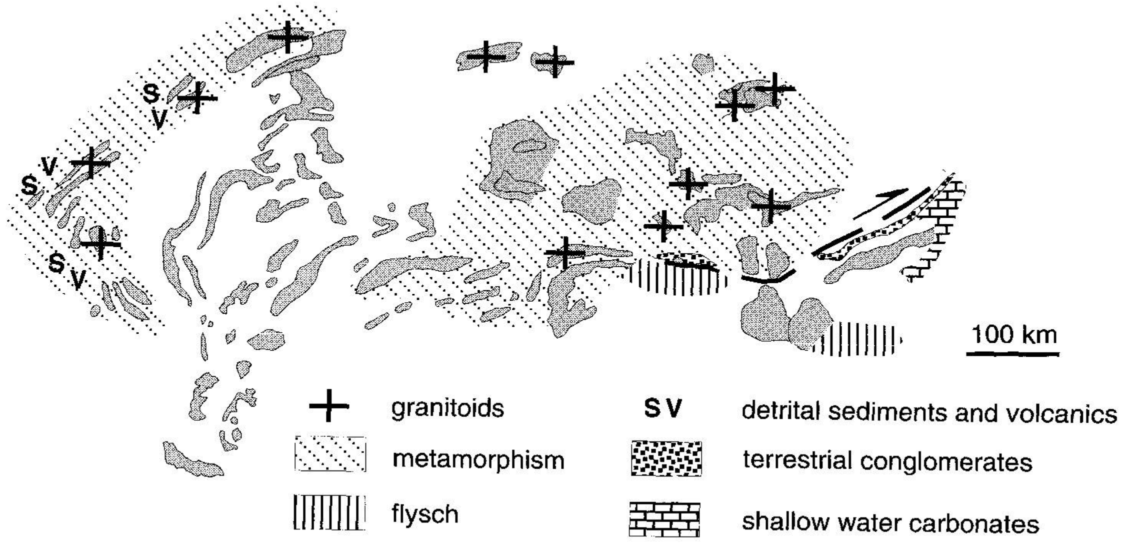


Fig. 3 Pre-Mesozoic basement in the Alps (approximate Late Variscan configuration, see Fig. 2) and distribution of tectonostratigraphic events for distinct time periods.
a) Late Proterozoic / Early Palaeozoic: period of rifting; hatched area – formation of oceanic crust (black boxes) at different times and places indicate a mobile type of crust among the northern and southern more continental blocks.
b) Cambro-Ordovician: beginning of general crustal shortening; occurrence of island-arc type granitoids; supposed limit of the active margin (hatched line with triangles).
c) Silurian-Devonian: distinction between the Ligerian active continental margin (mainly the Helvetic domain) and the Noric terrane, a passive continental margin in the SE and covered by sediments.
d) Visean: nappe stacking and final collision accompanied by metamorphism in all parts; formation of flysch at the southern rim.

comes probable, that besides the External domain also the Austroalpine-Southalpine domains have been the place of a subduction zone during Ordovician times.

Silurian-Devonian collision

Also during this period, different tectonic settings can be recognized across the pre-Mesozoic basement. In the SE (Upper Austroalpine units), shelf sediments were deposited on a passive margin with formation of basins and highs, alkaline volcanism, and formation of mature detrital sediments. This margin, towards the NW, probably was separated by an oceanic basin from other Alpine basement units (HEINISCH, 1988; NEUBAUER and SASSI, 1993).

The eastern domains of the Austroalpine nappe complex expose, in the footwall (Wechsel unit), a supposed Early Palaeozoic accretionary wedge with a Devonian high-pressure metamorphic overprint (NEUBAUER, 1993) which could have formed, together with the Ligerian Zone and the Helvetic basement, an active continental margin. The external massifs, during this period at the latest, are considered to have formed part of the internal zone of the Variscides, as they were the site of high-pressure metamorphism (eclogites; PAQUETTE et al., 1989). The Helvetic basement is characterized by Devonian thrusting, formation of nappes and crustal thickening, the pressure-temperature path indicating a collisional type of evolution. As some of the eclogites of the polymetamorphic basement yield Silurian / Early Devonian ages (Belledonne, Aiguilles Rouges), they may have suffered, like their country rocks, this overprint. Such events indicate strong metamorphic transformations at the level of the lower and middle crust, precursors of collision of continental margins comparable to the advanced stage of under-thrusting discussed for the French Central massif (BOUCHARDON et al., 1989).

Further to the west, in the Belledonne area (external massifs, MÉNOT and PAQUETTE, 1993), the Devonian Rioupéroux-Livet plutonic and volcanic complex indicates continental thinning and rifting accompanied by the intrusion of trondhjemitic melts. In this way, the external massifs, after the main phase of compression, underwent an extensional regime.

Devonian / Lower Carboniferous late collision

A second, major period of crustal events started after the Devonian rifting observed in the most external monometamorphic parts of the Helvetic domain and, separated from these areas, in the sedimentary basins (Upper Austroalpine units) in the south of the polymetamorphic Austroalpine basement. All domains underwent crustal shortening since the Early Carboniferous. Towards the hanging-wall of the nappe-complex, middle Austroalpine I-type granites may reflect subduction-related processes, and subsequent granites accompanied by high-temperature metamorphism record a collisional evolution. In consequence, these units are considered to be a part of the internal zone of the Variscides (NEUBAUER, 1988; FRISCH and NEUBAUER, 1989). Tangential and strike-slip tectonics led to the formation of south-directed nappes of higher crustal level accompanied by magmatic events in the Helvetic domain. Earlier granites, in the Aar Massif, were deformed by south-vergent nappe tectonics (OBERHÄNSLI et al., 1988). In the Belledonne area, the south-directed nappe tectonics has been dated by MÉNOT et al. (1987, K–Ar on amphiboles; 324 ± 12 Ma), and dextral strike-slip accompanied by anatexis yielded an age of 317 Ma (U/Pb monacite, BUSSY and VON RAUMER, 1993). The Austroalpine domains, at this time period, were the place of final collision (NEUBAUER, 1988). Flysch sediments were deposited on the lower plate, and thrusting prograded from internal to external parts. Although the thermal climax was reached in the Early Carboniferous, granite intrusions are much less abundant than in the internal domains, probably due to the lower-plate position during Variscan collision. In consequence, it may be concluded, that the Austroalpine basement, a Devonian passive margin, and the Helvetic basement, a Devonian compressive zone, accreted together during the Carboniferous collision. The accompanying nappe tectonics could be the product of wrench tectonics as a response to the general strike slip and transpressional regime which, since the Early Carboniferous, dominated southern Europe (ARTHAUD and MATTE, 1977; NEUGEBAUER, 1988).

Late Carboniferous / Permian post-collisional evolution

From the Carboniferous on the entire domain, in all Alpine basement units, suffered the multiple transformations of post-collisional evolution accompanied by uplift and erosion. Major longitudinal zones, in response to the general strike-slip tectonics, are underlain by granitoids or are the place of volcanism or detrital sedimentation. SCHULZ and VON RAUMER (1993), for the Aiguilles Rouges, discussed syndeformational uplift during Late Variscan strike-slip. Following MERCOLLI and OBERHÄNSLI (1988), granitoids, in the Aar Massif, evolve from calc-alkalic rocks in the Late Carboniferous to intraplate granites with an increasing alkalic component in the Permian, and intense syn- to late-orogenic magmatic activity in the Penninic basement underlines the spatial neighbourhood of the Helvetic and Penninic basement domains during the Carboniferous and Permian. Following BONIN et al. (1993), most basement areas of the Helvetic and Pennine domains display a distensive regime giving way to the formation of granitic plutonic bodies and locally some volcanic suites. In contrast, in the Eastern and Southern Alps late Variscan granitoids seem to document a plate margin convergence at the southern rim of the Variscan Belt. Major volcanic activity, as in the Western and Ligurian Alps, might have been at the sites of pull-apart. Sedimentary troughs follow the same trend and indicate a Carboniferous extensional or transtensional regime (MATTER, 1987; ESCHER, 1988; KRAINER, 1993) or a transpressive regime (NEUBAUER and VON RAUMER, 1993).

The general late Variscan evolution of the Alpine basement has to be seen in an extensional environment (DAL PIAZ, 1993) triggering the emplacement of very different magmatic rocks and giving way to sedimentary basins at surface. GRAF (1992) compared the evolution with that of the basin-and-range-province during the Cretaceous-Cenozoic times.

Conclusions

The pre-Alpine basement in the Alps, situated between Laurasia and Gondwana, has been the site of distension and crustal shortening at different moments and, based on the actual interpretation of isotopic data, all main orogenic time periods since the Precambrian can be recognized. After faunal and sedimentological criteria from the extra-Alpine domain (OCZLON, 1992; PARIS and ROBARDET, 1990; SCHÖNLAUB, 1993), the pre-Mesozoic basement of the Alps should represent pieces of the North-Gondwana margin, partly in the continuation of the Ligerian fold-belt, that drifted towards Laurussia. Enlarged through crustal growth, after the Devonian, the final collision welded together the two mega continents. Differences of metamorphic evolution with changing style of tectonics on the western and northern limits could have its origin in an asymmetric collision (indenter).

The pre-collisional evolution in this zone is difficult to unravel, but it is supposed that relics of a cryptic suture are preserved. A candidate for a major pre-Variscan, complex suture having separated the passive Gondwana margin from the active Laurasian margin are probably the basement units in the Alpine Penninic domain and adjacent areas (e.g., Gotthard Massif, Helvetic domain; parts of the Austroalpine units, called the Penninic-Austroalpine mobile belt. It is likely to represent a special type of palaeotectonic environment, which might have been influenced by a large zone of thinned crust already since the Proterozoic, thus indicating a prefiguration of main structures since that time.

Based on the different data, we propose an evolution comprising two main steps leading to the collision, an early collision of crustal margins at the level of the lower and middle crust during the Silurian-Devonian, and followed by the final collision since the Carboniferous. Regional differences are imaginable, where a Cadomian metamorphic basement, after rifting, suffered the entire metamorphic evolution between Upper Devonian and Lower Carboniferous.

It is understood that the evolution has to be consistent with the adjacent Variscan framework outside the Alps, the Alpine basement occupying only a small sector in the pre-Permian Variscan mountain chains. The whole discussion has been based on a pre-Mesozoic reconstruction (De Graciansky, 1993; Pfiffner, 1993; Ratschbacher and Frisch, 1993). Such configurations have already to be adapted to those discussed very recently by Stampfli (1993). It also becomes necessary to have a better insight in the Carboniferous and even older distribution patterns of crustal pieces. Taking into account several hundreds of kilometers of tectonic transport for each period of opening, strike-slip and convergence during the Alpine events (Winkler, 1988) and applying comparable rates of transport for the time span between the Early and Late Carboniferous, the palinspastic reconstruction for the Lower Carboniferous might change considerably and, in consequence, the presentation of pre-Carboniferous distribution patterns on the base of a pre-Mesozoic configuration cannot represent a definite solution. As the former oceanic domains should appear in such reconstructions, a sound base for discussion are the palaeogeographic distribution maps presented by Schönlaub (1993).

Nonetheless, the cross-section through the pre-Mesozoic basement in the Alps includes a major suture between Gondwana and Laurasia, a highly condensed (through Alpine events) cross-section through the Variscan fold belt, where early rifting and subsequent crustal shortening was followed by obduction and collision, and where the Late Variscan evolution, through post-orogenic collapse, strike-slip and exhumation, prepared the main tectonic lines for the Alpine evolution.

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