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CRUSTAL EVOLUTION AND BASEMENT ELEMENTS IN THE ITALIAN AREA: PALAEOGEOGRAPHY AND CHARACTERIZATION

Abstract. Identification of different basement components within the Mediterranean region (including Italy) is usually based on palaeotectonic restorations starting from the Triassic continental plate assembly called Pangaea. In this way, older crustal evolution during both Palaeozoic and Precambrian times is simply neglected. Here, an attempt is made to start restoration from the late Precambrian Pangaea so as to consider the roles played by Panafrican, Hercynian, Cimmerian and Alpine crustal consolidation cycles. Following the Panafrican consolidation, there is a substantial southward time migration of the tectogenesis in the Mediterranean area (Fig. 2A). However, the major control of the crustal evolution in the area is related to recurrent inversion (dextral to sinistral and viceversa) in the transform rifts cyclically affecting the area (Figs. 1 and 2B). Of primary importance in this scenario is a careful evaluation of the Permian (and Triassic) dextral rifts as opposed to the Jurassic sinistral one. A set of new palaeogeographic-palaeodynamic maps (Figs. 4-7) of the late Carboniferous to middle Permain time interval are presented at both the regional and hemi-global levels. The maps suggest 1) a persistent late Devonian to early Permian dextral strike-slip kinematics of the Hercynian orogen; 2) a relative independence of the widespread small-scale late Carboniferous transtensional regime from the large-scale Permian (and later Triassic) rift; 3) a major dextral strike-slip rift belt, striking from the Persian Gulf to Sicily, Tunisia, Texas and Bolivia, dividing Laurasia from Gondwana for some tens of Ma, and resulting in the formation of a narrow seaway floored with oceanic crust in the present Ionian and eastern Mediterranean seas. Increasing stratigraphic and facies evidence of early to mid Permian pelagic deposits support the reconstruction above, which is also consistent with mid to late Triassic marine facies distributions. A short characterization of the main basement and Palaeozoic elements of the Italian area in terms of overall geological evolution is given. Three elements are distinguished in the Southern Alps (Carnic Alps, Venetian and central-western areas), four in the Northern Apennines (Elba-P. Bianca-Massa, Alpi Apuane-M. Pisano, southern Tuscany and Cerreto areas), two in Sardinia (Iglesiente-Sulcis and remaining areas) and two in Calabria (part of Sila and the remaining composite areas). Finally, on the basis of these various types of data, the following crustal zonation of the Italian and central Mediterranean area is suggested: 1) Baikalian-Panafrican, 2) European Hercynian, 3) thinned Hercynian, 4) Ionian Permo-Triassic fossil oceanic, and 5) Balearic Miocene and Tyrrhenian Plio-Pleistocene new oceanic zones.

FOREWORD

Some preliminary axiomatic statements are needed when tackling the problems connected with the recognition and characterization of basement elements incorporated within the seas surrounding the Italian peninsula.

1) Both spreading and passive, Neogene and Quaternary, oceanic lithosphere areas are lacking, or have completely lost, all features of their original bordering and/or component basement rocks. This apply to parts of the Ligurian, Tyrrhenian (Vavilov and Marsili abyssal plains) and Sardinia seas.

2) Basement blocks or microplates of a given type may have been detached from their birth area and accreted to basement bodies of different types and ages. Such accretions may

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have occurred in the study area during the important late Cambrian to early Ordovician, early Silurian, late Devonian to Dinantian, early to middle Permian, middle Triassic, Jurassic and the minor Palaeogene to Neogene rift phases (Vai, 1991) (Fig. 1). Judging from the accretion of quite different terranes in Calabria, which is related to minor tectogenetic cycles (Vai, 1992), one can argue that significant basement reassembling may have occurred in the central Mediterranean area during earlier major cycles.

Today, it is quite easy to assign a confidence level to the first statement. Much more difficult, however, is to do the same for the second. This is indeed the basic problem to face when trying to drew a predictive map of basement types by interpolating the few, scattered data on basement and Palaeozoic rocks available from bore-holes, dredgings, and outcrops.

3) The majority of basement outcrops in the study area have been more or less rejuvenated by the Alpine-Apennine deformation (with the exception only of partly submerged Sardinia and the different Adriatic blocks). Moreover, different quantities of these basement oucrops were significantly involved in the Hercynian tectogenensis (with the exception of only the south-eastern area, roughly confined by the Agip Assunta well (northern Adriatic Sea) and the Farma basin in Tuscany (Vai and Cocozza, 1986)).

4) The last statement regards the experimental and conceptual independence of the geologic basement and the "magnetic" one (see also Cassano et al., 1986 and Arisi Rota and Fichera, 1987). Lacking more precise geological data, information on the magnetic basement can only be used as a substitute with large uncertainties.

Methodologically, both synthetic and analytic approaches will be used here whenever possible. Only palaeogeographic and palaeotectonic problems of basement elements will be addressed in this paper, starting from an updated review of recent, qualified sources. A more original treatment will be devoted to the crucial late Carboniferous to early Permian time interval, comparing personal opinions, discussed earlier, with new data.

SYNTHETIC APPROACH

Maps of the original positions of present basement elements are usually drawn starting from a Permo-Triassic (Bullard's or other) reconstruction of Pangaea (e.g., Dewey et al., 1973; Dercourt et al., 1985). However, taking into account the relevance of Palaeozoic tectogenetic and related rift cycles (Zonenshain, 1987; Van der Voo, 1988; Vai, 1991), it may be more appropriate to start from late Precambrian Pangaea (Piper, 1982; Vai, 1991). Indeed, the study area has always evolved in direct contact with, or in proximity to, the Africa craton (and acting as such since the late Precambrian).

Let us start with a tentative crustal map of the Gondwana, SW Europe, Middle East and Kazakhstan regions in the late Precambrian (ca. 750-550 Ma, Fig. 2). A cluster of sialic masses appears to be made of Archaeozoic and early Proterozoic nuclei (like the W and S African, the Arabian, the Indian, the Kazakhian nuclei, etc.) welded to each other by later crustal consolidation strips corresponding to the late Precambrian tectogenetic cycle known as the Panafrican (or Cadomian, Assyntian or Baikalian). In this map, the distributions of the areas involved in the Hercynian and Alpine deformation cycles are superimposed (Fig. 2A). One can see that 1) the last two cycles have almost exclusively reactivated areas of previous Panafrican deformation, and 2) the last two deformation belts only partially overlap, and show a time migration of the deformation towards Africa. This Alpine migration implies a significant destruction of the north African craton margin (African Promontory) previously preserved from the Hercynian deformation.

Let us now plot on the same map the main or better known post-Hercynian rift axes (Fig. 2B). It appears that these rift axes, following their trend, migration and left- or right-lateral component, exert a strong control on the location and type of strain field. The role of the Permo-Triassic rifts in changing the late Hercynian crustal characterization is particularly relevant. This depends also on the fact that 1) these rifts have not succeeded in completing their tectogenetic cycle in the study area, and 2) their effects on crustal thinning and stretching have been partly

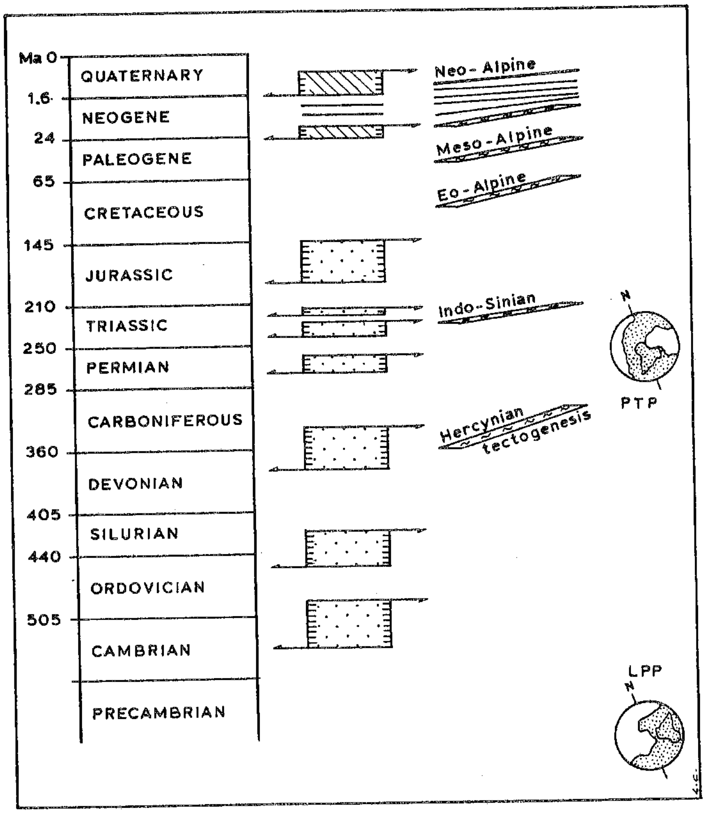


Fig. 1 — Main oblique to transform rifts (dotted) across the late Precambrian and Permo-Triassic Pangaeas in the circum-Mediterranean area. Minor, intra-Mediterranean Cenozoic rifts (hatched) and tectogenetic intervals are shown for comparison. LPP=Late Precambrian Pangaea; PTP=Permo-Triassic Pangaea (modified after Vai, 1991).

obliterated by the opposite, and differently trending Jurassic rift.

In this scenario, the relevance of the Permian (and mid-late Triassic) rift cycle is even greater. It explains well the large (in both tickness and width) subaerial to subvolcanic igneous plateaus (like those of the Adige valley, Corsica-Provence and Po valley subsurface, plus minor interposed ones) and the large granitoid volumes found in the middle crust of the Hercynian belt in the Alps, Sardinia and Calabria. It may also help in solving the geologic dilemma of the Ionian crust. The present Ionian crust, is, in fact, geologically almost continental (its thickness is greater than 20 km, with approximately 1/3 made up of Mesozoic-Cenozoic sediments with pelagic facies starting from the late Cretaceous at shallow depth, whereas now the Ionian Sea is the deepest of the Mediterranean, reaching more than 5,000 m) and geophysically almost oceanic (very high gravimetric values but low heat flow and magnetic anomalies) (Finetti and Morelli, 1973; Finetti, 1982; Finetti and Del Ben, 1986; Makris et al., 1986; Bianchi et al., 1989; Ben Avraham and Grasso, 1990; Pedley and Grasso, 1992).

The more or less aborted Permo-Triassic rifts may indicate the emplacement of oceanic crust, interrupted by inversion in the direction of wrenching and the different location of the Jurassic rift. The slow thermal contraction of the oceanic crust would have allowed for a thick accumulation of Mesozoic to Tertiary sediments. The Ionian basement would thus be made of a normal, fossil, not yet deformed oceanic crust (Finetti, 1986), likely Permian or Permo-Triassic in age, instead of Jurassic, as previously assumed, with a thickness of about a tenth of km, connected with the thinned continental crust of the N African margin. Further on, I present more factual data supporting this hypothesis. However, let us first check with an

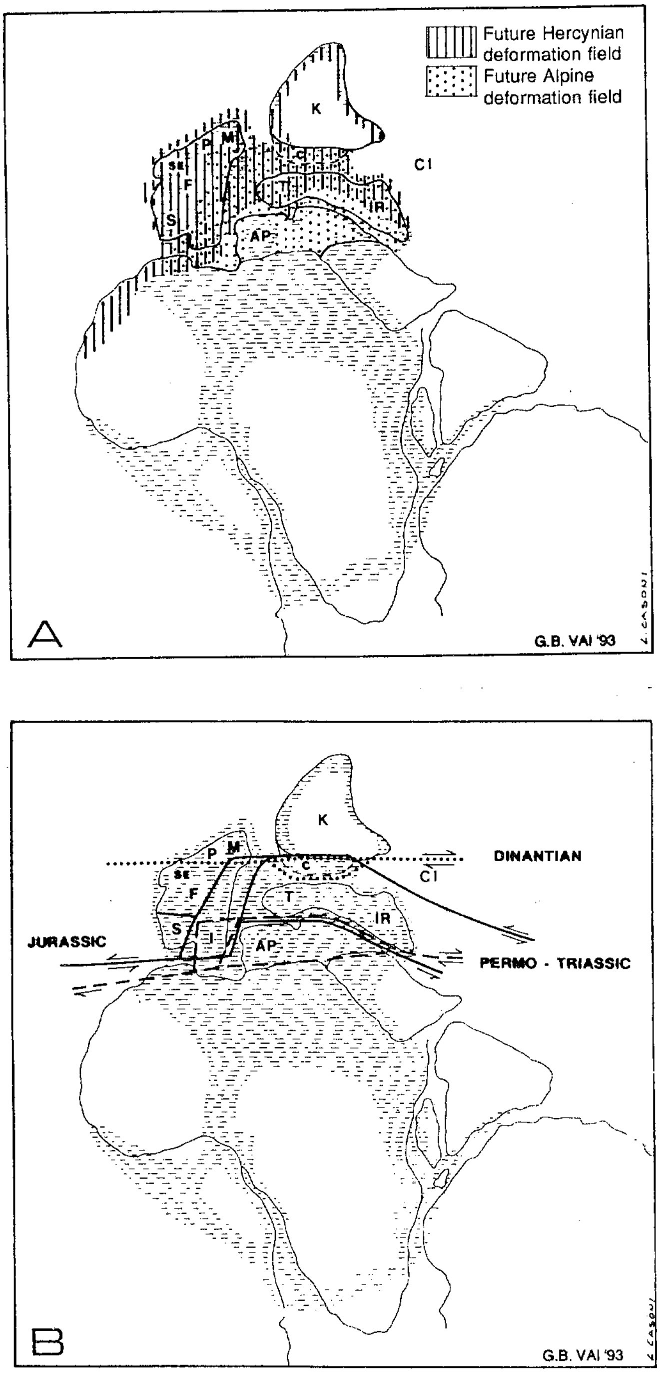


Fig. 2 — A: Late Precambrian (Pan African, Cadomian, Assyntian and/or Baikalian) crustal consolidation (ca. 750-550 Ma) in the Gondwanaland plus SW Europe and Near East regions. Possible locations for the Kazakhstan plate (K) and the future Uralia or Carnic-Dinaric (C) microplate are suggested. Sources of data on crustal consolidation age are Khain et al. (1979), Cogné and Wright (1980) and Piper (1982). AP=African Promontory; C=Carnic-Dinaric (=Uralia) microplate; F=France; I=part of Italy; IR=Iran; K=Kazakhstan; P=Poland; M=Moesia; S=Spain; SE=south England; T=Turkey.

B: Location of major Dinantian, Permo-Triassic and Jurassic transform rifts. Note the inversion from right- to left-lateral movements in the Jurassic.

independent and critical analysis if the data available support, contradict or are neutral to the hypothesis.

ANALYTIC APPROACH

I have already attempted, over the two last decades, such a palaeogeographic-palaeotectonic approach to the study of the early to middle Palaeozoic of the circum-Mediterranean area (Vai, 1976, 1980a, 1991). It was based on exclusively homogeneous, undisputable (stratigraphic, facies, palaeobiogeographic and tectofacies) field data, and excluded any compromises with *a priori* models or data more scattered and less reliable like the palaeomagnetic ones. There was an immediate, radical contrast between this map reconstruction (Vai, 1980a, 1991) and the more popular ones (Briden et al., 1974; Seyfert and Sirkin, 1973; Scotese et al., 1979; Smith, 1981; etc.). However, it gradually decreased with time, concurrently with another attempt at a palinspastic reconstruction of the entire Phanerozoic focussed on NW Europe (Ziegler, 1986, 1989). Ziegler's reconstruction, though accepting at the beginning the palaeomagnetic model, was so rooted in geological spot data, that following the increase in data available it became progressively modified and convergent with my own (Vai, 1991). For this reason, readers interested in palinspastic map reconstructions of the early and mid Palaeozoic in the circum-Mediterranean area are referred to Vai (1991) and to Ziegler (1989) for an integration.

Palinspastic restorations of the late Palaeozoic of the area are quite common, although more devoted to the Triassic than to the Permian side (Hsü, 1971; Bosellini and Hsü, 1973; Scandone, 1975; Biju-Duval et al., 1976; Rau and Tongiorgi, 1981; Dercourt et al., 1985). Recent developments in the Tethys Project (Dercourt et al., 1985, 1992) provided me with the opportunity of convening specialists to construct two new maps for the Moscovian and early Permian. I hope to be able to integrate the two groups of specialists separately producing map *up* to the Permo-Carboniferous or *from* the Permo-Triassic (actually late Triassic). It is noteworthy how the meso-Cenozoic mappers neglect the efforts made by the Palaeozoic ones. An instance is represented by the maps of C. Sengör (e.g. 1984, 1985) with its misuse of priority in the meaning of Palaeo-Tethys (cfr. Kober, 1923; Kahler, 1939; Stille, 1951; Flügel, 1972, 1981; Vai, 1976, 1991) following the bad example of Stöcklin (1974) and Laubscher and Bernoulli (1977) (for a further example of confusion-generating terminology see Sengör, 1986, p. 187-188).

So, I focussed initially on late palaeogeography by going back to a previous discussion on a brilliant but speculative interpretation by Rau and Tongiorgi (1981): the Permo-Triassic (versus Devono-Dinantian) accretion of the Uralian terrane represented by the present Carnic-Dinaric block (Vai, 1976, 1991). The preliminary results of this are summarized in the three draft maps of the circum-Mediterranean area (Figs. 4-6), whose meanings and implications are provided in Figs. 7-9. These maps together contain the view point that I have built up in years of discussions during field trips all over the circum-Mediterranean late Palaeozoic area, and following cross-checks with the new data available.

The following items are important to stress.

Hercynian orogeny

The Hercynian tectogenesis in the eastern part of the circum-Mediterranean area is a minor, occasional perturbation event, both in space and time, in a region characterized by geodynamic calm or divergence. This is clearly documented by a careful concurrent reading of Figs. 4-6 coupled with Figs. 3 and 14-15 in Vai (1991).

Unlike the eastern, the central-western Mediterranean area was a field of persistent, winding convergence. The most prominent feature shown here is the continuing transcurrent signature of this part of the orogen (Badham and Halls, 1975; Vai, 1976, 1980a; Badham, 1982; Vai and Cocozza, 1986; Vai et al., 1984), persisting even after the complete consumption of the Rheic oceanic crust (Vai, 1991, Figs. 14-15) and the following continental collision between the western African and the eastern North American margins (Arthaud and Matte, 1977) (Fig. 3). The early Permian onset of the Middle East to Texas transcurrent zone (which can be

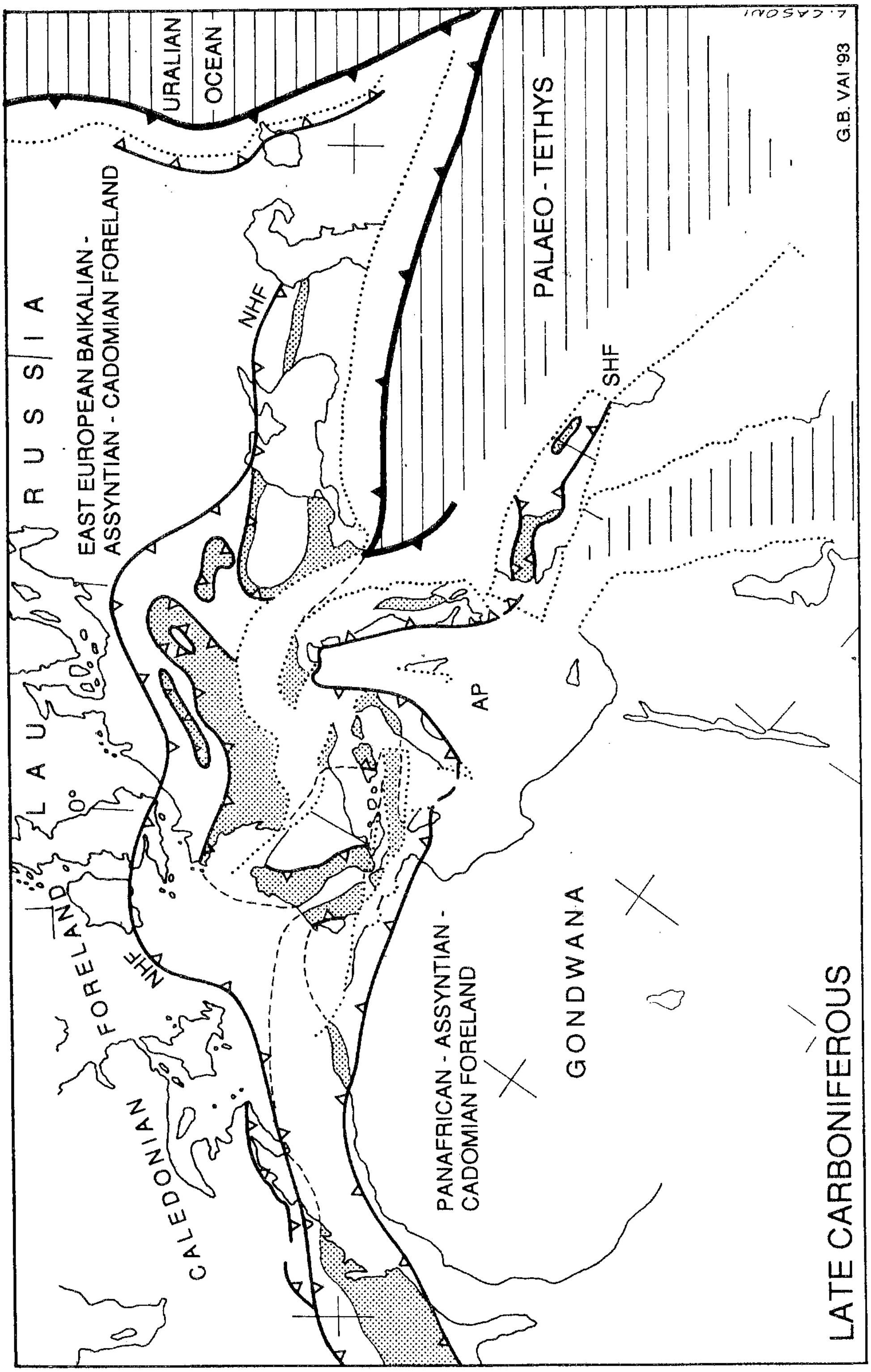


Fig. 3 — Tentative palinspastic map of the Hercynian internides (shaded) and externides during late Carboniferous (modified after Vai, 1980) (transform and wrench faults not shown).

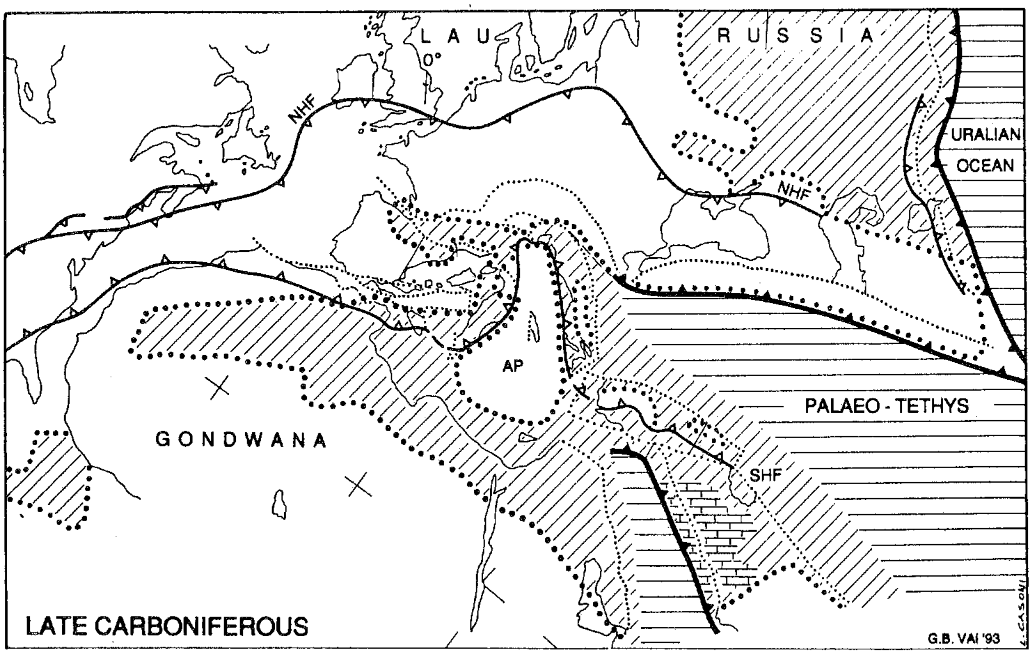


Fig. 4 — Tentative late Carboniferous palaeogeographic-palaeotectonic map of the circum-Mediterranean area; see Fig. 7 for key to symbols.

considered as a trans-Gondwanan transform connecting the Permo-Triassic Tethyan spreading-axes with the subduction trench of the southern Cordigliera) is, in fact, responsible for completion of the tectogenetic cycle in the Mauretanides and the Alleghenydes (Figs. 4-5).

Extension and transtension in the late Carboniferous

The late Carboniferous palaeogeographic and palaeotectonic scenario is markedly different from that at the beginning of the Permian (much more than one can see on a small-scale map like that in Fig. 4). It is consistent over a wider area with the features already detected in the Southalpine-Austroalpine area (Vai, 1976; Cassinis et al., 1980, 1988; Massari, 1988; Cassinis and Perotti, 1993) and, especially, the Carnic one (Venturini et al., 1982; Venturini, 1983, 1990).

The late Carboniferous of the central circum-Mediterranean area is characterized, in fact, by a relevant basin fragmentation in both continental to transitional and marine environments (see Vai, 1980b, for a list). Such basins commonly had a rectangular to rhombic outline and formed a tight network of small-sized pull-aparts. It is important to note, however, that no first order wrench fault appears in the map (Fig. 4). A further general feature of the late Carboniferous is an extent of marine deposits far greater than during early Permian (Figs. 4-6). It can be assumed that the orogenic uplift was still quite slow during the late Carboniferous and that the isostatic balance was occasional and limited to local tectonic structures. In such a picture, a corresponding network of volumetrically low, deep-seated granitoid intrusions would be expected.

The Permian mega-shears and the Ionian-eastern Mediterranean rift

A Permian rift is well known in the area, and has mainly been referred to as middle to late Permian. Our maps support its identity, showing an earlier evolutionary phase and explaining coherently its connection with the previous geological history of the area.

The two features traditionally characterizing this Permian rift are: 1) the very uniform, transgressive onlap of the Gardena Sandstone (and its New Red-type equivalents) over extremely wide, flat, eroded areas (this dramatic change in style, geometry and size of the basins was taken as the boundary between the Hercynian and the Alpine sedimentary supercycles, e.g.

Vai, 1976, and Cassinis et al., 1980), and 2) the huge amount and extent (in concentrated belts) of Permian volcanics and related intrusions (Vai et al., 1984) with quite variable chemical affinities and marked bimodality (Ziegler, 1984).

These features are mirrored and supported by the progressive development of a large-size system of mega-shears and associated rifts breaking the marginal parts of Gondwana and, more pervasively, the whole of Laurussia (Figs. 4-5 at the Carboniferous/Permian and early Permian). At the same time, the rejuvenation of inactive oceanic ridges (possibly with a different trend) with the onset of major transform faults allowed the drift of the Cimmeric block (or blocks) to start, accompanied by a first, aborted, pulse at breaking Gondwana from Laurussia. A further, possibly twofold, and similarly aborted, well known rift pulse occurred during the middle to late Triassic; then in the middle Jurassic the transform inversion lead to the fragmentation of Pangaea.

Our maps show an important general retreat of the Permian coastlines with respect to the late Carboniferous ones. The retreat lasted until the already-mentioned mid Permian Gardena Sandstone transgression in the circum-Mediterranean area, and the late Permian Zechstein transgression in Boreal Europe. In spite of this setting, clearly suggesting a pronounced general uplift from the end of the Carboniferous, the Permian deposits in the eastern circum-Mediterranean area are more frankly marine, or even of deep-water to oceanic environment, compared with the late Carboniferous. This suggests the Permian development of an elongated, narrow transform rift, comparable in size and geometry with the present Red Sea-Gulf of Aden system. This rift allowed migration of the Tethyan benthos (brachiopods, fusulinids, etc.) from the east up to the Texan and Bolivian shelf of Panthalassa (Stehli, 1973; Gobbett, 1973), at least during part of the Permian. Generally, this same mid to late Permian transgressive trend in the Euro-Mediterranean-Northafrican area is a clear regional anomaly (requiring a specific explanation) compared with the systematic regression of the late Permian on the global scale, especially in Gondwana (Dickins, 1985). Also on this basis (the marine regression from the continental shelves as we know them today), the concept of a Permo-Triassic Pangaea was born.

The hypothesis of a transform, suboceanic rift separating Gondwana from Laurussia (and/or Laurasia in due time) via the Eastern Mediterranean-Ionian Sea-Tunisia is indeed not popular (cf. Scotese, 1984; Sengör, 1984; Nakazawa, 1985; Tollmann and Kristan-Tollmann, 1985; Belov et al., 1986; Ziegler, 1989; Zonenshain et al., 1990). Some hints, at a purely speculative level, came from Smith and Woodcock (1982) (following Irving's fit) and from Robertson and Dixon (1984), according to which, however, the dextral transcurrent faults should run north of the Adriatic Promontory. Also Rau and Tongiorgi (1981), following the same Pangaea fit, have suggested "large dextral shears in a moment enclosed between the beginning of the Permian and the middle Triassic", with displacement and rotation of Apulia. The main evidence quoted by them is, however, questionable, as mentioned above.

At any rate, the hypothesis of an Ionian Permian rift, although unpopular, is also supported by the distribution of the marine, transitional and continental deposits associated with the mid Triassic and Norian rifts, which are under many aspects equivalent to the early and mid Permian ones. Of particular importance are the more pelagic facies of western Sicily (distal turbidites and radiolarites) which have their maximum frequency and extent just in the middle to upper Triassic of the Sicani and Imerese domains (Di Stefano, 1990; Catalano et al., 1991). The same is true for the Lagonegrese Domain with the radiolaritic *Halobia* limestone of the mid to late Triassic M. Sirino Fm. (Selli, 1962; Scandone, 1967; Ciarapica et al., 1990).

The Levantine-Sicilian-Texan seaway and the birth of Adria

The idea of a possible Permian marine corridor from Sicily and Tunisia to Texas and the present-circum-Caribbean area has often been invoked, for instance by Gobbett (1973), to explain the migration of Tethyan benthic forms into those areas. Moreover, it had even been outlined much earlier, starting from Gemmellaro (1887-89). It should have appeared even more convincing looking at the palaeogeographic maps of the 60's and 70's year in the light of palinspastic global tectonics, and the palinspastic maps like those suggested by the present writer in the early 80's, especially those drawn for Dinantian times (in Cocozza et al., 1985), should have

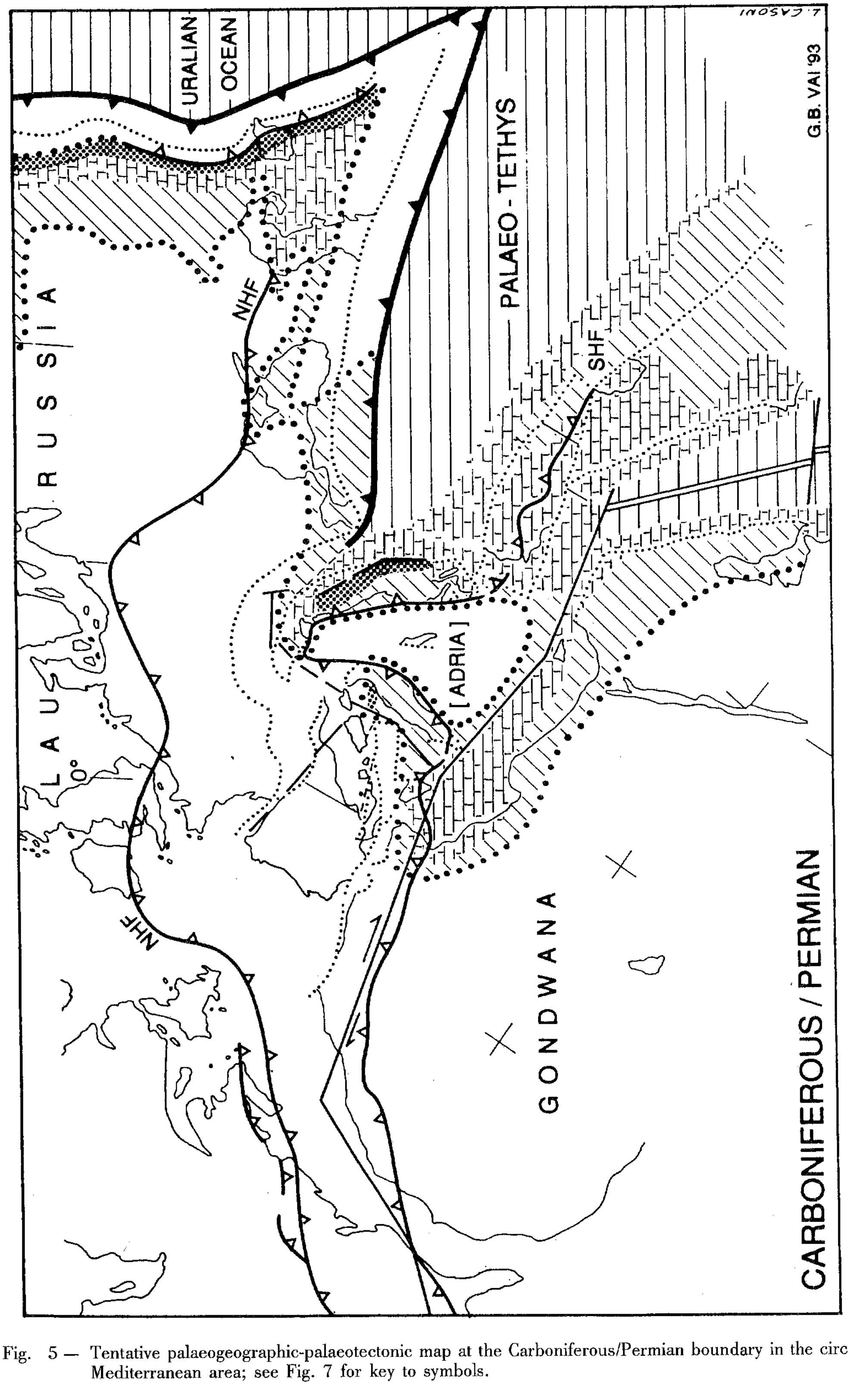


Fig. 5 — Tentative palaeogeographic-palaeotectonic map at the Carboniferous/Permian boundary in the circum-Mediterranean area; see Fig. 7 for key to symbols.

led to the same conclusion. However, acceptance of the idea was hampered by an overestimated Pangaea concept, extending from the Permo-Triassic to the Permo-Carboniferous, together with the confortable appeal of Bullard's fit. Thus, the various palaeomagnetic schools engaged in map reconstruction have never been tempted by such an idea. Their working method, in fact, is blind to any longitudinal plate movement. As is well known, palaeomagnetists began to be effectively acquainted with independent palaeogeographic data quite late, and even later with facies and geological data (e.g. Van der Voo, 1988).

The silicoclastic and carbonate deposits of ?Carboniferous to Permian age in Sicily have been reconsidered as large olistoliths resedimented in a deep Permian or Triassic basin (Vai, 1978), being associated with much more continuous, distal "Carnian Flysch" ("wild Flysch" or "Permian Flysch" *Auctorum*, Caflisch and Schmidt di Friedberg, 1967); a possible, subsequent, gravitational and/or tectonic embedding of these deposits within muddy sediments of the Apennine-Maghrebian Miocene foredeep was also considered (Ruggieri and Di Vita, 1972). After recovery of the pelagic conodont genus *Neogondolella* (Corradini and Olivieri, 1975), beside the similar data in Bender and Stoppel (1965), the interpretation of a basinal origin for part of these deposits was reinforced.

Further evidence consistent with, or suggesting a basinal Permo-Triassic connection through Sicily and/or the southern Apennines was the partly basinal, anomalous Tuscan succession of Punta Bianca (La Spezia) and the Massa-zone (Vai, 1978; Rau and Tongiorgi, 1981; Martini et al., 1986; Passeri, 1988; Rau et al., 1988; Rau, 1990), as well as the even deeper succession of the Lagonegro basin (Selli, 1962; Scandone, 1967; Scandone and Dietrich, 1972; Ciarapica et al., 1990), which are both characterized by alkaline basic volcanics, like the middle Triassic deposits of western Sicily. Also the large Scythian marine limestone blocks found in the M. Quoio Conglomerate (Verrucano Group of southern Tuscany, Cocozza et al., 1975) are very important. They suggest a rapid uplift of a marine depositional area of very early Triassic age located nearby, possibly to the south. Finally the American affinity of the conodonts and the Cantabric signature of the Derryan to Missourian age (mid-late Pennsylvanian) corals found in the Farma valley of southern Tuscany (Ferrari et al., 1977) implied that also during the late Carboniferous direct faunal exchanges among America, Spain and the present Apennines were possible. Further, a possible, at least biogeographic separation of the Apennines from the Carnic-Dinaric and eastern Mediterranean areas was deduced from the same data (as it appears on Fig. 4).

Recently, a set of important new data and outcrops on the Permian of the Sicani Mts. in Sicily (Catalano et al., 1991 *cum bibl.*) has provided potential evidence crucial for demonstrating the former existence of a Permian deep basin there, although some caution is still needed. Similar evidence of pelagic early to middle Permian has been found in Crete (Krahl et al., 1986). More caution is required in Sicily by the fact that the assumed Permian is mostly represented by turbidites and olistostromes *(wild Flysch)* of possible repeated recycling, in an area of severe shortening and fragmentation such as central Sicily. However, a mainly radiolaritic mid to late Triassic is convincingly documented there, with an overlying succession persistently developed in basinal conditions from Liassic to Miocene.

Now, if all the pelagic fossils described as Permian in Catalano et al. (1991) are Permian in age, this is important evidence of an inter-oceanic, trans-Gondwanan Permian seaway. In this picture, however, the circum-Pacific or Tethyan affinity of the new faunas found by Catalano et al. (1991) is not surprising, when the previous well known data on benthic faunas (see above) are considered.

Turning back to our maps (Figs. 4-6), *late Carboniferous* marine deposits are well known in the North African-Arabiana-Oman-Persian-Turkish-Elleno-Dinaric-eastern Southalpine belt. They have been recently documented also in the Farma valley, at Iano and Elba island (Ferrari et al., 1977; Vai, 1978 (see Fig. 3 for a palaeogeographic analysis of Tuscany during the middle-late Palaeozoic); Cocozza et al., 1975, 1985), in Corsica and the Cantabric foredeep (Julivert, 1981; Martinez-Garcia, 1991). The problem of a marine connection from the western border of the Carboniferous Palaeotethys toward the Carnic Alps and the Cantabric Mountains leaves a southern way only open through the Near East, North Africa and Tuscany. The northern,

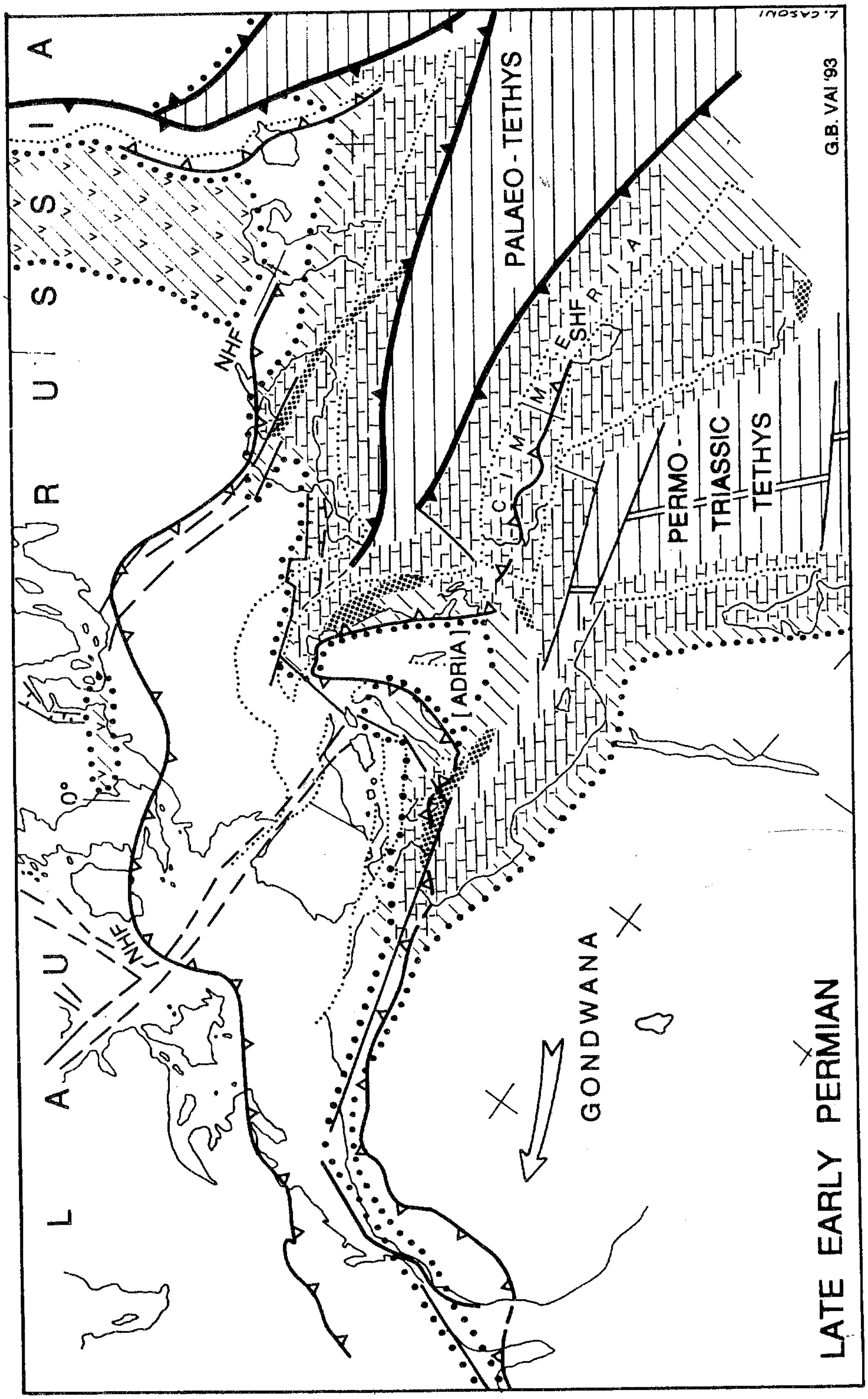


Fig. 6 — Tentative late early Permian palaeogeographic-palaeotectonic map of the circum-Mediterranean area, see Fig. 7 for key to symbols.

more direct way seems to be precluded by the evidence of continental deposits in Tuscany north of the Arno river, in the Lombard lake district, and along the whole Western and Maritime Alpine arc (Vai, 1976), besides Sardinia and the remaining part of Spain.

During the *early Permian* the sea retreated from the Cantabric zone, Corsica and Tuscany (north of the Capraia-Siena line). The northernmost early Permian marine deposits of Italy (excluding those, quite apart, of the Carnic Alps) are found in the Farma valley, on Elba island (Vai, 1978), in the M. Amiata subsurface (Pandeli and Pasini, 1990) and possibly in Argentario and Monti Romani (Vai, 1978). Calcarenitic to calciruditic blocks of late early and late Permian age have been reported (Donzelli and Crescenti, 1970) also from the II Lagonegrese tectonic unit of the southern Apennines (Scandone, 1972). They are chaotically associated with the Scythian-Ladinian M. Facito Fm. (Ciarapica et al., 1990), in a setting very similar to that of the Permian of Sicily (Di Stefano, 1990; Catalano et al., 1991).

Thus, it does not seem by chance that pelagic basinal and turbidite deposits of early Permian age are found in Sicily, most likely in Lucania (southern Apennines), at Crete (Krahl et al., 1986), in the clastic Trogkofel basin of the Dinarides (Ramovs, 1963), and, slightly later in the middle Permian, in Oman associated with pillow lavas (De Wever et al., 1988; Blendinger, 1988) and in Iran (Vasicek and Kullmann, 1988). Moreover, it does not seem by chance that within or near these areas of deep marine Permian sedimentation, alkaline basic volcanics are found associated with pelagic Anisian-Ladinian deposits, like in the W Sicily (Broquet et al., 1966), the Pindos (Jakobshagen et al., 1976) and Budva (Ciric, 1965) zones, in the Lagonegro area (Scandone and Dietrich, 1972) and at Punta Bianca near La Spezia (Ricci and Serri, 1975). In the Iblei Mountains of SE Sicily the same type of volcanism is associated with shallow-water carbonate deposits (Campione, 1961; Cristofolini, 1966; Grasso et al., 1983). The Iblei Mts. represent a case of special importance, showing the persistence of an alkaline basic magmatism punctuated over an extremely long (mid Jurassic, late Cretaceous, Eocene, Miocene, Pliocene and Sicilian) time interval.

I should remark, finally, that, just at the apex of the two distinct Tethyan branches of Fig. 5, the calcareous-radiolaritic pelagic facies of Hallstatt (Tethyan closing arm) and those of Lagonegro and the Sicani Mts. (Tethyan opening arm) occurred at the end of the Triassic.

Catalano et al. (1991) claimed not to have found oceanic crust remains associated with the early Permian pelagic deposits of Sicily. I don't believe this is a major problem. First, because the Triassic of the Sicani Mts. is definitely detached from its stratigraphic base, and the Permian deposits show an even more complex history of previous décollements. Second, because the Permian pelagic deposits might have been placed at the edge of a narrow belt of crustal thinning and oceanic opening (possibly not wider than a few hundreds of km) located in the area of the present anomalous Ionian crust (see above). We can assume that this oceanic seaway started opening from the NW tip of the Permian Tethys near the Persian Gulf, expanding later on in the Levant and south Ionian seas, and then closing in Tunisia. From here westward, a simple transform shear-zone cutting along a belt of stretched crust through the Atlas, the Maroccan meseta and Florida reached the Panthalassa between the Texan and the Colombian shelfs. The transform shear-zone along this tract was presumably accompanied by a narrow seaway often interrupted and reactivated with time (Figs. 5-6). The suggested oceanic arm aborted definitely after the middle and late Triassic rifts. It also escaped reactivation or inversion because of the different location of the mid-Jurassic rift axes and especially because of their different types of kinematic (dextral slip motion for the Permo-Triassic rifts, and sinistral for the middle Jurassic and following ones). The Permo-Triassic crust of this oceanic arm, following a slow thermal subsidence, would have been "thickened" by a tall blanket of Meso-Cenozoic sediments, thus reaching the thickness of the present Ionian crust.

There is another important point in favour of this hypothesis. The long, cyclic series of volcanic events in the Iblei Mts. shows no evidence of crustal contamination in the chemical composition of the magma (Grasso et al., 1983; Bianchi et al., 1989). Further, and even more important, lower sialic xenoliths have never been found in the frequent Hyblean diatremes, whereas simatic rocks are common (M. Grasso, pers. com. 1992). This fact is consistent with a pre-late Triassic oceanic lithosphere underlying or immediately adjacent to the Iblei Mts.

If the present restoration is correct, the Adriatic Promontory would have been a palaeodynamic feature clearly outlined since the late Precambrian (Fig. 2) which was detached from its mother Africa starting from the early Permian (Fig. 5). This should be the birth date of the "Adria" microplate (a term which is preferred to Apulia). Since that time, the microplate has acted kinematically independent of the Africa plate, although the thick sedimentary blanket just on the dividing neck (showing a complete post-mid Triassic inactivity of the major early Permian transform) masked its inferred function as promontory junction with Africa (Channel et al., 1979) for most of the Mesozoic and the Tertiary.

RESULTS OF THE PALAEOTECTONIC ANALYSIS

A summary of the most recent data around the Italian area, leaving apart any interpretative models, allows us to draw a picture of the temporary crustal consolidation achieved at the end of the Hercynian orogeny in the late Carboniferous. Soon after that, the Permo-Triassic rifts, although intimately associated with the major right-lateral kinematics of the late Hercynian orogeny, resulted in a radical perturbation of the preceding palaeogeography and sedimentary pattern.

A tectono-metamorphic zonation with main orogenic polarity from WNW to ESE was achieved in some phases from the early Carboniferous to Westphalian. Only the major part of the Carnic Alps, the Farma valley area (Monticiano-Roccastrada "Massif") and part of the areas originally south of the Sardinia Massif (mostly found now in the tectonic units of Stilo, Bocchigliero and Longi-Taormina in the Calabria-Peloritani "Massif") were almost completely preserved from the Hercynian metamorphism. Hercynian foredeeps of Carboniferous age are well known only in the Carnic Alps (plus Karawanken and the external Dinarides) and the Apennine Farma area. New data show evidence of a similar foredeep also in the Sarrabus, S Sardinia (Vai and Cocozza, 1986; Barca et al., 1992). Outside this foredeep belt the outer Hercynian deformation front is found over a Hercynian foreland, whose slightly folded edge runs from the Antiatlas to the Pelagian Block and the Ragusa Platform, up and down around the Adriatic platforms encompassing the Agip Assunta well, down to Cyprus and the N edge of the Arab-Iranian Platform close to the Ormutz Strait (Vai and Cocozza, 1986).

This Hercynian foreland in north Africa and Arabia bears close evidence of Panafrican (or Baikalian) crustal consolidation at the Precambrian/Cambrian boundary (620-560 Ma). A similar age is inferred also for the metamorphics hosting the Assunta well granitoids dated at 446 ± 18 Ma, a date corresponding to one of the two modal dates measured for the Ordovician thermal event through large parts of Europe and the Mediterranean area (Vai and Cocozza, 1986). The granitoids of the Assunta well are sealed by a thin veneer of clastic Triassic deposits, suggesting a structurally high position for this outpost of the Adriatic Promontory and "Adria" during the Palaeozoic. In the Amanda 1 well nearby, however, also early to middle Permian marine deposits related to the Pontebba Supergroup are interposed between the granitoid basement and the Triassic clastics (Sartorio and Rozza, 1991).

Following this picture, all the fragments of the Hercynian orogeny known in and around Italy are derived from Palaeozoic sedimentation over a Precambrian continental crust consolidated by the Panafrican orogeny, and involved later on in magmatic intrusive and extrusive events of mainly Ordovician and Ordovician/Silurian age. The sedimentary and magmatic signature of this Palaeozoic is unitarian for each time interval, but also monotonous and not diagnostic of the different parts of the area. Peculiarities are restricted solely to the Carnic-Dinaric province. This is the only one where 1) the Devonian is represented by reef-complexes and shallow-water platform-limestones, 2) a palaeobiogeographic Uralian affinity in the late Silurian and early Devonian is found, in sharp contrast with the remaining Palaeozoic in Europe and the Mediterranean, 3) thick alkali-olivine-basaltic and sometimes ultrabasic bodies, suggesting oceanic opening nearby to the E, are common, and 4) a very thick, molasse-like marine succession is developed in late to post-Hercynian times. However, this last feature, although less thick and only partly marine, is found also in the Carboniferous to Permian cover of the Apennine Farma and Sicily areas. Moreover, the Permo-Triassic rifts probably prompted the opening of a narrow, oceanic seaway in the present Levant and Ionian seas. Similar opening effects cannot be ruled out in the Dinarides and eastern Southern Alps (as suggested also by G.B. Dal Piaz, verbal com. at the Crop Meeting, Bologna 1992). However, they are much more difficult to document, possibly because of their far less original extent as compared to the eastern Mediterranean, and the effects of the following Alpine inversion.

In summary, there are objective and quite precise limits to any attempt at distinguishing specific domains in the Italo-Mediterranean Palaeozoic basins. However, it is useful to try to characterize the main types of sedimentary and magmatic evolution of the individual fragments of the Hercynian basement.

GEOLOGIC CHARACTERIZATION OF THE MAIN BASEMENT ELEMENTS

Southern Alps

The Southern Alps are characterised by unique conditions of superb exposure and detailed knowledge as a consequence of the 90° change in polarity of the Alpine versus the Hercynian deformation. This is the main reason for the good preservation of the Hercynian structure. The Southern Alps are divided into three parts (Vai and Cocozza, 1986):

1) *Carnic Alps and eastern Cadore with upper Comelico* (and their E to SE extension). This is an Uralian fragment (''Uralia'') incorporated into the Southalpine Hercynian segment in the early Carboniferous (Vai, 1976, 1991). It is characterized by the impressive alkali-olivine-basaltic volcanics of the early-middle Carboniferous; the late, very rapid polyphase deformation (part of the Westphalian); the immediate onset of the marine molasse sedimentation, and the poorly developed Permian volcanis. The Carnic Palaeozoic is systematically detached from its basement or substrate at the Caradocian level.

2) *Venetian to Adige Area* (Recoaro, Agordo-Cereda, Judicaria and Alto Adige). The Hercynian metamorphic basement seems to be detached at the level of the Cambrian. A clastic Cambro-Ordovician succession bearing clear evidence of the Ordovician thermal event (porphyroids) is documented. Shallow-water carbonates of possible Devonian age are also present, whereas Hercynian Flysch is lacking. The Hercynian deformation started earlier. There is a thin continental molasse of early Permian age with the climax of granitoid intrusion at the boundary between the Carboniferous and Permian, and impressive bimodal early Permian volcanics (the Adige Porphyric Platform). Both granitoid and volcanic bodies are concentrated along a meridian belt.

3) *Central-western Southalpine area.* This has characteristics quite similar to the Venetian. However, older protoliths, including carbonates of possible Cambrian age and siliciclastic sediments of late Precambrian, are involved in a polymetamorphic complex of westward-increasing grade. Sections of middle and lower Hercynian crust accompanied by a late Hercynian mantle intrusion are exhumed and still exposed in the western part (Vai, 1992). A second meridian belt of concentrated Permo-Carboniferous epi-plutonic and volcanic bodies is found in the Lombard lake district. It is accompanied by one of the most important continental pull-apart basins of the Southern Alps, closely related to the early Permian transform rift: the Collio basin (Cassinis and Perotti, 1993).

It is worth mentioning that each of the two meridian-trending post-Hercynian volcanic and granitoid belts have a counterpart in the Po plain subsurface, where drilling and aeromagnetic surveying by Agip have shown a thick Permian volcanic plateau in the Pavia block (Monza and Battuda wells) co-axial with the Permian granitoid and volcanics E of Lake Como. Even wider Triassic volcanics have been found SSW of the Venetian Platform in the Mantua block (because of the well depth, however, associated Permian volcanic bodies cannot be excluded). Such meridian trends of the late to post-Hercynian magmatic intrusions and volcanics follow quite regularly the Hercynian structural axes and more precisely the two main ensialic subduction belts of the chain (Vai and Cocozza, 1986; see also Castellarin and Vai, 1981, 1986). They also correspond to two master faults of the Permian rift (Fig. 5).

Apennines

Exposures, extent and state of knowledge of the different basement elements in the Apennines are poorer by far than in the Southern Alps. Moreover, the same sense of orogenic polarity for both Hercynian and Alpine deformations results in a further misidentification.

I have already emphasized elsewhere the four different Hercynian basement types and related cover successions which can be distinguished in the Northern Apennines (Vai and Cocozza, 1986; Vai, 1988):

1) *Elba, Punta Bianca and Massa area.* This is characterized by a eastern Sardic - to Venetian - type basement (possible Cambro-Ordovician clastics, porphyroids and pelagic Silurian and mid-late Devonian) and by a late Carboniferous to Permian marine molasse cover, followed by the early to mid Triassic Punta Bianca succession, which is the most Southalpine-like of the Alpennines (together with those of Lagonegro and the Gimigliano window in the Sila mountains). The last three distinct late Palaeozoic or early Triassic, more or less pelagic basins are of pull-apart rift-controlled type.

2) *Apuane-Pisano area.* This has the same basement type as Elba island, with possible Cambro-Ordovician clastics, porphyroids and pelagic carbonates of mid-late Silurian and possibly Devonian age. The cover, however, is purely continental, with Permo-Carboniferous small-sized lacustrine basins (e.g., San Lorenzo), discontinuous and thin Permo-Triassic pocket-like deposits and quite different thicknesses of mid-late Triassic, classic Verrucano. These also are pull-apart basins.

3) *South Tuscan area.* Part of the Palaeozoic basement (Risanguigno, Farma and other areas) is poorly to unmetamorphosed (what there is being essentially of Alpine origin). A carbonate to radiolaritic Devonian and silicoclastic turbidite Kulm-type Carboniferous with carbonate olistostromes and olistoliths are known. The facies succession shows the characteristic of a quite outer foredeep. Its sediments have suffered a weak and late polyphase deformation, making a distinction between syn- and post-tectonic tectofacies (Flysch and molasse respectively) quite difficult. The sedimentation maintains a completely marine character during the mid-late Carboniferous and part of the Permian, passing to transitional in the early Triassic. It should be remembered that in the Castelnuovo well (drilled by Enel) red sandstones petrographically similar to the Gardena Sandstone have been found.

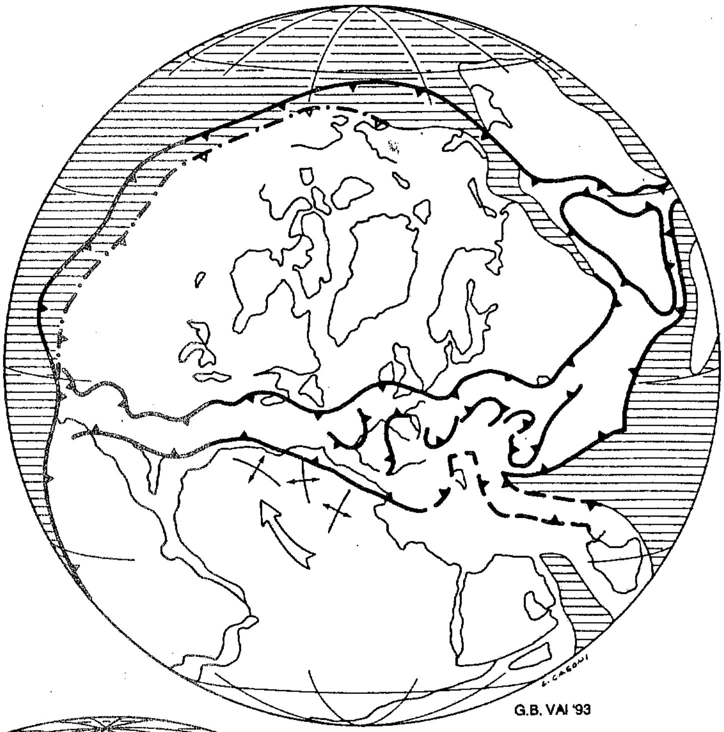
4) *Cerreto area.* The Hercynian basement made up of micascists and amphibolites has a metamorphic grade comparable to that of the Apuane Alps and Elba island. However, it is still too poorly known to give a precise characterization. Evidence of Palaeozoic is lacking. The first sediments having possible primary contact with this basement are Verrucano quartzites and pelites followed by late Triassic evaporites.

Is is difficult to say whether these four distinct areas have the characteristic of original pre-late Triassic palaeogeographic domains (possibly related to a Hercynian tectono-metamorphic zonation) which have been displaced and have thrusted each other eastward to form four main tectonic units. One can state certainly that the differences in the tectonostratigraphic evolution among these four areas are more important than those commonly used for separating the Tuscanid I (or Apuane "Autochthonous" core), the Tuscanid II (or Massa-Pisano zone) and the Tuscanid III (or Tuscan Nappe). This division, in fact, was based mainly on Alpine metamorphism, Grezzoni versus Cavernoso Fms. occurrences, and presence versus absence of the Verrucano Group.

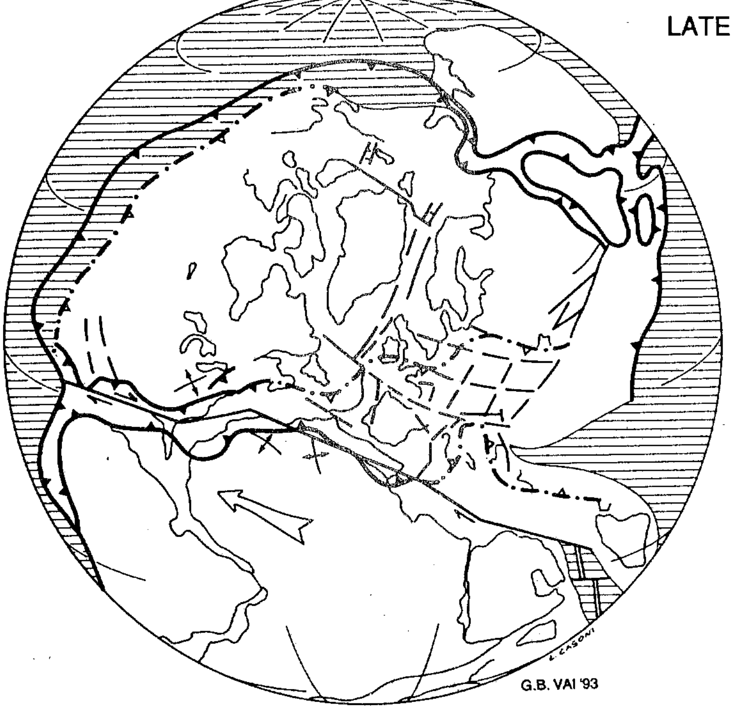
Nowhere in the Southern Apennines and maghrebian Sicily is direct, outcropping evidence of Hercynian basement found. I have assumed its existence by extrapolation from the Northern Apennines. The important difference in geometry and Neogene kinematics between the two major Apennine arcs, with a complex mega-duplex structure in the southern one (Patacca and Scandone, 1989) may explain the disappearance of the Hercynian basement by burial (Mostardini and Merlini, 1986; Ortolani et al., 1992). The little knowledge on the late Palaezoic covers has been discussed above.

Sardinia

The Sardic basement and Palaezoic show a coherent, well articulated, SW-verging structure



LATE CARBONIFEROUS
310 - 300 Ma



CARBONIFEROUS / PERMIAN
OR LATEST CARBONIFEROUS
290Ma

Fig. 7 — Schematic palaeotectonic restorations of Laurussia (later on Laurasia) and Gondwanaland (sources: Cocozza and Vai, 1986; Ziegler, 1989; Vai, 1991).

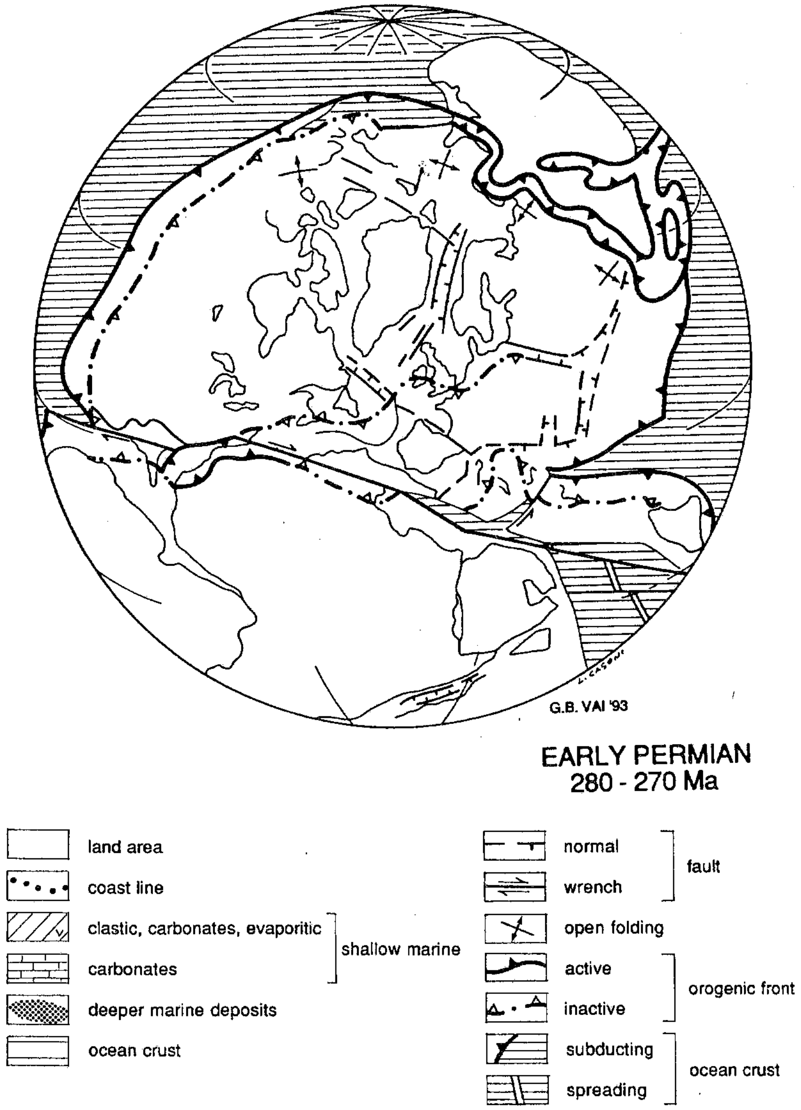


Fig. 7 — (continued).

(Vai and Cocozza, 1986; Barca et al., 1992; Carmignani et al., 1992a), in which two main domains may be distinguished: 1) the *Iglesiente-Sulcis* to the SW, characterized by an impressive development of a mainly carbonate Cambrian succession, and 2) *all remaining* domains to the NE, in which the Cambrian is incomplete and purely silicoclastic. Moreover basin evolution and its feeding provenance during late Ordovician is different between the two domains (Loi, 1993). There is recent evidence to suggest the accretion of a terrane of Armorican (or west European) origin on the NE edge of the Sardic Hercynian segment (Carmignani et al., 1992 b).

As a whole, the Sardic basement forms a key to the interpretation of the Tuscan, especially northern basement (Carmignani et al., 1977; Gattiglio, 1988). However, it is distinct in the total absence of a Permo-Carboniferous marine molasse and the poorly represented late Carboniferous deposits. Moreover during the Triassic the marine deposits, though German in facies, are practically unrepresented, excluding the Nurra and small outlets on the W coast (Gelmini, 1985). The Permian volcanism (and, more generally, magmatism) is very important; it reaches a volume comparable with that of Corsica-Provence and the Southern Alps. I would

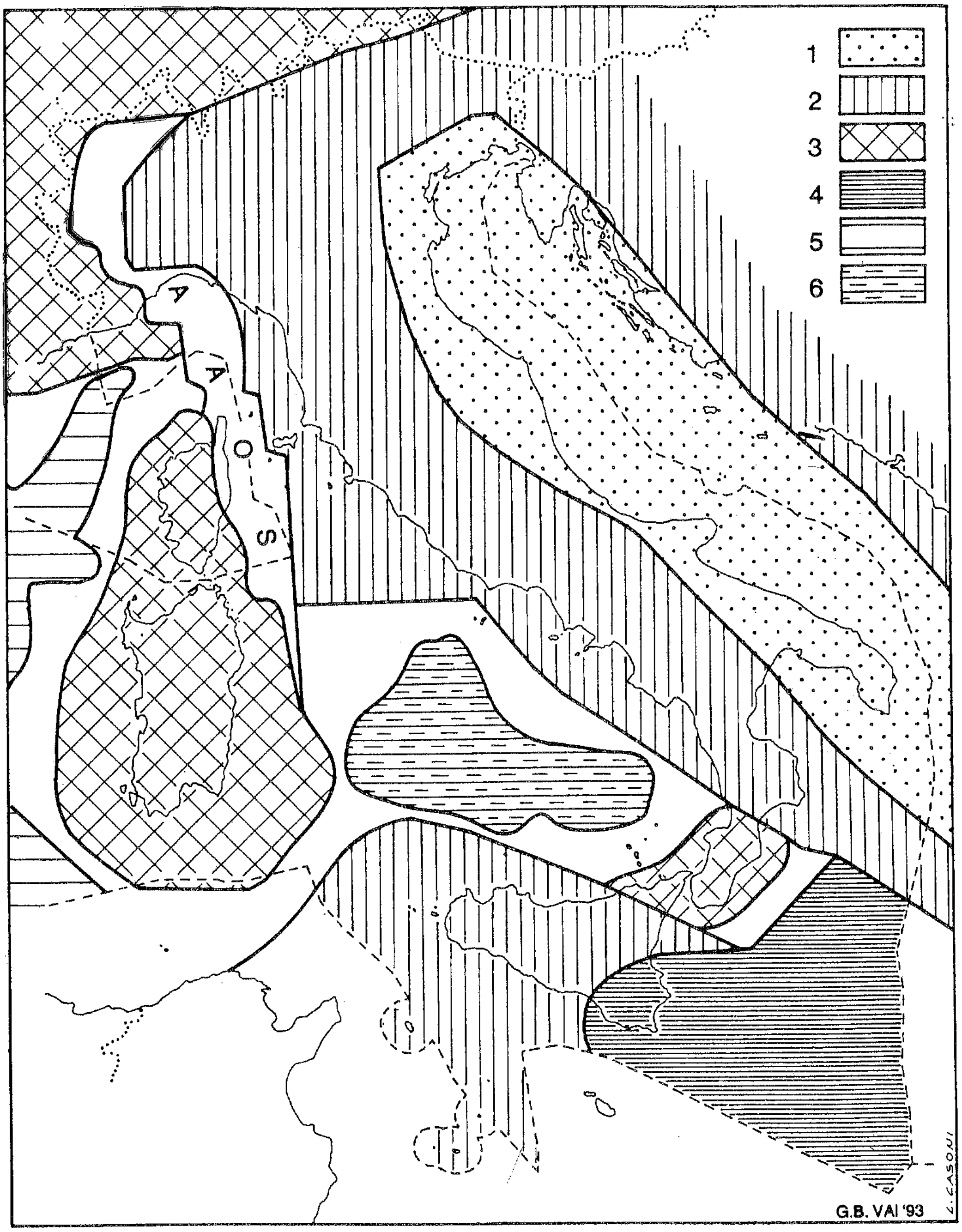


Fig. 8 — Virtual crustal zonation of the Italian area based on basement and Palaeozoic rock evolutions. Effects of Alpine crustal thickening and rejuvenation have not been considered. Miocene and Plio-Pleistocene oceanic crust accretion in the Balearic and Tyrrhenian seas are reported for reference only. Blank areas represent transitional or uncertain areas. (AAOS = Alps-Apennines ophiolitic suture).

Legenda: 1 = Baikalian-Panafrican crust; 2 = thinned Hercynian crust; 3 = European Hercynian crust; 4 = Ionian Permo-Triassic fossil oceanic crust; 5 = Balearic Miocene new oceanic crust; 6 = Tyrrhenian Plio-Pleistocene new oceanic crust.

like to stress again that such large volcanic plateaus are located along one arm of the Permian rift (Figs. 5-6).

Calabria

Here too, beside many varieties of basement element related to a long lasting tectonic fragmentation (Vai and Cocozza, 1986; Vai, 1992), two main parts can be distinguished.

1) The Sila *pro-parte block*, to which an Austroalpine affinity has usually been assigned (Scandone, 1982); part of it (the Gimigliano tectonic unit) was recently indicated as pertaining to the Southalpine or Apennine domain of Lagonegro-Punta Bianca type (because of the presence of inferred Scythian to Anisian limestones and Ladinian "pietra verde" equivalents) (Vai, 1992).

2) A *composite block*, originally including the elementary terranes of Longobucco, and Serre-Stilo-Aspromonte-Peloritani (as well as the similar submerged or exposed Kabilian ones), all characterized by the same Hercynian metamorphic basement and Palaeozoic of Sardic type, but clearly distinct from the Longobucco terrane because of its Jurassic sedimentary pattern. The eastern Sardic affinity of all these terranes is also suggested by the lack of Carbo-Permian-Triassic deposits (Vai, 1992).

CORRELATION AND CONCLUSIONS

No cylindrical correlation among the Hercynian isopic zones distinguished in the Southern Alps, the Apennines and Sardinia can be assumed at whatever level or time of evolution. However, the problems of a non-cylindrical connection or transition between identical or similar domains in the three different palaeochain segments need to be explored.

The key correlation criteria which have to be considered in any attempt at translational and rotational backstripping of Sardinia, the Southern Alps and the Apennines are the following.

1) The Carnic-Dinaric Hercynian basement element is limited to the Southern Alps-External Dinarides and has no equivalent in either the Apennines or Sardinia. This is consistent with its Hercynian terrane character, probably blocked in its westward drift by a Panafrican basement salient representing an Adriatic Palaeo-Promontory (Fig. 2).

2) The four distinct areas in the Northern Apennines have a Hercynian metamorphic basement comparable with both the Sardic (S European) and the central-western Southalpine (N African) ones. Only part of southern Tuscany is different, being similar to very external segments of the S Hercynian chain, like Sicily, S Portugal, the Pyrenees and Cantabria.

3) Partial similarities are also found between the Southalpine (plus Austroalpine) in general and the Apennine areas of southern Tuscany, Elba-Punta Bianca-Massa, Lagonegro (Lucania) and the Sicani Mts. (Sicily) during the Permian and Triassic. The similarities consist of punctuate "Alpine" facies occurrences within a primarily "Germanic" scenario, at least in the NW of the region. This implies necessarily either a basin continuity or convergence of processes during the Permian and mid-late Triassic rifts. The result is that any attempt at tracing the Southalpine and Austroalpine domains into the Apennines is difficult, as demonstrated by the W truncation of the Insubric Lineament (Figs. 5-6).

4) Finally, the problem of placing a physical boundary between the Southalpine and the Apennine provinces is firmly dictated by the above point.

If we assume as diagnostic criteria the effects of the Permian rifts (such as epi-plutonic intrusion belts, bimodal volcanism, and the great Gardena Sandstone-Verrucano Lombardo basin) together with a well developed Mesozoic pattern of alternating platforms and basins, it is easy to accept that the whole Pedealpine Homocline up to the Mantua and Pavia crustal blocks (Castellarin and Vai, 1986) was still part of the Southalpine palaeogeographic domain. Also the deepest and less displaced NE-verging sheets found in the Cavone and Monestirolo-Ferrara wells by Agip would have pertained to the same province.

Following these criteria, we could assume in Agip's Po plain cross-sections a conservative boundary for the southward extent of the Southalpine domain in the Po plain and the Apennine chain passing along a virtual surface connecting the Po delta through the Ferrara and Modena plains, and the Pedeapennine margin to the Pontremoli well, and eventually continuing south of Volpedo well and slightly north of Turin. It is important to remember that red Gardena Sandstone-type deposits have been cored beneath the Ligurid and Tuscanid (with Hercynian basement and Verrucano cover) Apennine sheets in the structurally high position of the Pontremoli well.

As one can see, control and interdisciplinary updating of the few basement and Palaeozoic elements both outcropping or found in deep wells will be crucial for a more coherent and articulated scenario of the pre-Triassic palaeogeography and domains in the Mediterranean.

The first demonstration of this statement is found in the maps presented here (Figs. 4-6), from which a clear physical boundary between the Southalpine and Apennine provinces during the Permo-Triassic appears. It was represented by the structural high of Adria, whereas the continuity and the supply to the Apennine basins was assured by the Levant-Sicily-Texas seaway.

In conclusion, a summary of the preliminary results can now be given in Fig. 8. It shows the main basement (or crustal) types distinguished in the area around Italy.

At this point, after checking the present palaeodynamic hypothesis of a Permian Ionian oceanic rift, it will be interesting at a later stage to make a comparison between a zonation (even more detailed than that presented in Fig. 8) and the features of the magnetic basement shown in Cassano et al. (1986) and Arisi Rota and Fichera (1987).

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