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Eclogae geol. Helv. 89/1: 13–42 (1996)

0012-9402/96/010013-21 $1.50 + 0.20/0
Birkhäuser Verlag, Basel

The Intra-Alpine terrain: A Paleotethyan remnant in the Alpine Variscides

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Key-words: Variscides, Alps, S-Europe, Paleotethys, exotic terrain

ABSTRACT

A Cordilleran type evolution is proposed for the Variscan orogen of middle Europe. This orogenesis is regarded as mainly evolving through terrain accretion and subsequent collapse of the overthickened crust. A major terrain accretion took place between late Devonian and early Carboniferous when the Intra-Alpine terrain collided with the Ligerian-Moldanubian active margin.

This terrain is regarded as being a segment of the northern margin of Paleotethys. Oblique subduction of Paleotethys under the newly accreted terrain is responsible for the voluminous calc-alkaline magmatism in late Carboniferous.

The Paleotethys subduction has generated a lateral displacement of the eastern part of the Intra-Alpine terrain inducing a duplication of its western end. The late Carboniferous closure of Paleotethys in middle Europe is not found eastward where this closure happened only in early-Triassic times, following the simultaneous opening of the Neotethys ocean and the Meliata back-arc.

Palinspastic models of the western Tethyan realm are proposed from the Carboniferous to early Jurassic.

RESUME

Une évolution de type Cordillère est proposée pour la chaîne varisque d'Europe moyenne. Cette orogenèse serait le résultat d'accrétion de «terrains» évoluant vers l'effondrement de la chaîne et de sa croûte sur-épaissie. Une accrétion majeure de terrain prit place du Dévonien supérieur au Carbonifère inférieur, lorsque la cordillère Ligéro-Moldanubienne rencontra le terrain Intra-Alpin.

Ce terrain représente un segment de la marge nord de la Paléotéthys. La subduction de la Paléotéthys sous ce terrain nouvellement accrété engendra un magmatisme d'arc calco-alcalin au Carbonifère supérieur. La subduction oblique de la Paléotéthys engendra aussi un déplacement latéral du terrain Intra-Alpin et son dédoublement dans sa partie ouest. Une fermeture de la Paléotéthys au Carbonifère supérieur est envisagée dans cette région. Vers l'est cette fermeture se fait seulement au Trias moyen, à la suite de l'ouverture simultanée de la Néotéthys et du bassin d'arrière arc de Méliata.

Des modèles palinspastiques du domaine téthysien occidental, du Carbonifère au Lias, sont proposés.

Introduction

Recent actualistic modelisations of the Variscan orogeny offer a large panel of possibilities and a good ground to start a review of this still puzzling mountain belt.

We intend to comment here on some of these present day points of view but also to present the end of a story often ignored by some respected hercynologists. Effectively the "Variscides collisional processes" are usually situated from early Devonian to late Carbo-

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niferous and the "Tethyan cycle" (opening of the Alpine Tethys-Central Altantic system) as not starting before mid-Triassic times. An apparent lack of major tectonic events during the Permian an Triassic of SW Europe or in the Appalachian domain, is certainly responsible for the focussing of attention mainly on the Carboniferous history of the Variscides of central Europe. But the Variscan domain does extend over the whole Alpine area and even further in the Dinarides and Hellenides. It also extends in time as deformations seem to become younger, possibly grading into early Cimmerian (Triassic) deformations southward and eastward. In the late Carboniferous, the Paleotethyan domain was not fully closed in SE Europe and even lasted up to some time in the Permian in the Hellenides and even in Triassic times more to the East. Stampfli et al. (1991) discussed this diachronous closure of the large Paleotethys ocean insisting on the likely development of back-arc oceans or basins within the Permo-Triassic Eurasian margin (Baud & Stampfli 1989; Baud et al. 1991a). The opening of a back-arc ocean in an active margin transforms part of that margin into a passive margin setting (i.e. the Korean margin of the Sea of Japan), where volcanic activity and deformation stop after break-up. The drifting side of the back-arc remains an active margin setting. Placing oneself on the southern border of the Alpine domain (upper Austro-Alpine), such a tranquil ending of the Variscan orogenic cycle did take place, whereas an active margin persisted more to the SE, in the Dinaro-Hellenide domain.

Most of our references will be taken from recent compilations on the Alpine side of the Variscan orogen:

- Società-Geologica-Italiana 1979
- IGCP project 5 (Flügel et al. 1987; Sassi & Zanferrari 1989)
- IGCP project 276: (Baud et al. 1991b; Carmignani & Sassi 1992)
- von Raumer & Neubauer (1993b)
- IGCP project 369 (started in september 1994)

The main actors: the oceans

If a lack of concensus exists in regard to the evolution of the Variscides of middle Europe, it is mainly because of the lack of information on the oceanic domains which disappeared during the late Paleozoic. On top of that, and as shown for many other orogenies, back-arc oceans are the source of most ophiolites whereas main oceans can subduct without leaving any trace of oceanic crust.

It would be quite time consuming to fully discuss such problems here but to simplify, it can be accepted that three main oceanic domains disappeared in the European transect of the western Variscides, from north to south:

- the Iapetus which was closed during the accretion of Baltica to North-America and is mainly related to the Caledonian cycle.
- the Rheic-Tornquist ocean (and related marginal seas) whose closure gave birth to the Variscides s.str.
- the Paleotethys, implicated in the early Cimmerian orogeny in the Middle East (Stampfli 1978; Sengör 1979; Stampfli et al. 1991) and Far East (Sengör & Hsü 1984) but which certainly extended up to southern Europe in the Carboniferous as we intend to demonstrate in this paper.

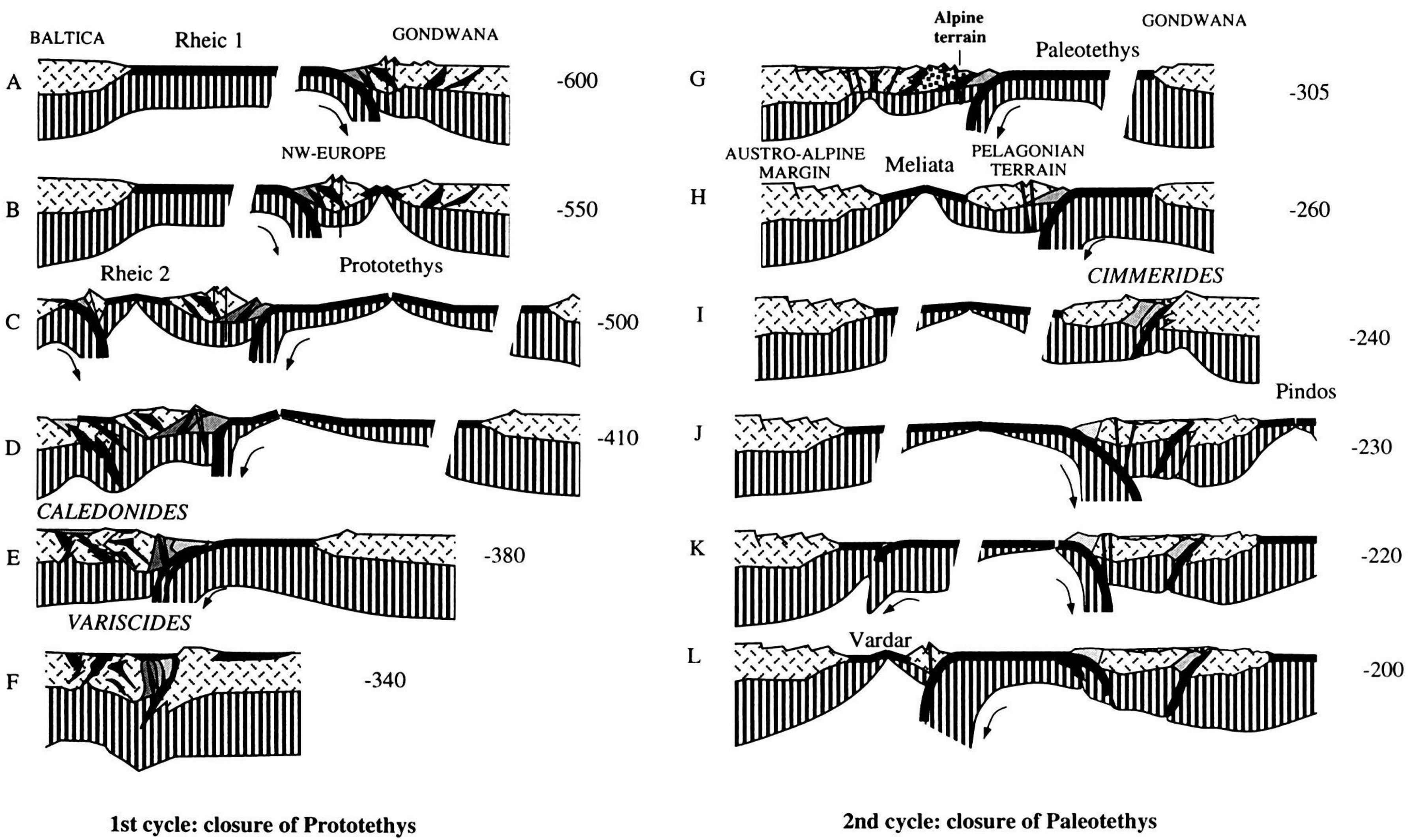

Fig. 1. Geodynamic evolution of the Variscides: the 1st cycle represents the geodynamic evolution on a western Europe transect. The 2nd cycle would be located on an Eastern Europe transect.

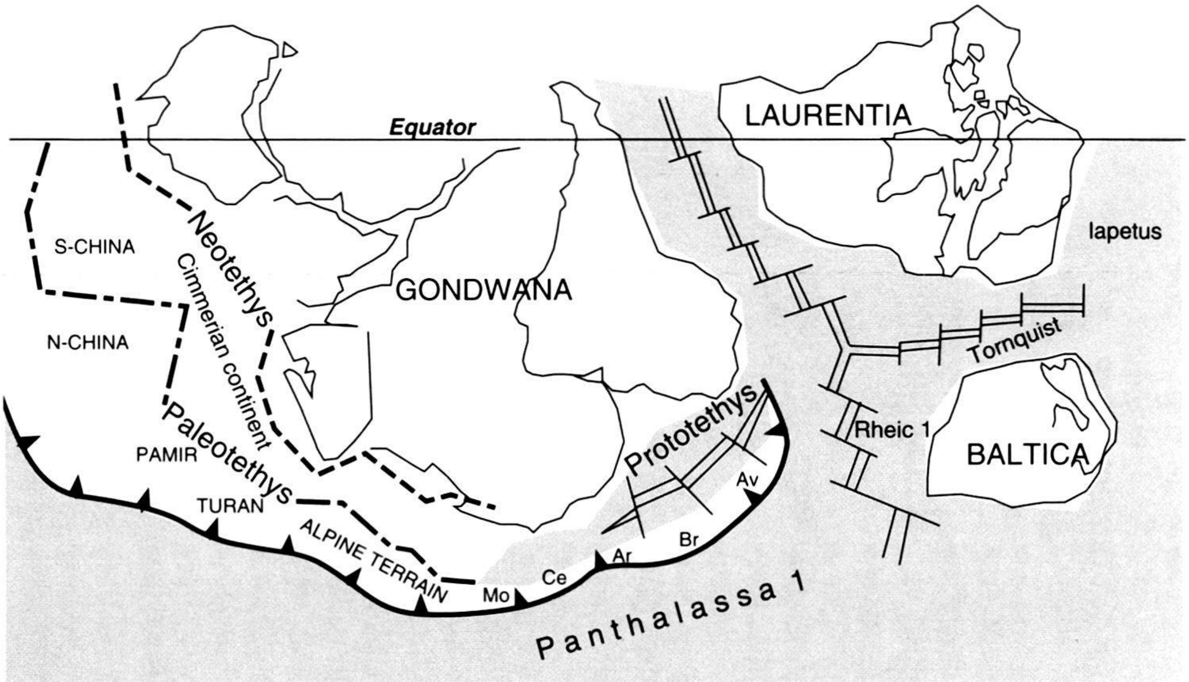

Fig. 2. Cambrian reconstruction (modified after Hoffman 1991) showing the drifting of Baltica and Laurentia from Gondwana. The Prototethys opened as a back-arc. The Paleotethys opening would take place in the Ordovician/Silurian, the Neotethys in the Permian. Ar, Armorica; Av. Avalonia East and West; Br. Brabant; Ce, Central European blocks; Mo, Moesia.

Were these oceans three totally separate entities or were they connected in space and time? We propose the following scenario (Fig. 1, 2):

- a late Proterozoic ocean whose opening separated Baltica and Laurentia from Gondwana (Hoffman 1991). Remnants of that ocean may be found in the Rheic and Tornquist sutures. However it is probable that oceanic remnants found in these sutures are derived from back-arc type offsprings of a large Proterozoic ocean (Fig. 1). Iapetus could have been a lateral extension of this ocean.
- a Prototethys (Mauretanian-Phoibic) ocean opening in late Proterozoic/early Paleozoic time as a consequence of the subduction of the Rheic 1 and/or Panthalassa 1 under Gondwana. Following this opening the active late Proterozoic margin of North-Africa became a passive margin as observed in the Anti-Atlas of Morocco. Most of the N-European blocks involved in the Variscan orogeny could be derived from this opening. From faunistic data (e.g. Robardet et al. 1994) and paleomagnetic data (e.g. Channell in press-a), it appears that Avalonia (East and West, including the Brabant terrain) was the part that drifted away from Gondwana at that time. The Armorican terrain seems to have remained close to Gondwana until the Ordovician (Perroud et al. 1984), when it accelerated it journey to collide with Laurussia in the Devonian together with other mid-European terrains (Moesia included). This implies the opening of second order marginal basins in the midst of a former N-European terrain or that

Armorica and other related terrains were part of a new set of terrains leaving Gondwana later on during the opening of Paleotethys.

- a Paleotethys ocean opening in late Ordovician/Silurian time, whose subduction started only in the Carboniferous when most of the Prototethys had been subducted and its northern margin (the Intra-Alpine terrain) had been accreted to Eurasia. This subduction is likely to generate back-arc basin opening along the Eurasian border (i.e. Meliata, Dobrogea, Caucasus, Agh-Darband and northern Afghanistan).

A schematic 2D point of view of such a scenario is shown in figure 1 and a Cambrian plate reconstruction is proposed in figure 2 in order to locate the successive rifting phases and oceanisations which affected Gondwana during the Paleozoic. Scenario A to F of figure 1 can be applied to the part of Gondwana and Laurussia which collided in the Carboniferous. As can be seen on the reconstruction of figure 3, this collision affected the Appalachians and SW Europe on the active margin side and western Africa and Morocco for the passive margin side. East of Spain and Morocco the likelihood of a remaining late Carboniferous oceanic space between Gondwana and Europe can be discussed on the base of two types of information:

1. well-dated late Carboniferous to early Permian marine deposits, usually of flysch type, found in Spain, Sicily, the Alboran plate, the Tuscan nappes, the Carnic Alps (see Sassi & Zanferrari 1989 and references therein for an overview of these sedimentary sequences).

2. the related late Carboniferous and early Permian calc-alkaline plutonism grading to post collisional or extension related magmatism in early to mid-Permian which is found in the same areas: Catalonia (Enrique & Debon 1987), the Pyrenees (Bixel 1988), Calabria (Acquafredda et al. 1994), Sardinia, Corsica and Provence (Carmignani et al. 1989, Di Vincenzo 1992), the Tuscan nappes (Bagnoli et al. 1979), the Briançonnais domain (Cortesogno et al. 1992; Cortesogno et al. 1993), the Southern Alps (Oberhänsli et al. 1985; Hunziker et al. 1992; Schmid 1993; Siletto et al. 1993), the Eastern Alps (Becker et al. 1987 and the numerous articles on the Eastern Alps in von Raumer & Neubauer 1993b).

Some authors would regard this late Variscan calc-alkaline activity as being related to post-orogenic processes rather than to arc magmatism (see for example the review of Bonin 1993). They incorporated the so-called non or post orogenic Variscan granites in a "Basin and Range model", (although the model was formerly used to explain the post orogenic large scale extension of the Variscan orogen, Malavieille 1993). As far as we know, the Basin and Range Province is situated in the active margin of the NW Pacific ocean not in the midst of a continent-continent collision zone.

The other opinion considers this calc-alkaline magmatic activity as being related to subduction, as shown for example for the late Carboniferous Alpine intrusives when compared to modern analogs (Finger & Steyrer 1990 or Mercolli & Oberhänsli 1988). The oceanic realm subducting south of the Variscan domain in late Carboniferous is considered here as being the Paleotethys.

Paleotethys evolution

The opening of Paleotethys is well constrained on an Iranian transect (Alborz range, North Iran, Stampfli 1978; Stampfli et al. 1991). Late Ordovician to early Devonian

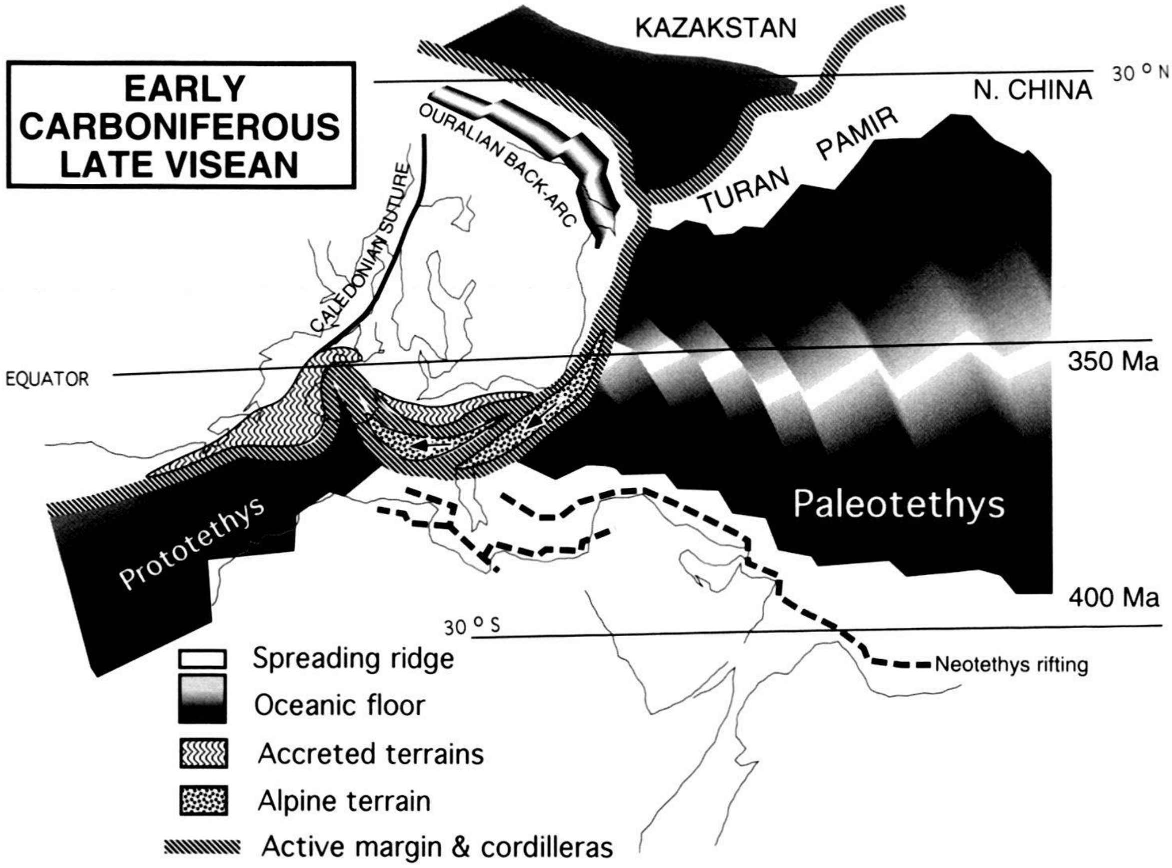

Fig. 3. Early Carboniferous reconstruction showing the westward displacement and duplication of the Intra-Alpine terrain. This terrain was formerly in continuity with the Turan Pamir micro continent representing the northern margin of the Paleotethys. Continent positions from Scotese et al. (1979).

flood-basalts, rift shoulder uplift in the Silurian followed by the onset of thermal subsidence in the Devonian point to a late Ordovician/early Silurian rifting. Oceanisation took place in the Silurian and the rift shoulders were completly flooded by late Devonian. From mid-Devonian till mid-Triassic a carbonate dominated passive margin developed.

What drifted away from Gondwana at that time were Gondwana relicts found nowadays just north of recognised Cimmerian elements. On figure 3 we put the Turan and Pamir (the Kara-Kum/Tarim terrain of Zonenshain et al. 1990; see also Khain 1994) and parts of China as candidates for elements escaping Gondwana in the Silurian. In view of the extension of the southern Paleotethys margin into the Mediterranean realm (Stampfli et al. 1991; Stampfli & Pillevuit 1993), remnants of the northern margin should extend farther west than the Middle East into south-western Europe.

The Transcaucasian massifs (Adamia & Kutelia 1987; Adamia et al. 1987) and parts of the E-Pontides could represent part of the immediate continuation of the Turan blocks, although they would fit better in a scheme of detachment from the Eurasian margin by back-arc spreading (Stampfli et al. 1991; Khain 1994). Anyhow, the large-scale deformation and general uplift of the Eurasian active margin of the Caucasus in the Carboniferous points to a collision process with a terrain to the south, terrain which seems to have disappeared.

Farther west we enter the Alpine region s.l. where Paleotethyan elements may be represented by the Austro-Alpine, Carnic Alps and Tuscan Paleozoic series and parts of the inner Carpathians and Dinaro-Hellenides.

The Carnic Alps series shows a passive margin type of sequence which could fit the Paleotethys development. Taking the sequence as exposed by Tollmann (1985), Schönlaub (1985) and Ebner et al. (1989), the late Ordovician may be regarded as synrift with its large sprectrum of facies and tuffites. The so-called Taconic phase may mark the thermal expansion and shoulder uplift phase with some areas being flooded only in late Silurian/early Devonian. Thereafter, the development of a passive margin setting is marked by carbonate deposition up to the Visean. Deep-water facies development shows that it was a starved margin. Early Carboniferous platform limestone clasts have been found in Moscovian clastics, showing that a shallow platform existed in that area too (Pasini 1992).

The Tuscan Paleozoic is also represented by an open marine Silurian/early Devonian carbonate sequence following a rhyolitic mid-Ordovician event (Gattiglio et al. 1989). Sequences reported from Calabria and Sicily are metamorphic and deformed. However the Bivongi series of Calabria shows a development similar to that of the Carnic Alps, with an evolution of facies from Devonian platform carbonates to pelagic radiolaritic cherts in early Carboniferous (Majesté-Manjoulas et al. 1984). Beside these possible elements of a northern margin of the Paleotethys stand the Paleozoic series exposed in Austria, Sardinia and Spain.

The Betic sequence is not too different from the previous ones with a clastic late Ordovician/early Silurian sequence followed by a Devonian carbonate platform also with pelagic facies (Gomez-Pugnaire 1989). In Sardinia (Carosi & Gattiglio 1989), the mid-Ordovician rhyolitic event (rifting?) is followed by clastics and a carbonate sequence from late Silurian to early Carboniferous. In southern Sardinia (Iglesiente) a slightly different sequence is found, also with a mid-Ordovician deformational event marking the onset of clastic sedimentation on top of a Cambro-Ordovician platform. Noteworthy is the presence of early Silurian metabasites, extruded at the same time as flood-basalts in the Alborz.

The Graz Paleozoic of Austria (Ebner et al. 1989) is part of a Siluro-Devonian carbonate platform extending up to the Namurian. It may be the equivalent of the deeper facies of the Carnic Alps. The Grauwacken zone Paleozoic is characterised by a middle to late Ordovician uplift phase and rhyolithic effusives. Silurian intraplate volcanism, slope type facies as well as carbonate platform facies lasting up to the Visean are found there too. The basement of this sequence could be related to an early Paleozoic accretionary complex including ophiolitic remnants (Ebner et al. 1989).

The review of these Paleozoic series points to a Paleotethyan margin affinity. These series could represent either the northern or the southern margin of the Paleotethys. The southern margin can be followed from Iran to Turkey (i.e. the Silifke series in the autochthonous of the Taurides, Demirtasli 1984, 1989). Westwards it is either deeply buried or covered by Alpine nappes whose stratigraphic series do not display Paleozoic elements. We would favor a northern margin origin for these Alpine series as some bits and pieces of Variscan basement are found south of them in the internal Dinarides and Hellenides, where final collision with Gondwana took place later on in late Permian-early Triassic, as exemplified by the following key areas:

- The Chios outcrops (Papanikolaou & Sideris 1983; Baud et al. 1990) may be regarded as an accretionary prism marking the closure of the Paleotethys as they contain pelagic elements of Ordovician to Early Permian in a Permo-Carboniferous matrix (Stampfli et al. 1991). These series are sealed in the allochthonous nappe of Chios by late Permian carbonates showing that subduction processes probably lasted there at least up to that time. In the autochthonous series they are sealed by early Triassic sequences.
- Mélanges containing Variscan basement elements along with Paleotethyan carbonates are found in many places in Greece (Papanikolaou & Sideris 1989). In the Pelagonian "basement" units of Euboea (Stampfli et al. 1995) a not yet dated wildflysch unit contains blocks not younger than late Permian. This points to a collision of the active Eurasian margin with the Gondwana side of the Paleotethys from late Permian to mid-Triassic. These types of mélanges extend to western Turkey (Bursa sequence in Demirtasli 1989).

The above mentioned Alpine sequences affected by Variscan deformation already in the Visean or Namurian are different from sequences found in Greece in a more external, southern part of the Variscides, or even in the Cimmerides. A northern Paleotethyan margin origin for the Alpine sequences is therefore very likely, these sequences represent what we call the Intra-Alpine terrain.

As shown by Spaletta et al. (1979) the Carnic series would have changed from a passive to an active margin setting in late Visean with the deposition of the Hochwipfel flysch containing acidic lava clasts possibly related to the onset of arc volcanism. Before that, and as seen for other sequences of the Intra-Alpine terrain, the deepening noticed in late Devonian/early Carboniferous could be related to the flexuration of the plate approaching the trench of the active Eurasian margin. Volcanism becomes more basic in the Dimon flysch and dominates the sedimentation of this Westphalian sequence. The alkali-basalts point to an extensional event affecting the margin in late Carboniferous and the Waidegg-Auernig (Stephanian) and the following fusulinid-bearing series of early to mid-Permian age (Vai et al. 1979; Ebner et al. 1989) could be interpreted as a syn-rift sequence in a back-arc setting.

This rift is regarded as having given birth to the Hallstatt-Meliata ocean or marginal sea (Kozur 1991). From an active margin setting this southern Austro-Alpine margin became passive and developed a thick carbonate sequence starting in late Permian with the widespread deposition of the Bellerophon limestone grading into thick Mesozoic carbonate platform.

In this context, the Saalian phase is interpreted as marking the drifting unconformity or the transgression of the rift shoulder following the onset of thermal subsidence. The Verrucano s.l. may also be considered as derived from the erosion of reliefs created by the thermal expansion of the rift. The Verrucano represents a composite sequence with varying facies found in many Alpine nappes, but it is not well dated. The Verrucano Lombardo (Rossi 1975) and the Val Gardena sandstone and Bellerophon formation (Massari et al. 1994) are late Permian and pass conformably into early Triassic marine deposits (Werfen formation). They clearly seal the early Permian extension phase and volcanic activity in the southern Alps.

The Variscan orogeny in middle and southern Europe: terrain accretion and active margin setting

The Alpine series related to the northern margin of the Paleotethys may have formed a relatively narrow strip of continental fragments which eventually collided with Eurasia as their eastern equivalents did (Kara-Kum Tarim accretion between 340 and 280 Ma, Khain 1994). They can therefore be regarded as terrains and have already been grouped under the labels of Intra-Alpine terrain by Ziegler (1988) and Austro-Alpine terrain or Noric-terrain by von Raumer & Neubauer (1993a). Generally speaking, carbonate sedimentation changed diachronously to flysch between the Visean and the Namurian in these series. There are two possible explanations for this change:

– either it is a flysch of the Sudetian Variscan phase somehow directly related to what is going on within the Variscan orogeny, or it is an after-effect of this orogeny and marks a southward jump of the subduction (the onset of the Paleotethys subduction).

We prefer the latter solution because the Variscan orogeny does not comprise only one phase of deformation but a continuum of deformations affecting an active margin from early Devonian to mid-Carboniferous (e.g. Ziegler 1993), when it finally grades into a major terrain accretion. This accretion jammed the previous subduction pattern, and subduction may have jumped southward.

A striking fact is that the Intra-Alpine terrain possesses a foreland consisting of the Carnic zone and South-Sardinia. Both areas were little affected by Variscan deformation and metamorphism (Vai & Cocozza 1986). But as previously discussed, this foreland is not the southern margin of Paleotethys. Marine connection persisted all along the southern side of the Intra-Alpine terrain at least until the late Carboniferous (Moscovian), precluding any major collision with Gondwana to the South before that time. Thus, the Devonian to Carboniferous Variscan orogeny of middle Europe cannot be related to a major continent-continent collision (Eurasia-Gondwana) but rather to the accretion of the Intra-Alpine terrain to an active margin to the North. In this setting, the late Carboniferous flysch basins of the Intra-Alpine terrain, developing on a passive margin sequence, may be regarded as fore-arc basins which is consistent with the calc-alkaline magmatism affecting these areas in late Carboniferous. Westward, a continent-continent collision occurred between a West-African promontory and the Appalachian margin as shown on figure 1 A to F and figures 3, 4. But moving from the Appalachians to Spain and France we enter an entirely different domain, in terms of geodynamics, characterised by an active margin setting possibly lasting up to early Permian based on the following facts:

- the presence of the Sicanian, early Permian flysch in Sicily (Catalano et al. 1991)
- the transition from calc-alkaline magmatism to post orogenic alkaline volcanism found in late Carboniferous/early Permian in most of the Intra-Alpine terrain and the areas listed previously.

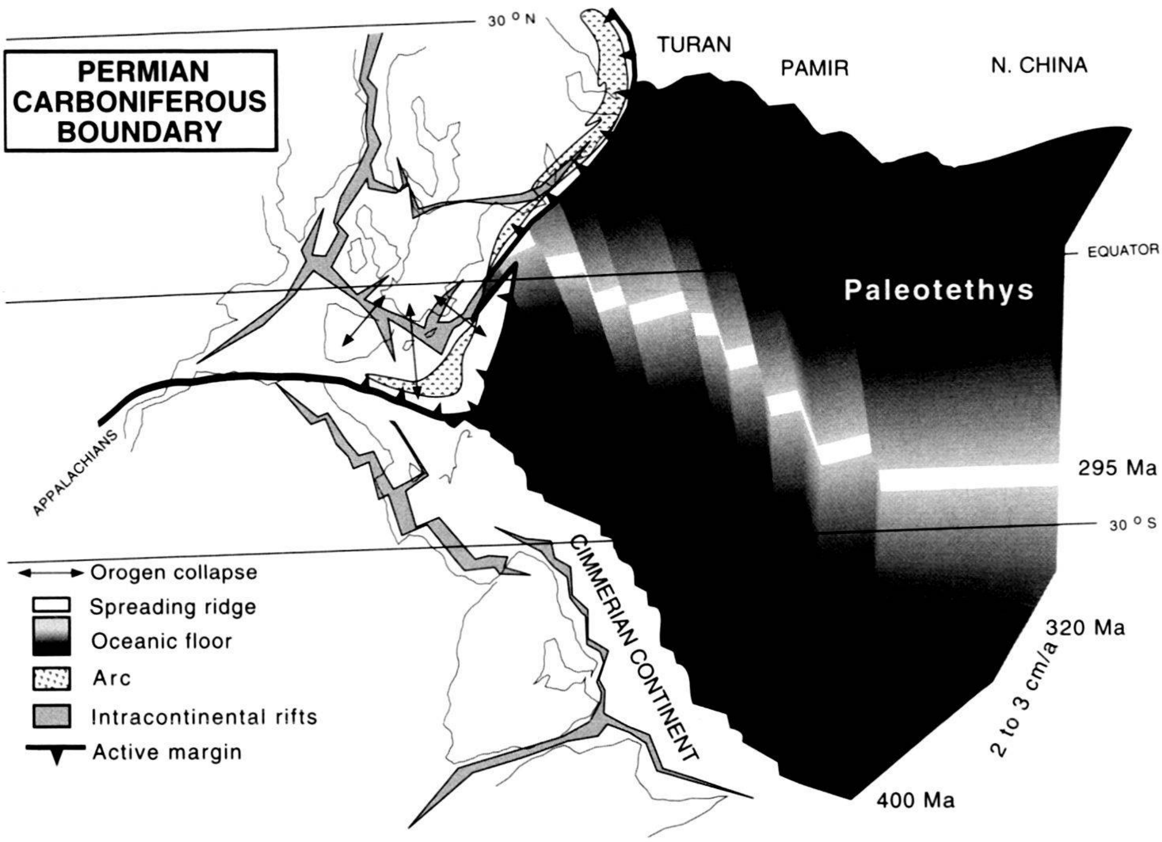

Fig. 4. Late Carboniferous reconstruction showing the final closure of the Paleotethys between Africa and Europe due to collapse of the Variscan Cordillera. Opening of a back-arc (linked with the North-European rift system) is related to the oblique subduction of the Paleotethyan mid-ocean ridge and the Paleotethys roll-back. Continent positions from Scotese et al. (1979).

We have already interpreted the Sicanian flysch as having been deposited in the southern foreland basin of the Variscan orogen (Stampfli et al. 1991) or as a possible extension of the East-Mediterranean basin (Stampfli & Marchant in press). Actually, the Sicanian deep-water basin must have been connected to an open sea during the whole Permian and Mesozoic. If the Paleotethys closed in that area in the late Carboniferous, a connection must have persisted through the East Mediterranean area (Pillevuit 1993; Catalano et al. 1995).

Terrain kinematics

In the recently accreted terrains found along the eastern coast of the Pacific, the kinematics are mainly constrained by paleomagnetics and facies recognition. However, solutions are not unique. To decipher what happened to the Intra-Alpine terrain in terms of displacement is not a simple matter: as its Carboniferous displacement is latitudinal, paleomagnetics will not be of much use. Then we have to consider what may have driven this terrain from Gondwana to Eurasia from the Silurian to late Carboniferous. Certainly it was the opening of Paleotethys, but in which geodynamic context?

In view of: i) presence of a volcanic series found in mid-Ordovician, ii) a substratum with ophiolitic sequences and iii) the widespread "Caledonian" metamorphism of the Austro-Alpine basement (Becker et al. 1987; Bonin 1993), one may be tempted to propose a back-arc situation for the creation of Paleotethys, at least in its western part. As shown on figure 2 this would correspond to a younger continuation of the Prototethys back-arc.

In Iran however, rifting is of intracontinental type. There the pre-rift sequence does not comprise remnants of volcanic activity apart from some basalts in the early Cambrian Lalun sandstone (Stampfli 1978), possibly related to the opening of the Prototethys.

The other problem is to know at what speed and in which direction the ocean opened.

Remnants of Paleotethys are scarse (Sengör 1987), however recent work in eastern Iran shows the incorporation of Permian Paleotethyan oceanic floor into Permo-Triassic mélanges (Ruttner 1993). If it is the Paleotethys ocean floor and not that of a back-arc, it would mean that the mid-ocean ridge of Paleotethys was accreted along the Eurasian active margin in late Permian/early Triassic in this region. We can therefore place the mid-ocean ridge of Paleotethys in our late Permian reconstruction and deduce its average half spreading rate which is in the order of 2 to 3 cm/y.

In the proposed reconstructions the mid-ocean ridge of Paleotethys was subducting under Eurasia in an oblique and diachronous fashion, in a way similar to the Pacific ridge subducting under North-America in the Cenozoic. From large scale continental reconstructions (e.g. Scotese et al. 1979) we also can see that during the Carboniferous the NE corner of Gondwana approached Eurasia very obliquely along a latitudinal course. This implies that once accreted to Eurasia, the Intra-Alpine terrain was likely to be dragged westwards along that margin by Gondwana (Fig. 3) and pushed in the same direction by the subducting mid-ocean ridge of Paleotethys (Fig. 4). This may induce a duplication of this terrain on a European transect and explain the complexity of the French and Iberian Variscan orogen.

Basin and Range model

A Basin and Range model has been proposed to explain the large scale plutonism and associated extension affecting the Variscan chain during middle to late Carboniferous (Ménard & Molnar 1988). As said earlier, we agree with this interpretation albeit the fact that we consider the Basin and Range to be located and strongly connected with the evolution of an active margin and not with a continent-continent collision (as envisaged so far by most authors who used that comparison).

A general review of the Cordilleran orogen of the North-American Pacific coast is found in Burchfield et al. (1992). When compared with South America or the west Pacific regions, the whole setting of the North-American coast was and still is influenced by the subduction of the Pacific spreading ridge. The Basin and Range geodynamic setting is certainly related to this subduction during the Cenozoic. The exact mechanism is still not fully understood although there is a clear relationship between magmatism and extension (Wernicke 1992). This author recognises four stages in this extensional event:

- formation of early intermontane basins
- eruption of intermediate to silicic volcanites
- large scale extension during or just after the eruptive stage
- basaltic or bimodal volcanism and lesser extension

The extension affecting a large portion of the U.S. Cordillera is accompanied by the opening of the Gulf of California which can be regarded as a back-arc basin. Independently of what was happening in terms of compression or extension, andesitic volcanism was always present throughout the Cenozoic in the U.S. Cordillera (Lipman 1992). Major shifts of the volcanic centers (sometimes in the order of 1000 km) can be observed and correspond to changing subduction angles. This confirms that although the geodynamic context can be locally very different, the margin as a whole remains an active margin and the extensional context creates a tendency for the upper plate to override the oceanic plate (Page & Brocher 1993).

Using this active margin analogy, the general extension (Burg et al. 1994) and magmatism (Schaltegger & Corfu 1995) which affected the Variscan orogen in late Carboniferous can certainly be compared to a Basin and Range situation. Between 300 and 270 Ma the margin evolved from arc to back-arc opening, arguments in favor of such a geodynamic change are:

- Late Carboniferous rifts, like the Zone Houillère, that were dominated by calc-alkaline volcanism (Cortesogno et al. 1993).
- emplacement of Permian gabbros in the Penninic zone (Pfeifer et al. 1993; Thélin et al. 1993)
- early Permian (275 ± 18 Ma) MORB basalts in the Austroalpine domain (Thöni & Jagoutz 1993)
- an evolution from typical calc-alkaline to transitional basalts with an E-MORB signature (Traversa & Vaccaro 1992) of the late Variscan dykes in Sardinia.

The Cordilleran collapse model

Gravitational collapse of an active margin seems necessary knowing that in some instances the margin has a 70 km thick crust. This is the case for the South-American margin of the Andes (Kay et al. 1991; Zandt et al. 1994). A cordilleran collapse model was presented by Lister et al. (1984) for the evolution of the Aegean arc in the Neogene times. It is shown that starting from a thickness of 60 km the Aegean crust underwent major extensional processes located along two belts presently marked by metamorphic core-complexes. The present crustal thickness of 20 to 30 km has been reached in a time span of 15 to 20 Ma. The outflow of the arc on the retreating East-Mediterranean slab can be estimated at 200 km (average speed 1 cm/y).

The Andes or Cordilleran model would better fit the Variscan orogen than a Tibetan plateau stage metamorphosing itself into a basin and range setting (Ménard & Molnar 1988), in term of size, amplitude of uplift and timing. The Variscan orogen was bordered by seas on both sides at least up to the Namurian (the sea of Namur). However orogenesis and crustal thickening (up to a Tibetan plateau stage) is expected to be Late Devonian to Visean, a period corresponding to the main metamorphic, plutonic and folding phase. The Namurian sea to the north of the orogen gave place to the continental Westphalien foreland basin and it has certainly not been raised to several 1000 m of altitude. The pre-collapse width of the orogen from the foreland basin to the Intra-Alpine terrain, where marine sedimentation persisted in the Permian, would be between 300 and 400 km, not 1000 km as it is the case for the Tibetan plateau. In the Andes the thickened crustal belt is a few hundred kilometers wide and is bordered by a continental foreland basin (Amazon and Chaco) on one side and by the Pacific ocean on the other. The process by which the crust is doubled depends mainly on the coupling of both lower and upper plate in the subduction zone and on the amount of underplated material accreted under the upper plate. This is directly related to the buoyancy of the lower plate (Cloos 1993). The more buoyant it is the more coupling and underplating there will be. This buoyancy will increase when the ocean being subducted becomes younger (approaching a mid-oceanic ridge) or when buoyant material is overlying the oceanic mantle (island arc, volcanic plateaus) or is attached to it (micro-continent).

The accretion of the Intra-Alpine terrain was rapidly followed by the subduction of the Paleotethys mid-ocean ridge creating an Andean situation between late Visean to late Westphalian, followed by a Basin and Range situation in the Stephanian.

The collapse of the active margin followed the southward retreat of the sinking Paleotethyan slab (roll-over effect). In southern Europe this rapidly closed the limited space between Gondwana and Eurasia. In areas of maximum curvature, however, remnant marine basins persisted in the Permian (Sicanian basin of Sicily), either in a foreland position or as extensional basins on the upper plate (like the present Sea of Crete). Rb/Sr dating in the Peloritan basement (Sicily) shows that extension or collapse of the Variscan basement in this region lasted until mid-Permian (262 Ma) (Atzori & Ferla 1992).

Terrain duplication

Before commenting on the Permian part of the history, let us come back to the implications of a duplication of the southern Eurasian margin by terrain displacement in a transform margin setting. Large scale strike-slip displacement between Euramerica and Gondwana affecting mainly the southern part of Europe has been proposed by people studying the Variscides (e.g. Matte 1986) and used as a basic concept for the Permo-Triassic reconstructions of the "Tethys group" (Ricou 1994). This displacement is necessary to allow Gondwana to close the gap of the southern Appalachians and to generate the Ouachita orogen in the Permian. In this context the Alpine terrain and part of the Eurasian margin into which it collided could be duplicated. I suggest that the former western undisplaced prolongation of the Intra-Alpine terrain consists of the southern Massif-Central and northern Spain (Montagne Noire, Pyrenees and Catalonia) bordered to the south by the Cantabrian basin (Aquitaine-Cantabrian terrain of Ziegler 1988). The Montagne Noire sequence (Demange 1989) was folded in the Namurian. The Paleozoic sequence shows a typical Paleotethyan evolution:

- Ordovician clastic sequence and volcanism
- unconformity with differential transgression of the late Silurian/early Devonian on older rocks
- carbonate platform development in the Devonian and deepening of the sequence marking mature passive margin stage or flexuration in the Visean.

A similar evolution is reported from the Pyrenees (Munoz et al. 1989; Santanach 1989), with a late Ordovician unconformity and magmatic event; there the flysch sedimentation lasts up to middle Moscovian (Westphalian).

The Catalonian sequence (Julivert et al. 1989) comprises a late Ordovician to early Silurian clastic sequence with volcanics (synrift) followed by a deepening carbonate platform setting. Flysch sedimentation started in late Visean and lasted up to early Westphalian. The Stephanian is represented by continental conglomerates. Late Carboniferous calc-alkaline magmatism is reported from the three areas, as already mentionned.

The Cantabrian trough to the south contains a deep marine sequence starting in the Silurian after a more clastic, shallow marine Ordovician. Sedimentation changed to flysch in the Westphalian (Bashkirian) and to shallower environments in the Moscovian (Lys 1986). Synsedimentary deformation is locally important. Sedimentation continued at a very high rate (4700 m of Myachkovian). Marine deposits persisted up to the Kasimovian (mid-Stephanian) in the Asturian basin and in SE Spain (lower Ebro valley, Lys 1986). This precludes any final continent/continent collision between Gondwana and Eurasia before that time.

To the SW and in the possible contact zone between northern Africa and the displaced part of the Intra-Alpine terrain, the flysch facies with open marine fauna (radiolarians) continues at least to the Namurian (Southern Spain and internal Rif, Lys 1986). In the internal Betic the flysch extend into the Westphalian (Bashkirian). On the African side (Morocco) the flysch contains olistoliths up to late Visean in age, both in the High-Atlas and in the Rif (Chalouan 1987; Jenny 1988). In the Meseta, the final uplift is post early Westphalian (Bashkirian). Going eastward in the Jerada this uplift is post Westphalian (Moscovian) (Nedjari 1994). Therefore a likely diachronous closure between "Eurasia" (Intra-Alpine terrain) and "Gondwana" (North-Africa) took place between late Visean and the Moscovian on the southern side of the displaced Intra-Alpine terrain (its Iberian/Moroccan part).

We regard the late Carboniferous evolution of this area as marked by the westward displacement of part of the Intra Alpine terrain in front of SW Europe and in front of its westernmost undisplaced part. This displacement also cuts off marine incursions in the trapped trench or fore-arc basin represented by the Cantabrian basin. The displaced part of the terrain and the non-displaced part were finally welded in late Stephanian. The cumulative lateral displacement of the Intra-Alpine terrain is in the order of 1000 to 2000 km.

The Intra-Alpine terrain first collided with the Eurasian margin before being dragged along it. For example, in North Sardinia absolute dating and P-T pathes done by Ricci (1992) show that either isostatic or denudation type uplift took place between the late Carboniferous and the early Permian (290 Ma) (associated with the emplacement of peraluminous granites); but the migmatitic event preceding the uplift was dated at 344 Ma (Visean).

After being accreted and partly underplated, the displaced terrain occupied the whole southern European margin during the Stephanian. Collision and related uplift may have been more severe in the Montagne Noire/Sardinian transect and more of a collage type in Spain, depending on the available space between Gondwana and Eurasia and the presence of promontories along the Gondwana margin.

To conclude, we propose a doubled Intra-Alpine terrain from southern France to Spain. The eastward extension of this duplication depends on the recognition of a possible suture in the midst of the Alpine Variscan belt.

The suture

The limit between the Intra-Alpine terrain and the active European margin (suture) or the limit between a displaced Intra-Alpine terrain and a non-displaced one (transform margin limit) should be a prominent tectonic feature. The problem is that we had first a zone of collage or subduction/obduction between a terrain and an active margin (this can be regarded as a real suture containing deep water sediments and locally ophiolitic remnants). This suture became a zone of extension of the collapsing orogen affected by large scale strike-slip deformation and accompanied by along strike displacement of part of the colliding terrain. At that stage of its history this limit is quite similar to a "San Andreas fault" plate boundary. The San Andreas fault is nearly 2000 km long, it is a plate limit but not a suture in the sense that it has no ophiolites (although in its present northward drift the Baja California terrain could eventually trap some of the Juan de Fuca plate oceanic floor) but at the same time it is cutting through or in between accreted terrains in which ophiolites are found.

Such a suture or transform margin limit should be primarily characterised by crustal mylonites and mélanges at shallower levels. Certainly mylonites are quite typical of the Variscan basement and found, for example, in the external massifs of the Alps. These massifs present a typical active margin setting starting in the Ordovician with accretionary processes which include ophiolitic remnants (Pfeifer et al. 1993), grading into an Andean type setting in the Devonian (von Raumer et al. 1993). This type of setting is found elsewhere in Europe and represents the Ligerian-Moldanubian Cordillera. It is interesting to note that subduction along this cordillera started more or less at the same time as Paleotethys opened. We now have a dilemna because an active margin setting of Ligerian-Moldanubian type may be found along the Eurasian margin as well as along the northern side of the Intra-Alpine terrain, it all depends on the polarity of subduction, not excluding a subduction on both sides of the closing ocean.

The geochemistry of Devono-Carboniferous gabbros and amphibolites from the Austro-Alpine basement (Visonà 1992) points to a supra-subduction zone setting. If the Alpine terrain was migrating from Gondwana following the opening of a back-arc, the northern side of the terrain should have remained an active margin.

What will finally be juxtaposed on both sides of the suture are two types of basements which may be not so different at least as to their pre Carboniferous evolution. Therefore, it is not easy to point out the exact location of a suture between the Intra-Alpine terrain and the Ligerian-Moldanubian cordillera in the midst of the polymetamorphic nappes of the Alps. Where the Paleozoic sequence is present it is easier because a Siluro-Devonian carbonate platform development should characterise the Intra-Alpine terrain (due to its drifting through tropical waters, Schönlaub 1993) whereas a relative absence of carbonate in the European active margin may be expected due to the geographic and geodynamic setting.

The Penninic basement is one of these areas of uncertain affinity, either Ligerian-Moldanubian or belonging to the Intra-Alpine terrain; its basement contains ophiolitic and eclogitic remnants (Thélin et al. 1993). The large scale uplift of this basement (Cortesogno et al. 1992) and subsequent rifting in the Permo-Carboniferous accompanied by the emplacement of mafic rocks point to a setting close to the suture zone in between the two domains and becoming later on a transform margin limit.

This evolution of the Penninic basement seems to confirm a likely duplication of the Intra-Alpine basement only west of the western Alps are already suggested higher up. But the present state of knowledge leaves some open questions, mainly about what was duplicated and how many times: the Intra-Alpine terrain but also the Ligerian cordillera may be repeated several times on some transects by lateral transfer but also by large scale extension. An extreme and uniformitarian position would be to consider all terrains from Armorica to the southernmost parts of the Intra-Alpine terrain as formerly belonging to a single terrain forming the northern margin of Paleotethys. This elongated terrain would be incorporated into the Variscides by segments, from early Devonian to late Carboniferous, following its oblique collision with Laurussia. Paleomagnetic data and faunistic data do not really contradict this point of view.

Lateral extension of the Intra-Alpine terrain

The part of the Intra-Alpine terrain that was not subsequently displaced may be found nowadays in Northern Spain, the Pyrenees and Montagne Noire. This segment is cut by the Cévennes fault that separates two different types of Permian evolutions (Burg et al. 1994). East of it, the Maures sequence (Campredon & Boucarut 1975; Tempier 1978) and the external massif of the Alps (von Raumer et al. 1993) do not show much affinity with the Paleotethyan sequences. The continuation of the Paleotethyan sequence is found in the displaced part of the terrain in the Alboran plate (Betic, Rif, Kabylies) and it may continue into the Alps through southern Sardinia. Part of the Penninic domain and most of the Austro-Alpine domain would belong to this terrain, including some elements of the inner Carpathian chain (e.g. the Bakony mountains of Hungary, Lelkes-Felvari et al. 1994).

The Moesian platform sequence and the Balkanides of Bulgaria show an evolution quite typical of an active margin since the Devonian (Ianev 1991): a likely continuation of the Ligerian-Moldanubian cordillera. The Paleozoic sequence of these regions is not of northern Paleotethys type, but more of Eurasian type with Devonian carbonate developing in a marginal sea dominated by clastics and passing southward to a subduction trough with flysch deposits. The uplift of this southern area took place after the late Visean. The Moesian platform, the South Scythian platform and the Caucasus represent an Andean type of active margin during the Devono-Carboniferous. No large scale continent/continent collision happened before the middle Triassic or even later due to the closing of marginal basins. The deformation and metamorphism observed in these regions in the Carboniferous correspond to a collision with terrains or to subduction of a mid-oceanic ridge or oceanic plateaus.

Following the Balkanides into Turkey (Pontides), the Istanbul series (Demirtasli 1989) presents a Paleotethyan signature and was actually put into the Cimmerian continent by Sengör et al. (1984). This sequence with its Carboniferous flysch, however, cannot be a Cimmerian element (Stampfli et al. 1991) since the Cimmerian elements collided with Eurasia in late Permian/early Triassic in this region. It is more likely a Gondwana-derived terrain related to the opening of Paleotethys and not of Neotethys. The Istanbul flysch extends to the Namurian and the whole series is covered unconformably by early Triassic. This is a good equivalent for the Intra-Alpine terrain. A similar situation is found farther East in the Karadere and Zonguldag areas (Demirtasli 1989) where the

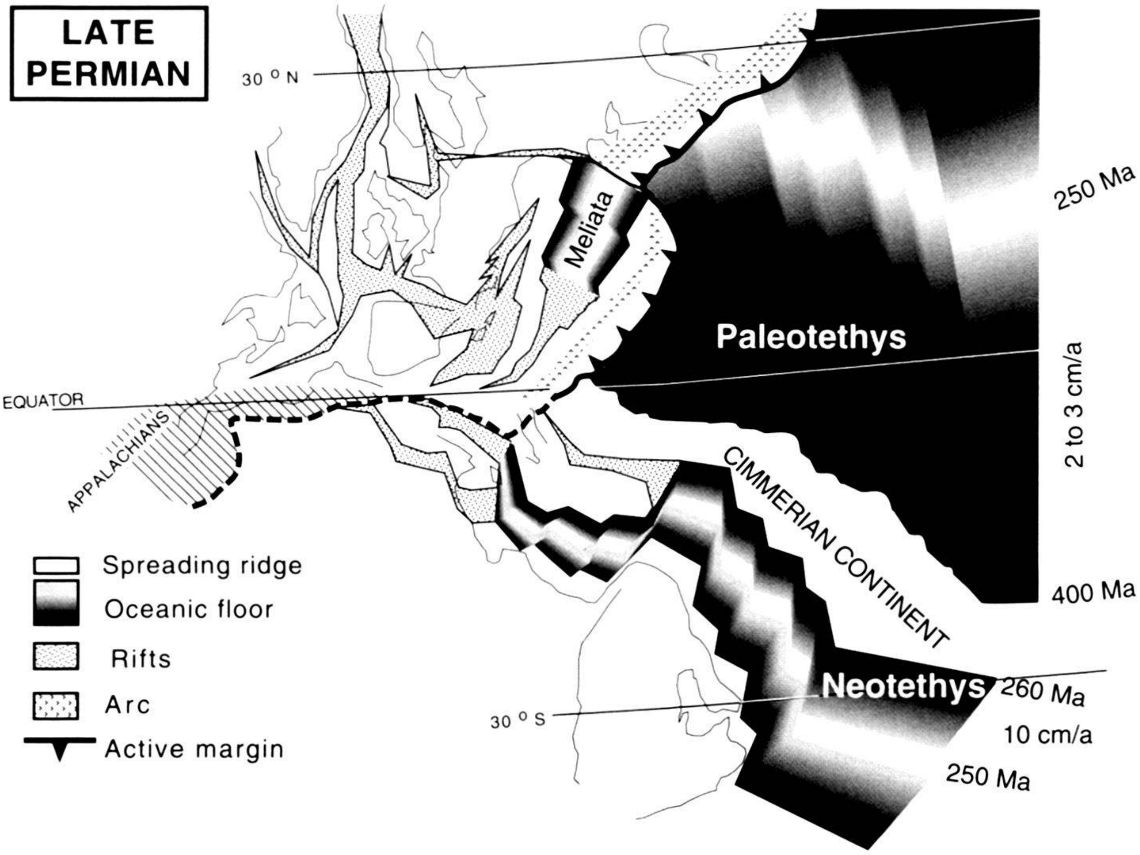

Fig. 5. Late Permian reconstruction showing the simultaneaous opening of the Neotethys and the Meliata back-arc ocean. The mid-ocean ridge of Paleotethys is being accreted in northern Iran at that time. Continent positions from Scotese et al. (1979).

Devono-Carboniferous carbonate platform is replaced by paralic to continental coal-bearing sequences of Namuro-Westphalian age, followed by a continental Stephano-Permian series. There, the Early Jurassic covers the Paleozoic sequence unconformably.

In view of the absence of Paleotethyan northern margin elements farther east (Caucasus, Caspian area) we are tempted to consider the previous Pontides sequences as the eastern end of the Intra-Alpine terrain, displaced westward from a Caucasian-Caspian region where it is absent. The terrain would formerly have been in continuity with the Turan-Pamir (Kara-Kum/Tarim) and Chinese drifting blocks.

Presentation of four paleogeographic maps

The Permian evolution of the western Intra-Alpine terrain is quite simple since not much happened before the opening of the Central Atlantic/Alpine Tethys in the Jurassic. The Variscan orogen collapse and related extensional events ended in late Permian. Most of the region was then covered by a shallow Triassic sea, excepted the Sicanian basin which stayed deep and connected to the East Mediterranean and Neotethys through the Lagonegro/Ionian sea basin (Stampfli & Marchant in press).

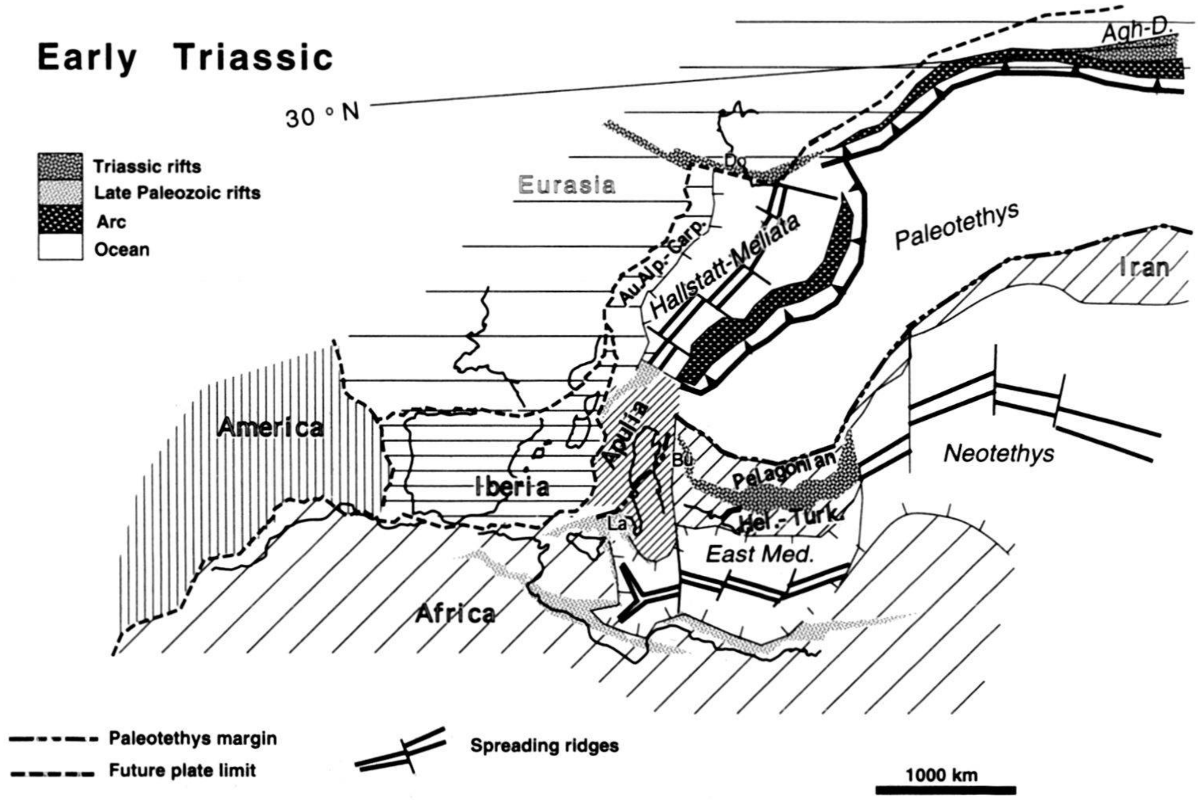

Fig. 6. Early Triassic reconstruction of the Mesogean/Alpine regions. See text for discussion. Agh-D: Agh Darband back-arc (NE Iran); Au. Alp.-Carp., Austro-Alpine/Carpathian; Bu: Budva; Do, Dobrogea; Hel.-Turk: autochthonous of Greece and Turkey; La, Lagonegro/Sicanian basin.

In the eastern part of the Intra-Alpine terrain, east of the Apulian promontory, the Permo-Triassic is a very active period (Fig. 1, G to L). The dominating geodynamic factor is the slab roll-back of the Paleotethys. The roll-back and related slab-pull forces were so important that they may be regarded as responsible for the opening of the Neotethys. The sinking southern half of Paleotethys tore away from Gondwana a relatively narrow sliver of lithosphere, the Cimmerian continent (Fig. 5).

The opening of Neotethys is well constrained in Oman (Pillevuit 1993; Stampfli & Pillevuit 1993) and in the Tethys Himalaya (Gaetani et al. 1990; Vannay 1993; Vannay & Spring 1993). Oceanisation can be placed in late Permian and the spreading rate can be calculated to be around 10 cm/y, bringing the Iranian part of Cimmeria to collide with Eurasia in mid-to late Triassic (Stampfli 1978).

For the opening and oceanisation of Meliata the main geodynamic factor we may use is the thermal subsidence which affected the whole Austro-Alpine margin and other internal parts of the Alps since the late Permian, implying a rifting phase just before that time. This subsidence induced the deposition of a more or less complete Triassic sequence, presenting a large diversity of facies and thicknesses locally approaching 3 to 4 km. Without the presence of the Hallstatt-Meliata ocean it would be difficult to explain the development of such a large scale carbonate platform and margin sequences before the opening of the Alpine Tethys. At Meliata the oceanic series are not older than mid-

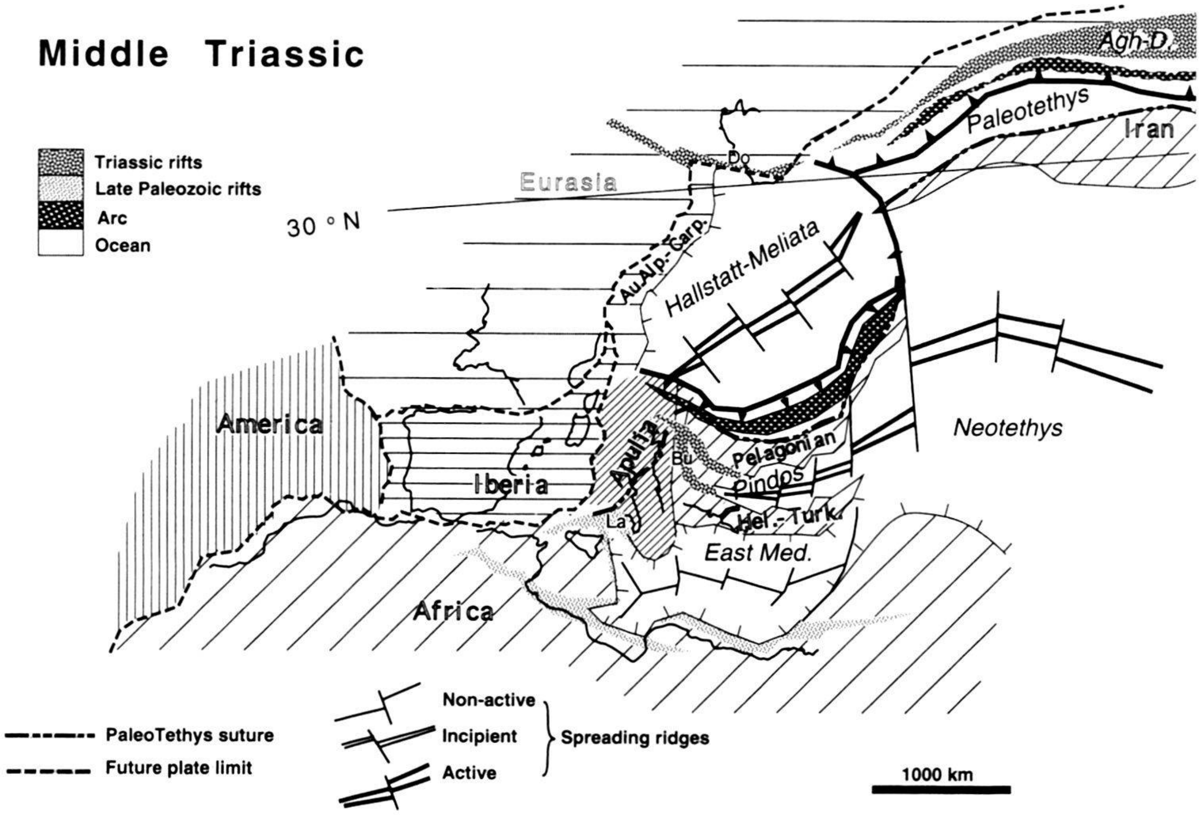

Fig. 7. Middle Triassic reconstruction of the Mesogean/Alpine regions. See text for discussion.

Triassic (Kozur 1991), but these oceanic remnants represent the accretion/obduction of the Meliata ridge during its subduction, implying an older age for the onset of sea-floor spreading. Pillow basalts of MORB affinities are reported from the North Dobrogea area (Niculitel formation, Seghedi et al. 1990, Cioflica et al. 1980) they are interbedded in late Scythian (Spathian) limestone (Mirauta 1982). This spreading event is regarded as originating in a back-arc setting following Permian, arc related, volcanic activity. In our reconstruction we consider Moesia to have been part of the Austro-Carpathian domain at that time and to be located west of its present location. The North Dobrogean Triassic margin sequences were then part of the Meliata ocean northern margin. Through the opening of the Alpine Tethys, the Moesian block shifted eastward and actually deformed this margin during a mid-Jurassic Cimmerian folding phase (Gradinaru 1988).

Westward, this rifting can be followed into the southern Alps where it is represented by the Permian metamorphic event of the Ivrea lower crust (Gebauer 1993). It is interesting to note that some Italian authors proposed a subduction continuing in this area in the Permian. The Graniti dei Laghi and related volcanics of early Permian age could represent an arc (Boriani et al. 1990a; Boriani et al. 1990b). This rift could continue to the SE toward Calabria and Sicily (Sicanian basin) or branch from Sardinia into the Pyrenees and the north European Permian rift system. It could also branch into the Iberian rift system already active in the Permian (Salas & Casas 1993).

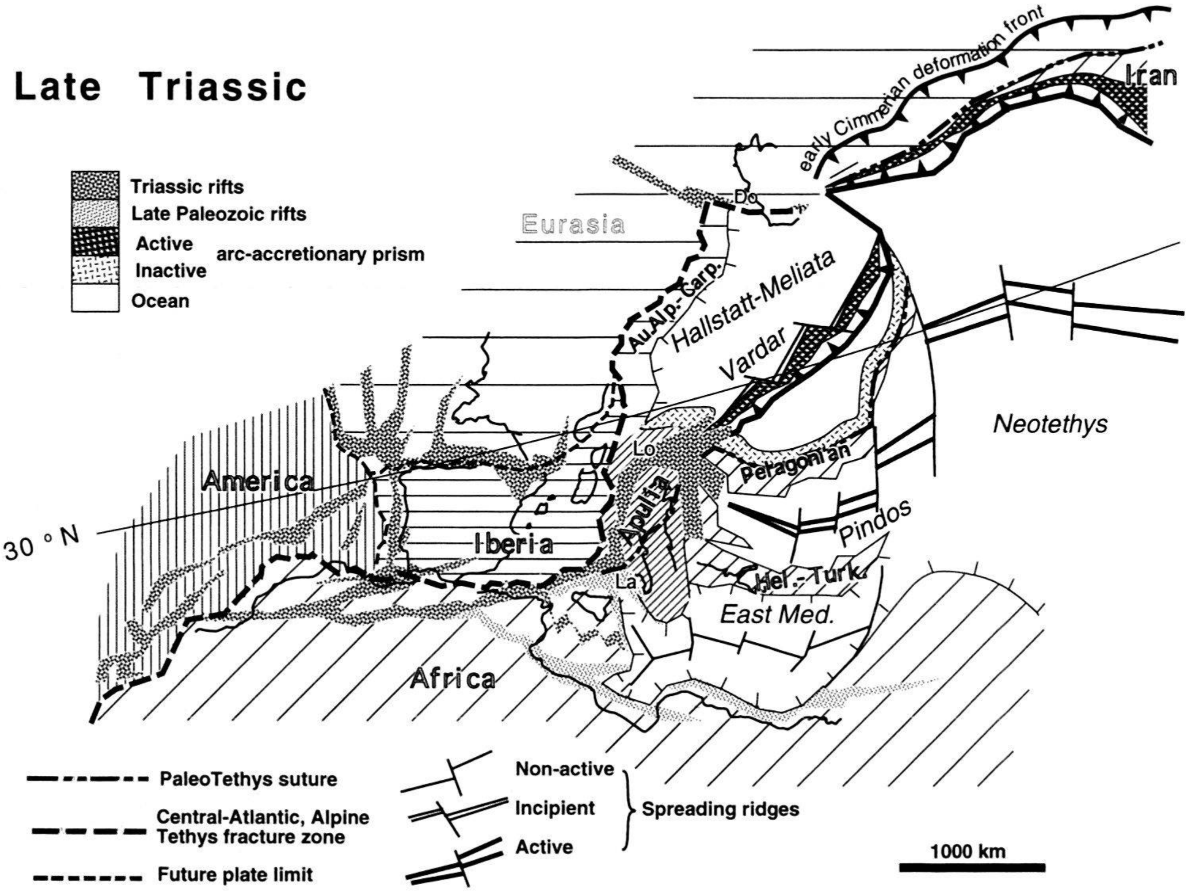

Fig. 8. Late Triassic reconstruction of the Mesogean/Alpine regions. See text for discussion. Lo: Lombardian rift.

These connections could provide an important kinematic constraint on the position of Apulia in regard to Europe. But mainly to be considered here are the Permian openings of the East Mediterranean basin (Lagonegro pro parte) and Neotethys which were responsible for the northern shift of Apulia and the final closure of the remnant oceanic space to the north. If the opening of the Lagonegro-East Mediterranean basin continued into the Triassic then the displacement of Apulia could be responsible for the closure of the Hallstatt-Meliata ocean at that time (Fig. 6, 7).

The simultaneous opening of the Meliata and Neotethys oceans accelerated the closure of Paleotethys, but due to the large space available (Fig. 5), the final closure did not take place before early Triassic in the Dinaro-Hellenide area, as discussed above.

Spreading in the Meliata type sequence may have lasted until the Carnian; later, the whole sequence was incorporated into accretionary mélanges (Kozur 1991). The southward subduction of the Meliata ocean generated the widespread Ladino-Carnian calc-alkaline arc volcanism found from northern Italy (Marinelli et al. 1980) through Greece (Pe-Piper 1982) to Turkey (Demirtasli 1989).

This volcanism gave way to a late Triassic carbonate platform suggesting that subduction ceased or was displaced. Late Triassic/early Jurassic volcanoclastic sequences are

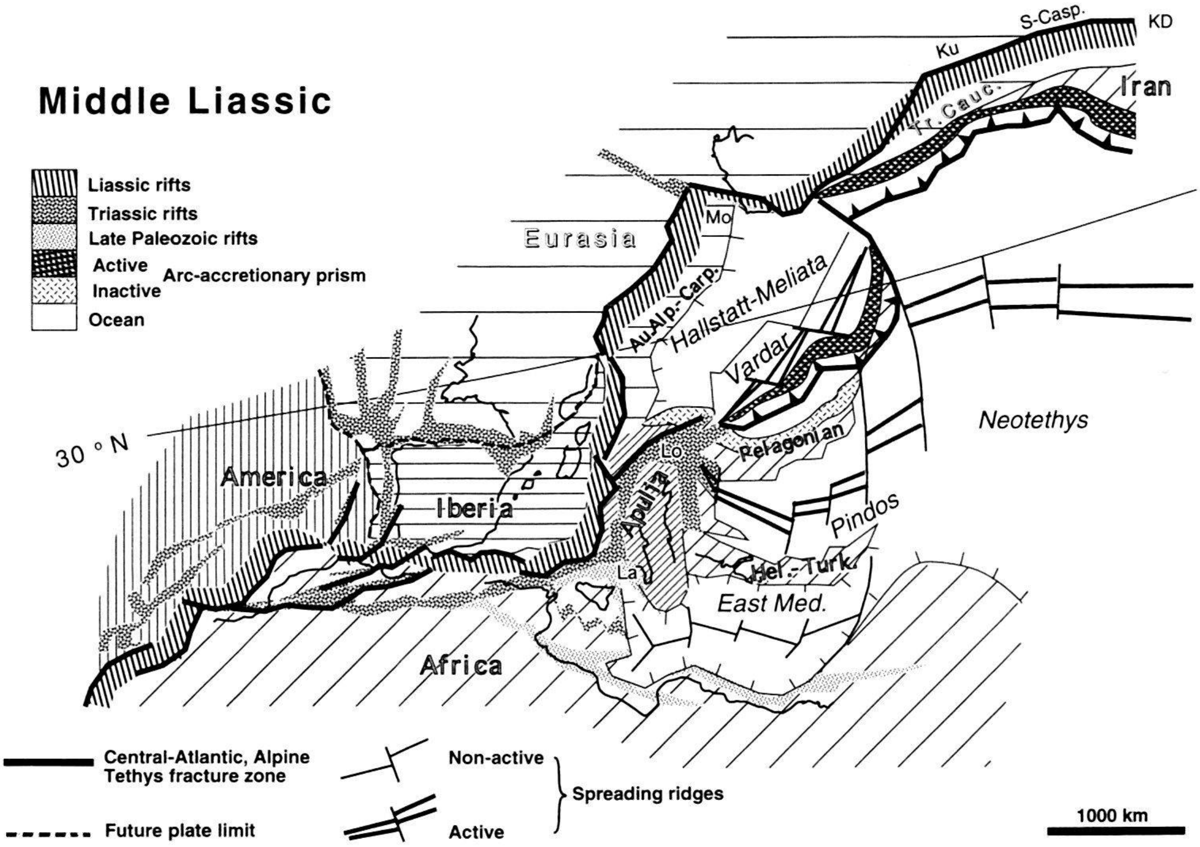

Fig. 9. Middle Liassic reconstruction of the Mesogean/Alpine regions. See text for discussion. The Liassic rifts are shown with changing vergence of the simple shear plane. KD, Kopet Dagh basin, Ku, Kura depression; Mo, Moesia; S-Casp., South Caspian basin; Tr. Cauc, Trans-Caucasian massifs.

known, however, in more internal units of the Hellenides (Peonian and Paikon zone of Mercier 1973). The late Triassic carbonate platform was drowned in mid Jurassic and then thrusted by the obducted Vardar ophiolites in late Jurassic (Baumgartner 1985). Therefore, we suggest that the Meliata subduction became intra-oceanic in late Triassic-early Jurassic and developed a new marginal basin (Vardar) which was obducted later on (Fig. 8, 9, 1 L).

The southward mid-Triassic subduction of the Meliata marginal sea may also be linked to the opening of the Pindos/Budva rift as a back-arc basin (Fig. 8). This induced the shift of the Neotethys spreading ridge from the East-Mediterranean basin to the Pindos which then became the main ocean in the area. This in turn terminated the southward subduction of Meliata and changed it into a northward intra-Meliata subduction, more in line with the sense of subduction under the Cimmerian blocks at that time (Fig. 8). The Vardar opening can then also be linked to the opening of marginal seas along the Eurasian margin from Crimea to the Kopet-Dagh through the Kura-South Caspian basin.

With the disappearance of Palaeotethys we enter a new geodynamic era, a slow spreading ocean is replaced by a fast spreading one (Neotethys). The main consequence is certainly the final break-up of Pangea following the opening of the Central-Atlantic/Alpine Tethys ocean in late Liassic. The Alpine Tethys will open in between Permo-Triassic rifted areas already thinned and cooled (Fig. 9).

The Variscan of the Dinaro-Hellenids

In view of the preceding, it appears that the Variscan elements found in the Dinaro-Hellenides domain once pertained to the Eurasian margin and most likely to its Austro-Alpine/Carpathian province. These elements drifted away from the Eurasian margin in late Carboniferous/Permian and were accreted to Gondwana in early to mid-Triassic and re-accreted to Europe during the Alpine orogenesis.

In this hypothesis they would have formed the core of island arcs, following the retreat of the sinking Paleotethyan slab (Fig. 5 to 9). They should present strong analogies with the Austro-Alpine basement, but younger intrusives could be found too. These metamorphic elements have not been studied in detail yet and certainly there is a lack of reliable absolute ages. Recent datings have been done mainly in continental Greece, in part of the Pelagonian basement and in the Phyllites series in Crete.

In the Pelagonian domain, the Kataphygion granite has been dated by U-Pb method on zircon at 305 ± 5 Ma (Stephanian) by Yarwood & Aftalion (1976) and the Varnoudas pluton at 247 ± 7 Ma (late Permian) by K-Ar method on biotites by Katerinopoulos & Marcopoulos (1987). Ordovician intrusions are also present in the Varnoudas complex and dated as mid-Ordovician 463 ± 12 Ma. These datings, if verified to be reliable, are certainly in good agreement with the proposed evolution and origin of these Variscan basements.

We are presently studying the Pelagonian basement in Euboea (Stampfli et al. 1995). The dominating sequence consists of a polymetamorphic basement overlain by Verrucano with a marine, late Permian interval (Bellerophon limestone) and an early to mid-Triassic transgression. These Verrucano, late Permian and early Triassic carbonates may represent the sequence corresponding to the rifting and drifting phase of a former Pelagonian micro-continent initially attached to Europe. Most blocks of the series, regarded as mélanges in this region, turned out to be due to interfering structural trends. However, there is a turbiditic sequence of wildflysch type containing small blocks not younger than late Permian and locally resting directly on the basement. On the mainland in Attic, Clément et al. (1971) found marine late Carboniferous (Bashkirian) and early Permian carbonate blocks in a similar pelitic matrix. These remnants of a shallow Permo-Carboniferous carbonate platform may derive either from the Pelagonian sub-terrain (part of the Intra-Alpine terrain and part of the Paleotethys northern margin) or from the southern Paleotethyan margin with which the Pelagonian block collided in early Triassic as shown by the Chios outcrops. It was more a collage than a collision as the whole area stayed under marine influences.

While most of the Paleotethyan northern margin early Carboniferous sequences exhibit relatively deep water facies sometimes with radiolarites, we are dealing, in the Pelagonian, with inner platform facies. Hence we would be tempted to place them on the southern margin of Paleotethys. This implies that the Paleotethyan suture should be found somewhere in the internides of the Hellenides. This problem has already been discussed by Papanikolaou (1989) who considers most of the Hellenides basement as pertaining to Gondwana, by placing the Paleotethys suture in a more internal position north of the Rhodope. These diverging points of view can be reconciled when the Triassic Paleotethys of Papanikolaou is replaced by the Hallstatt-Meliata ocean as Paleotethys had already dissappeared at that time. Also to be considered here is the Permian age of the East-Mediterranean/Sicanian basin (Stampfli et al. 1991; Catalano et al. 1995) so far ignored in most reconstructions.

In Crete, Variscan basement blocks are found in units of more external origin than the Pelagonian nappes. The Variscan metamorphites described and dated by Seidel et al. (1982) are mainly outcropping as slices in the Permo-Triassic Phyllite Quartzite group of eastern Crete. Here again we are dealing with a mélange whose age is given as Triassic. K-Ar dating on muscovites spread over 100 Ma (205–315 Ma) and the dating of hornblendes on 30 Ma (270–300 Ma). There are also Permo-Triassic metavolcanites of calc-alkaline and alkali-basalt affinities. The latter gave K-Ar ages around 250 Ma (late Permian). These data fit quite well with the proposed evolution, the mixed calc-alkaline and alkaline volcanites point to back-arc rifting setting in the Permian. In view of the different tectonic positions of the Pelagonian nappes and the Phyllites-Quartzite nappe, it appears that Alpine structural units are discordant in regard of the Paleozoic geodynamic zonation as already pointed out by Hall et al. (1984). Large scale extensional collapse of the Aegean cordillera (Lister et al. 1984), may also explain this situation.

Paleotethyan suture in Apulia

These observations leave open the question of the Paleotethys suture in southern Europe. Running from northern Iran into Turkey (Karakaya complex containing pelagic Permo-Carboniferous sediments, Okay & Mostler 1994), this suture enters the Pelagonian domain (Chios mélanges). From there going westward it remains hidden under the Alpine nappes and thick Apulian autochthonous cover.

Somehow this suture should go toward the Sicanian basin north of Sicily, and from there to Morocco. It may therefore cut through the Apulian plate, separating it into a northern Variscan part (S-Alps, N-Apennines) and a southern Gondwana part (S-Apennines, Apulia s.str.). But this separation is expected to disappear during the Permian when the Apulian plate became an African promontory as suggested by paleomagnetics (Channell & Doglioni 1994; Channell in press-b). The lithosperic and magnetic maps of Italy (Bigi et al. 1992) show important variations in the middle of the Apulian plate. The lithosphere thickness is reduced to 70 km (Marson et al. 1995) and the whole southern part is magnetically positive whereas the northern part is negative with positive anomalies. We are dealing with two different magnetic signatures which may reflect a former division as we are suggesting here.

Conclusions

We have tried to show that in order to understand an orogenesis process well defined in space and time like the Variscan deformation of middle Europe, one has to put it back into a much larger plate tectonic model.

This model proposes that a large oceanic space (Paleotethys) remained unclosed south of the Variscides until late Paleozoic. The Devonian to mid Carboniferous collisional process may be due to the accretion of the Intra-Alpine terrain. This terrain presents strong affinities with the Paleotethyan passive margin sequences found for example in northern Iran (Alborz). The latter are regarded as representing the southern margin of this ocean, the Intra-Alpine terrain being the northern margin.

This northern margin was separated from Gondwana in the Ordovician/Silurian. The collision with the Ligerian-Moldanubian active margin started in the Visean, the subduction was then jammed and jumped into the Paleotethys. Subduction of the Paleotethys is responsible for late Carboniferous calc-alkaline intrusions and volcanism found everywhere in the Alpine terrain. Closure of the Paleotethys was achieved in the Namurian north of Africa but is diachronous going eastward. East of a paleo-Apulian promontory, subduction continued into the Permian and generated opening of the Hallstatt-Meliata marginal ocean.

Closure of Paleotethys between Iberia and Africa resulted from the westward displacement of the Alpine terrain, producing its duplication. Its un-displaced portion is found in Spain (Pyrenees, Catalonia) and southern France (Montagne Noire) and is separated from its exotic portion by a marine trough lasting until the latest Carboniferous (Cantabrian, Asturian basin). Concomitant opening of the marginal Meliata ocean and Neotethys in late Permian accelerated the closure of the Palaeotethys in the Dinaro-Hellenide region. Late Permian to early Triassic mélanges found in Greece point to a final closure of this Paleozoic ocean at that time.

The subsequent subduction of the Meliata ocean generated a mid-Triassic volcanic arc found from northern Italy to Turkey. This arc most likely shifted into an intra-oceanic position in late Triassic and gave birth to the Vardar marginal ocean which was obducted in late Jurassic. Therefore, in a SE transect of Europe we can see how the Variscan orogen evolved into early and late Cimmerian deformations. The rather clear situation found in the Appalachians cannot be extrapolated much farther than western Iberia where Laurentia and Gondwana collided in the Carboniferous. In the rest of Europe, the collision never happened as such. There was a collision between the Eurasian active margin and terrains derived from Gondwana. One has to wait for the anticlockwise rotation of Africa in the Cretaceous to see a collision betwen Europe and Africa, giving birth to the Alpine orogen.

Acknowledgements

This paper is the fruit of a long thought wish to find the Paleotethyan remnants in the European Variscides. To fulfill this wish I first had to digest as much as possible of Alpine geology, a digestion which was made possible through a constant contact with my colleages from Lausanne whom I thank for their open collaboration during these eight last years. Recently J. Hernandez organised in Lausanne a series of conferences on Variscan Alpine geology which gave me the opportunity to test some of these ideas with the speakers; I would like to thank them here and more particularly J. von Raumer, R. Ménot, I. Mercolli, B. Bonin, M. Thöni and U. Schalteger for sharing some of their recent data and ideas on the Variscides. This paper benefited from a thorough review by J.-P. Burg.

Field work is supported by FNRS grant n. 20–39494.93.

REFERENCES

AQUAFREDDA, P., LORENZONI, S. & ZANETTIN LORENZONI, E. 1994: Paleozoic sequences and evolution of the Calabrian-Peloritan Arc (Southern Italy). Terra Nova 6, 582–594.

ADAMIA, S. & KUTELIA, Z. 1987: Paleotethys-Tethys: continuous development. IGCP, 5 newsletter 7, 109–115.

ADAMIA, S. A., BELOV, A. A., KEKELIA, M. A. & SHAVISHVILI, I. D. 1987: Paleozoic tectonic development of the Caucasus and Turkey. In: Pre-Variscan and Variscan events in the Alpine Mediterranean moutain belts (Ed. by FLÜGEL, H. W., SASSI, F. P. & GRECULA, P.). Alfa, Bratislava, 23–50.

ATZORI, P. & FERLA, P. 1992: The pre Alpine crystalline basement of the Peloritani mountains (Sicily). In: Contribution to the geology of Italy with special regard to the Paleozoic basements. (Ed. by CARMIGNANI, L. & SASSI, F. P.). IGCP project 276 newsletter 5, Siena, 311–320.

BAGNOLI, G., GIANELLI, G., PUXEDDU, M., RAU, A., SQUARCI, P. & TONGIORGI, M. 1979: A tentative stratigraphic reconstruction of the Tuscan Paleozoic basement. Mem. Soc. geol. ital. 20, 99–116.

BAUD, A., JENNY, C., PAPANIKOLAOU, D., SIDERIS, C. & STAMPFLI, G. 1990: New observations on the Permian stratigraphy in Greece and geodynamic interpretation. In 5 th. Congr. geol. ass. of Greece, Thessaloniki, 187–206.

BAUD, A. & STAMPFLI, G. 1989: Tectonogenesis and evolution of a segment of the Cimmerides: the volcano-sedimentary Triassic of Aghdarban (Kopet-Dagh, North-East Iran). In: Tectonic evolution of the Tethyan region (Ed. by SENGÖR, A. M. C.). Kluwer Acad. Publ., Amsterdam, 265–275.

BAUD, A., STAMPFLI, G. & STEEN, D. 1991a: The Triassic Aghdarband Group: volcanism and geological evolution. In: The Triassic of Aghdarband (AqDarband), NE-Iran, and its Pre-Triassic frame (Ed. by RUTTNER, A. W.). Abh. Geol. B.-A. 38, Wien, 125–137.

BAUD, A., THÉLIN, P. & STAMPFLI, G. 1991b: Paleozoic geodynamic domains and their alpidic evolution in the Tethys. In: Mémoires de Géologie, Lausanne, 10.

BAUMGARTNER, P. O. 1985: Jurassic sedimentary evolution and nappe emplacement in the Argolis Peninsula (Peloponesus, Greece). Mém. Soc. Helv. Sci. Nat., Birkhäuser, Basel.

BECKER, L. P., FRANK, W., HÖCK, V., KLEINSCHMIDT, G., NEUBAUER, F., SASSI, F. P. & SCHRAMM, J. M. 1987: Outlines of the pre-Alpine metamorphic events in the Austrian Alps. In: Pre-Variscan and Variscan events in the Alpine Mediterranean mountain belts (Ed. by FLÜGEL, H. W., SASSI, F. P. & GRECULA, P.). Alfa, Bratislava, 69–106.

BIGI, G., COSENTINO, D., PAROTTO, M., SARTORI, R. & SCANDONE, P. 1992: Structural model of Italy. CNR. Florence.

BIXEL, F. 1988: Le volcanisme Stéphano-Permien des Pyrénées Atlantiques. Bull. rech. Explor. Elf-Aquitaine 12, 661–706.

BONIN, B. C. A. 1993: Late Variscan magmatic evolution of the Alpine basement. In: Pre-Mesozoic geology in the Alps (Ed. by VON RAUMER, J. F. & NEUBAUER, F.). Springer-Verlag, Berlin Heidelberg, 171–201.

BORIANI, A., BURLINI, L. & SACCHI, R. 1990a: The Cossato Mergozzo Brissago line and the Pogallo line and their relationship with the late Hercynian magmatic and metamorphic event. Tectonophysics 182, 91–102.

BORIANI, A., GIOBBI ORIGONI, E., BORGHI, A. & CAIRONI, V. 1990b: The evolution of the "Serie dei Laghi" (Strona-Ceneri and Scisti dei Laghi): the upper component of the Ivrea-Verbano crustal section; Southern Alps, North Italy and Ticino, Switzerland. Tectonophysics 182, 103–118.

BURCHFIELD, B. C., LIPMAN, P. W. & ZOBACK, M. L. 1992: The Cordilleran orogen: conterminous U. S. Geol. Soc. Amer. G 3.

BURG, J. P., VAN DER DRIESSCHE, J. & BRUN, J. P. 1994: Syn-to post-thickening extension in the Variscan belt of western Europe: modes and structural consequences. Géologie de la France 3, 33–51.

CAMPREDON, R. & BOUCARUT, M. 1975: Alpes Maritimes, Maures, Estérel. Masson & Cie, Paris.

CARMIGNANI, L. & SASSI, F. P. 1992: Contribution to the geology of Italy with special regard to the Paleozoic basements. In: IGCP project 276 newsletter 5, Siena.

CARMIGNANI, L., CHECHI, A. & RICCI, C. A. 1989: Basement structure and Mesozoic-Cenozoic evolution of Sardinia. The lithosphere in Italy, atti dei convegni lincei. Accad. Naz. dei Lincei, Roma., 60–92.

CAROSI, R. & GATTIGLIO, M. 1989: Stratigraphic correlation form concerning the Sardinian Paleozoic basement (Italy). In: Pre-Variscan and Variscan events in the Alpine-Mediterranean belts, Stratigraphic correlation forms (Ed. by SASSI, F. P. & ZANFERRARI, A.). Rendic. Soc. geol. Ital. 12-2, 143–172.

CATALANO, R., DI STEFANO, P. & KOZUR, H. 1991: Permian circumpacific deep-water faunas from the western Tethys (Sicily, Italy) – new evidencens for the position of the Permian Tethys. In: Paleogeography and Paleoceanography of Tethys (Ed. by. CHANNELL, J. E. T., WINTERER, E. L. & JANSA, L. F.). Palaeogeogr., Palaeoclim., Palaeoecol. 87, Elsevier, 75–108.

CATALANO, R., DI STEFANO, P. & VITALE, F. P. 1995: Structural trends and paleogeography of the central and western Sicily belts: new insight. Terra Nova 7, 189–199.

CHALOUAN, A. 1987: Paleozoic nappes of the Ghomarides (Internal Rif, Morocco): review of stratigraphy, paleogeography and Variscan structurations. In: Pre-Variscan and Variscan events in the Alpine Mediterranean mountain belts (Ed. by FLÜGEL, H. W., SASSI, F. P. & GRECULA, P.). Alfa, Bratislava, 107–134.

CHANNELL, J. E. T. in press-a: Paleomagnetic study of Llandovery (lower Silurian) Red Beds in NW England. Geophys. J. Int.

CHANNELL, J. E. T. in press-b: Paleomagnetism and Paleogeography of Adria. Geol. Soc. London, Spec. Publ.

CHANNELL, J. E. T. & DOGLIONI, C. 1994: Early Triassic paleomagnetic data from the Dolomites (Italy). Tectonics 13, 157–166.

CIOFLICA, G., LUPU, M., NICOLAE, I. & VLAD, S. 1980: Alpine ophiolites of Romania: tectonic setting, magmatism and metallogenesis. An. Inst. Geol. Geofiz. 56, 79–96.

CLÉMENT, B., GUERNET, C. & LYS, M. 1971: Données nouvelles sur le Carbonifère et le Permien du Mont Beletsi, en Attique (Grèce). Bull. Soc. géol. France 7, 88–91.

CLOOS, M. 1993: Lithospheric buoyancy and collisional orogenesis: subduction of oceanic plateaus, continental margins, island arcs, spreading ridges, and seamounts. Geol. Soc. Amer. Bull. 105, 715–737.

CORTESOGNO, L., DALLAGIOVANNA, G., GAGGERO, L. & VANOSSI, M. 1992: Late variscan intermediate volcanism in the Ligurian Alps. In: Contribution to the geology of Italy (Ed. by CARMIGNANI, L. & SASSI. F. P.). IGCP 276 Newsletters 5, Siena, 241–262.

– 1993: Elements of the Paleozoic history of the Ligurian Alps. In: Pre-Mesozoic Geology of the Alps (Ed. by VON RAUMER, J. F. & NEUBAUER, F.). Springer Verlag, Berlin, 257–277.

DEMANGE, M. 1989: La montagne noire (France): geotraverse et coupes stratigraphique de corrélations. In: Pre-Variscan and Variscan events in the Alpine-Mediterranean belts, Stratigraphic correlation forms (Ed. by SASSI, F. P. & ZANFERRARI, A.). Rendic. Soc. geol. Ital. 12–2, 173–181.

DEMIRTASLI, E. 1984: Stratigraphic evidence of Variscan and early Alpine tectonics in southern Turkey. In: The geological evolution of the Eastern Mediterranean (Ed. by DIXON, J. E. & ROBERTSON, A. H. F.). Geol. Soc. Spec. Publ. 17, Blackwell, 129–146.

– 1989: Stratigraphic correlation forms of Turkey. In: Pre-Variscan and Variscan events in the Alpine-Mediterranean belts, Stratigraphic correlation forms (Ed. by SASSI, F. P. & ZANFERRARI, A.). Rendic. Soc. geol. Ital. 12–2, 183–211.

DI VINCENZO, G. & GHEZZO, C. 1992: Peraluminous Hercynian granitoids in Sardinia Corsica and Provence: a preliminary note. In: Contribution to the geology of Italy with special regard to the Paleozoic basements. (Ed. by CARMIGNANI, L. & SASSI, F. P.). IGCP project 172 newsletter 5, Siena 469–472.

EBNER, F., FENNINGER, A., GOLLNER, H., HOLZER, H. L. NEUBAUER, F., NIEVOLL. J., RATSCHBACHER, L., STATEGGER, K., TSCHELAUT, W., THALHAMMER, O. & ZIER, C. 1989: Stratigraphic correlation forms of Paleozoic units in Austria. In: Pre-Variscan and Variscan events in the Alpine-Mediterranean belts. Stratigraphic correlation forms (Ed. by SASSI, F. P. & ZANFERRARI, A.). Rendic. Soc. geol. Ital. 12–2, 213–239.

ENRIQUE, P. & DEBON, F. 1987: Le pluton permien calco-alcalin du Montnegre (Chaînes côtières Catalanes, Espagne): études isotopiques Rb-Sr et comparaisons avec les granites hercyniens des Pyrénées, Sardaigne et Corse. C. Acad. Sci. Paris 305, 1157–1162.

FINGER, F. & STEYRER, H. P. 1990: I type granitoids as indicators of a late Paleozoic convergent ocean continent margin along the southern flank of the central European Variscan orogen. Geology 18, 1207–1210.

FLÜGEL, H. W., SASSI, F. P. & GRECULA, P. 1987: Pre-Variscan and Variscan events in the Alpine Mediterranean mountain belts. Alfa, Bratislava, 487.

GAETANI, M., GARZANTI, E. & TINTORI, A. 1990: Permo-Carboniferous stratigraphy in SE Zanskar and NW Lahul (NW Himalaya, India). Eclog. geol. Helv. 83, 143–161.

GATTIGLIO, M., MECCHERI, M. & TONGIORGI, M. 1989: Stratigraphic correlation forms of the Tuscan Paleozoic basement. In: Pre-Variscan and Variscan events in the Alpine-Mediterranean belts, Stratigraphic correlation forms (Ed. by SASSI, F. P. & ZANFERRARI, A.). Rend. Soc. geol. Ital. 12–2, 245–257.

GEBAUER, D. 1993: The pre-Alpine evolution of the continental crust of the central Alps. In: Pre-Mesozoic geology in the Alps (Ed. by VON RAUMER, J. F. & NEUBAUER, F.). Springer Verlag, Berlin Heidelberg, 93–118.

GOMEZ-PUGNAIRE, M. T. 1989: Stratigraphic correlation form in the Betic Cordilleras (S-E Spain). In: Pre-Variscan and Variscan events in the Alpine-Mediterranean belts, Stratigraphic correlation forms (Ed. by SASSI, F. P. & ZANFERRARI, A.). Rendic. Soc. geol. Ital. 12–2, 259–263.

GRADINARU, E. 1988: Jurassic sedimentary rocks and bimodal volcanics of the Cirjelari-Camena outrop belt: evidence for a transtensile regime of the Peceneaga-Camena fault. St. cerc. geol., geofiz., geogr. Geologie 33, 97–121.

HOFFMAN, P. F. 1991: Did the breakout of Laurentia turn Gondwanaland inside out? Science 252, 1409–1412.

HUNZIKER, J. C., DESMONS, J. & HURFORD, A. J. 1992: Thirty-two years of geochronological work in the Central and Western Alps: a review on seven maps. Mém. Géol. (Lausanne) 13.

IANEV, S. 1991: L'évolution paléozoique de la partie orientale de la région des Balkanides. In: Paleozoic geodynamic domains and their alpidic evolution in the Tethys (Ed. by BAUD, A., THÉLIN, P. & STAMPFLI, G. M.). Mém. Géol. (Lausanne) 10, 71–82.

JENNY, J. 1988: Carte géologique du Maroc au 1/100 000, feuille Azilal, Mémoire explicatif. Notes & Mém. Serv. géol. Maroc 399bis.

JULIVERT, M., DURAN, H. & CARDELLACH, E. 1989: Stratigraphic correlation form of the Paleozoic sequence in the Catalonian coastal ranges. In: Pre-Variscan and Variscan events in the Alpine-Mediterranean belts, Stratigraphic correlation forms (Ed. by SASSI, F. P. & ZANFERRARI, A.). Rendic, della Soc. geol. Ital. 12–2, 289–294.

KATERINOPOULOS, A. & MARCOPOULOS, T. 1987: Acid magmatism in the Pelagonian and Rhodope belts (Macedonia Greece). In: Pre-Variscan and Variscan events in the Alpine Mediterranean belts (Ed. by FLÜGEL, H. W., SASSI P. B. & GRECULA P.). Mineralia slovaca, Alfa, Bratislava, 323–328.

KAY, S. M., MPODOZIS, C., RAMOS, V. A. & MUNIZAGA, F. 1991: Magma source variations for mid-late Tertiary magmatic rocks associated with a shallowing subduction zone and a thickening crust in the central Andes. Geol. Soc. Amer. Spec. Pap. 265, 113–138.

KHAIN, V. E. 1994: Geology of Northern Eurasia. Gebrüder Borntraeger, Berlin Stuttgart.

KOZUR, H. 1991: The evolution of the Hallstatt ocean and its significance for the early evolution of the Eastern Alps and western Carpathians. In: Paleogeography and paleoceanography of Tethys (Ed. by CHANNELL, J. E. T., WINTERER, E. L. & JANSA, L. F.). Palaeogeogr. Palaeoclimatol. Palaeoecol. 87, 109–135.

LELKES-FELVARI, G., SASSI, R. & ZIRPOLI, G. 1994: Lithostratigraphy and Variscan metamorphism of the Paleozoic sequences in the Bakony Mountains, Hungary. Mem. Sci. Geol. Padova 46, 303–312.

LIPMAN, P. W. 1992: Magmatism in the Cordilleran United States; progress and problems. The Geology of North America (Ed. by BURCHFIELD, B. C., LIPMAN, P. W. & ZOBACK, M. L.). Geol. Soc. Amer. G-3, 481–514.

LISTER, G. S., BANGA, G. & FEENSTRA, A. 1984: Metamorphic core complexes of Cordilleran type in the Cyclades, Aegean Sea, Greece. Geology 12, 221–225.

LYS, M. 1986: Biostratigraphie du Carbonifère et du Permien en Mésogée. Etudes micropaléontologique et paléobiogéographie. Doctorat d'Etat, Paris-Sud Orsay.

MAJESTÉ-MANJOULAS, C., BOUILLIN, J. P. & CYGAN, C. 1984: La série de Bivongi, type de succession paléozoique (Ordovicien à Carbonifère) de Calabre méridionale. C. Acad. Sci Paris 299, 249–252.

MALAVIEILLE, J. 1993: Late orogenic extension in mountain belts: insight from the Basin and Range and the late Paleozoic Variscan belt. Tectonics 12, 1115–1130.

MARINELLI, M., VIEL, G. & FARABEGOLI, E. 1980: Il Permo-Trias delle Alpi Meridionali: evoluzione tardo-ercinica di un bacino marginale di retroarco sialico. Ind. min. 6, 1–14.

MARSON, I., PANZA, G. F. & SUHADOLC, P. 1995: Crust and upper mantle models along the active Tyrrhenian rim. Terra Nova 7, 348–357.

MASSARI, F., NERI, C., PITTAU, P., FONTANA, D. & STEFANI, C. 1994: Sedimentology, palynostratigraphy and sequence stratigraphy of a continental to shallow marine rift-related succession: Upper Permian of the eastern Southern Alps. Mem. Sci. Geol. Padova 46, 119–243.

MATTE, P. 1986: La chaîne varisque parmi les chaînes paléozoïques péri atlantiques, modèle d'évolution et position des grands blocs continentaux au Permo-Carbonifère. Bull. Soc. géol. France 8, 9–24.

MÉNARD, G. & MOLNAR, P. 1988: Collapse of a Hercynian Tibetan Plateau into a late Paleozoic European Basin and Range Province. Nature 334 (6179), 235–237.

MERCIER, J. 1973: Etudes géologiques des zones internes des Hellénides en Macédoine centrale (Grèce). Ann. géol. Pays Hellén. 20, 792.

MERCOLLI, I. & OBERHÄNSLI, R. 1988: Variscan tectonic evolution in the Central Alps: a working hypothesis. Schweiz. mineral. petrogr. Mitt. 68, 491–500.

MIRAUTA, E. 1982: Biostratigraphy of the Triassic deposits in the Somova-Sarica Hill zone (North Dobrogea) with special regard of the eruption age. D. S. Inst. Geol. Geofiz. 64, 63–78.

MUNOZ, J. A., SABAT, F. & SANTANACH, P. 1989: Stratigraphic correlation form of the eastern Pyrenees. In: Pre-Variscan and Variscan events in the Alpine-Mediterranean belts, Stratigraphic correlation forms (Ed. by SASSI, F. P. & ZANFERRARI, A.). Rendic. Soc. geol. Ital. 12–2, 333–337.
NEDJARI, A. 1994: Images et événements fini hercyniens de l'Ouest du Maghreb (Algérie, Maroc). Mém. Serv. Géol. Algérie 6, 13–40.
OBERHÄNSLI, R., HUNZIKER, J. C., MARTINOTTI, G. & STEN, W. B. 1985: Geochemistry, geochronology and petrology of Monte Mucrone: an example of eo-alpine eclogitisation of Permian granitoïds in the Sesia Lanzo zone, western Alps, Italy. Chem. Geol. 52, 165–184.
OKAY, A. I. & MOSTLER, H. 1994: Carboniferous and Permian radiolarite blocks from the Karakaya complex in Northwest Turkey. Tr. J. Earth Sciences 3, 23–28.
PAGE, B. M. & BROCHER, T. M. 1993: Thrusting of the central California margin over the edge of the Pacific plate during the transform regime. Geology 21, 635–638.
PAPANIKOLAOU, D. & SIDERIS, C. 1983: Le paleozoique de l'autochtone de Chios: une formation à bloc de type wildflysch d'âge Permian (pro parte). C. Acad. SC. Paris 297, 603–606.
PAPANIKOLAOU, D. J. 1989: Are the medial crystalline massifs of the Eastern Mediterranean drifted Gondwanian fragements? Geol. Soc. Greece, Athens, 63–90.
PAPANIKOLAOU, D. J. & SIDERIS, C. 1989: Contribution to the Paleozoic of the Aegean. In: Pre-Variscan and Variscan events in the Alpine-Mediterranean belts, Stratigraphic correlation forms (Ed. by SASSI, F. P. & ZANFERRARI, A.). Rendic, Soc. geol. Ital. 12–2, 349–358.
PASINI, M. 1992: *Howchinia bradyana and Mediocris medocris* within the Bombaso formation, Carboniferous of the Carnic Alps. In: Contribution to the geology of Italy with special regard to the Paleozoic basements. (Ed. by CARMIGNANI, L. & SASSI, F. P.). IGCP project 276 newsletter 5, Siena, 279–281.
PE-PIPER, G. 1982: Geochemistry, tectonic setting and metamorphism of mid-Triassic volcanic rocks of Greece. Tectonophysics 85, 253–272.
PERROUD, H., VAN DER VOO, R. & BONHOMMET, N. 1984: Paleozoic evolution of the Armorica plate on the basis of paleomagnetic data. Geology 12, 579–582.
PFEIFER, H. R., BIINO, G., MÉNOT, R. P. & STILLE, P. 1993: Ultramafic rocks in the pre-Mesozoic basement of the central and external western Alps. In: Pre-Mesozoic geology in the Alps (Ed. by VON RAUMER, J. F. & NEUBAUER, F.). Springer-Verlag, Berlin Heidelberg, 119–144.
PILLEVUIT, A. 1993: Les blocs exotiques du Sultanat d'Oman évolution paléogéographique d'une marge passive flexurale. Mém. Géol. (Lausanne) 17.
RICCI, C. A. 1992: From crustal thickenning to exhumation: petrological, structural and geochrological records in the crystalline basement of northern Sardinia. In: Contribution to the geology of Italy with special regard to the Paleozoic basements. (Ed. by CARMIGNANI, L. & SASSI, F. P.). IGCP project 276 newsletter 5, Siena, 187–197.
RICOU, L. E. 1994: Tethys reconstructed: plates, continental fragments and their boundaries since 260 Ma from Central America to South-eastern Asia. Geodin. Acta 7, 169–218.
ROBARDET, M., VERNIERS, J., FEIST, R. & PARIS, F. 1994: Le Paléozoique anté-varisque de France, contexte paléogéographique et géodynamique. Géol. France 3, 3–31.
ROSSI, P. M. 1975: Structural and stratigraphical pattern of the Lombardy Southern Alps. In: Structural model of Italy (Ed. by OGNIBEN, L., PAROTTO, M. & PRATULON, A.). Consiglio Nazionale delle Ricerche, Roma, 67–120.
RUTTNER, A. W. 1993: Southern borderland of Triassic Laurasia in NE Iran. Geol. Rdsch 82, 110–120.
SALAS, R. & CASAS, A. 1993: Mesozoic extensional tectonics, stratigraphy and crustal evolution during the Alpine cycle of the eastern Iberian basin. Tectonophysics 228, 33–55.
SANTANACH, P. 1989: Stratigraphic correlation form of the western Pyrenees. In: Pre-Variscan and Variscan events in the Alpine-Mediterranean belts, Stratigraphic correlation forms (Ed. by SASSI, F. P. & ZANFERRARI, A.). Rendic, Soc. geol. Ital. 12–2, 391–395.
SASSI, F. P. & ZANFERRARI, A. 1989: Pre-Variscan and Variscan events in the Alpine-Mediterranean belts, Stratigraphic correlation forms. Rendic. Soc. geol. Ital. 12.
SCHALTEGGER, U. & CORFU, F. 1995: Late Variscan Basin and Range magmatism and tectonics in the Central Alps: evidence from U-Pb geochronology. Geodin. Acta 8, 1–16.
SCHMID, S. M. 1993: Ivrea zone and adjacent southern Alpine basement. In: Pre-Mesozoic geology in the Alps (Ed. by VON RAUMER, J. F. & NEUBAUER, F.). Springer-Verlag, Berlin Heidelberg, 567–584.

SCHÖNLAUB, H. P. 1985: Das Paläozoikum der Karnischen Alpen. In: Arb. Geol. B.-A. 1985, Wien, 34–52.
– 1993: Stratigraphy, Biogeography and climatic relationship of the Alpine Paleozoic. In: Pre-Mesozoic geology in the Alps (Ed. by VON RAUMER, J. F. & NEUBAUER, F.). Springer-Verlag, Berlin Heidelberg, 65–92.
SCOTESE, C. R., BAMBACH, K., BARTON, C., VAN DER VOO, R. & ZIEGLER, A. M. 1979: Paleozoic base maps. J. Geol. (Chicago) 87, 217–277.
SEGHEDI, I., SZAKACS, A. & BALTRES, A. 1990: Relationships between sedimentary deposits and eruptive rocks in the Consul unit (North Dobrogea) – implications on tectonic interpretations. D. S. Inst. Geol. Geofiz. 74, 125–136.
SEIDEL, E., KREUZER, H. & HARRE, W. 1982: A late Oligocene early Miocene High Pressure belt in the External Hellenides. Geol. Jb. Reihe E, Geophysik 23, 165–206.
SENGÖR, A. M. C. 1979: Mid-Mezozoic closure of Permo-Triassic Tethys and its implications. Nature 279, 590–593.
– 1987: Tectonic of the Tethysides: Orogenic collage development in a collisional setting. Ann. Rev. Earth planet. Sci. 15, 213–244.
SENGÖR, A. M. C. & HSÜ, K. J. 1984: The Cimmerides of Eastern Asia: history of the Eastern end of Paleo-Tethys. Mém. Soc. géol. France 47, 139–167.
SENGÖR, A. M. C., YILMAZ, Y. & SUNGURLU, O. 1984: Tectonics of the Mediterranean Cimmerides: nature and evolution of the western termination of Paleo-Tethys. In: The geological evolution of the eastern Mediterranean, (Ed. by DIXON, J. E. & ROBERTSON, A. H. F.). Geol. Soc. Spec. Publ. 17, 77–112.
SILETTO, G. B., SPALLA, M. I., TUNESI, A., LARDEAUX, J. M. & COLOMBO, A. 1993: Pre-Alpine structural and metamorphic histories in the Orobic Southern Alps, Italy. In: Pre-Mesozoic geology in the Alps (Ed. by VON RAUMER, J. F. & NEUBAUER, F.). Springer-Verlag, Berlin Heidelberg, 585–598.
SOCIETA-GEOLOGICA-ITALIANA 1979: Paleozoico e basamento in Italia aggionamenti e problemi. Roma.
SPALETTA, C., VAI, G. B. & VENTURINI, C. 1979: Il flysch ercinico nella geologia dei monte Paularo e Dimon (Alpi Carniche). Mem. Soc. geol. ital. 20, 243–265.
STAMPFLI, G. 1978: Etude géologique générale de l'Elbourz oriental au sud de Gonbad-e-Qabus (Iran NE). PhD. Thesis, Univ. Genève.
STAMPFLI, G. M. & MARCHANT, R. H. in press: Geodynamic evolution of the Tethyan margins of the Western Alps. In: Deep structure of Switzerland – Results from NFP 20 (Ed. by LEHNER, P., HEITZMAN, P., FREI, W., HORSTMEYER, H., MUELLER, S., PFIFFNER, A, & STECK, A.). Birkhäuser AG., Basel.
STAMPFLI, G. M. & PILLEVUIT, A. 1993: An alternative Permo-Triassic reconstruction of the kinematics of the Tethyan realm. In: Atlas Tethys Palaeoenvironmental Maps. Explanatory Notes (Ed. by DERCOURT, J., RICOU, L.-E. & VRIELINCK, B.). Gauthier-Villars, Paris, 55–62.
STAMPFLI, G., MARCOUX, J. & BAUD, A. 1991: Tethyan margins in space and time. In: Paleogeography and paleoceanography of Tethys (Ed. by CHANNELL, J. E. T., WINTERER, E. L. & JANSA, L. F.). Paleogeogr. Palaeoclimatol. Palaeoecol. 87, Elsevier, 373–410.
STAMPFLI, G. M., DE BONO, A. & VAVASIS, I. 1995: Pelagonian basement and cover in Euboea (Greece). In: abstract EUG 8, Strasbourg.
TEMPIER, C. 1978: Les événements calédoniens dans les massifs varisques du sud-est de la France, Corse et Sardaigne. Geol. Surv. Canada, 177–181.
THÉLIN, P., SARTORI, M., BURRI, M., GOUFFON, Y. & CHESSEX, R. 1993: The pre-Alpine basement of the Briançonnais (Wallis, Switzerland). In: Pre-Mesozoic geology in the Alps (Ed. by VON RAUMER, J. F. & NEUBAUER, F.). Springer-Verlag, Berlin Heidelberg, 297–316.
THÖNI, M. & JAGOUTZ, E. 1993: Isotopic constraints for eo-alpine high-P metamorphism in the Austroalpine nappes of eastern Alps: bearing on Alpine orogenesis. Schweiz. mineral. petrogr. Mitt. 73, 177–189.
TOLLMANN, A. 1985: Geologie von Österreich, Band II. Franz Deuticke, Wien.
TRAVERSA, G. & VACCARO, C. 1992: REE distribution in the late Hercynian dykes from Sardinia. In: Contribution to the geology of Italy with special regard to the Paleozoic basements. (Ed. by CARMIGNANI, L. & SASSI, F. P.). IGCP project 276 newsletter 5, Siena, 215–226.
VAI, G. B. & COCOZZA, T. 1986: Tentative schematic zonation of the Hercynian chain in Italy. Bull. Soc. géol. France 8, T II, 95–114.
VAI, G. B., FRANCAVILLA, F., FERRARI, A. & CONTARINI, M. T. 1979: La sezione del monte Carnizza (Carbonifero superiore, Alpi Carniche). Mem Soc. geol. ital. 20, 267–276.
VANNAY, J. C. 1993: Géologie des chaînes du Haut-Himalaya et du Pir Panjal au Haut-Lahul (NW Himalaya) paléogéographie et tectonique (PhD). Mém. Géol. (Lausanne) 16.

VANNAY, J. C. & SPRING, L. 1993: Geochemistry of the continental basalts within the Tethyan Himalaya of Lahul-Spiti and SE Zanskar. In: Himalayan tectonics (Ed. by TRELOAR, P. J. & SEARLE, M. P.). Geol. Soc. Spec. Publ. 74, 237–249.
VISONÀ, D. 1992: The gabbro-amphibolite complex of Corno Bianco (Bolzano, NE Italy): an eovariscan pluton in the Austroalpine of the eastern Alps? In: Contribution to the geology of Italy with special regard to the Paleozoic basements. (Ed. by CARMIGNANI, L. & SASSI, F. P.). IGCP project 276 newsletter 5, Siena, 477–479.
VON RAUMER, J., MÉNOT, R. P., ABRECHT, J. & BIINO, G. 1993: The pre Alpine evolution of the external massifs. In: Pre-Mesozoic geology in the Alps (Ed. by VON RAUMER, J. F. & NEUBAUER, F.). Springer-Verlag, Berlin Heidelberg, 221–240.
VON RAUMER, J. & NEUBAUER, F. 1993a: Late Preacambrian and Paleozoic evolution of the Alpine basement – an overview. In: Pre-Mesozoic geology in the Alps (Ed. by VON RAUMER, J. F. & NEUBAUER, F.). Springer-Verlag, Berlin Heidelberg, 625–640.
– 1993b: Pre-Mesozoic geology in the Alps. In: Springer-Verlag, Berlin Heidelberg.
WERNICKE, B. 1992: Cenozoic extensional tectonics of the U. S. Cordillera. In: The Geology of North America (Ed. by BURCHFIELD, B. C., LIPMAN, P. W. & ZOBACK, M. L.). Geol. Soc. Amer., G-3, 553–581.
YARWOOD, G. A. & AFTALION, M. 1976: Field relations and U-Pb geochronology of a granite from the Pelagonian zone of the Hellenides. Bull. Soc. géol. France 7, 259–264.
ZANDT, G., VELASCO, A. A. & BECK, S. L. 1994: Composition and thickness of the southern Altiplano crust, Bolivia. Geology 22, 1003–1006.
ZIEGLER, P. A. 1988: Evolution of the Arctic-North Atlantic and the Western Tethys. Amer. Assoc. Petrol. Geol. Mem. 43.
– 1993: Late Paleozoic early Mesozoic plate reorganisation: evolution and demise of the Variscan fold belt. In: Pre-Mesozoic geology in the Alps (Ed. by VON RAUMER, J. F. & NEUBAUER, F.). Springer-Verlag, Berlin Heidelberg, 203–218.
ZONENSHAIN, L. P., KUZMIN, M. I. & NATAPOV, L. M. 1990: Geology of the USSR: a plate tectonic synthesis. Amer. geol. Union Geodynam. Ser. Monogr. 21.

Manuscript received April 3, 1995
Revision accepted November 10, 1995