© 1981 GEOLOGIE EN MIJNBOUW 0016-7746/81/0300-0171 $ 2.50/0

STRUCTURAL AND PALAEOGEOGRAPHIC LINEAMENTS OF THE VARISCAN CYCLE IN SARDINIA

L. CARMIGNANI[1], T. COCOZZA[2], N. MINZONI[3] & P. C. PERTUSATI[1]

ABSTRACT

Carmignani, L., T. Cocozza, N. Minzoni & P. C. Pertusati 1981 Structural and palaeogeographic lineaments of the Variscan cycle in Sardinia. *In:* H. J. Zwart & U. F. Dornsiepen (eds.): The Variscan Orogen in Europe – Geol. Mijnbouw 60: 171-181.

In the Variscan orogen of Sardinia it is possible to distinguish:
(1) A Southwestern zone (foreland), restricted to the SW of the Cenozoic graben of Campidano, with slight metamorphism and minor folding without important overthrusts.
(2) A central zone that runs across the entire island from Nurra to Sarrabus, characterized by important overthrusts and a rather uniform metamorphism never exceeding the greenschist facies. The metamorphism grades towards the NE into the higher-metamorphic area.
(3) The Northeastern zone (granitized root zone) that includes the northern tip of the island and is characterized by the superimposition of several metamorphic episodes and by tectonic events that have intensively remobilized the pre-Variscan basement.

A conventional boundary between the two last belts may be drawn along the NW-SE line joining Stintino and Dorgali. Furthermore, there seems to be a parallellism between post-Cambrian palaeogeographic domains and Variscan tectono-metamorphic zones.

The absence of ophiolite associations, the Ordovician magmatism, the Silurian one with continental alkaline affinity and the Variscan metamorphism of low or intermediate pressure suggest that the Variscan orogenic cycle in Sardinia had an ensialic evolution.

The structural style of the different zones, the asymmetry of the belt, the division into metamorphic zones and the relationship between crystallization and deformation suggest also that the northeastern Sardinian Variscan belt represents the portion of the crust deeply subducted along intracontinental shear zones dipping towards the NE.

RIASSUNTO

Carmignani, L., T. Cocozza, N. Minzoni & P. C. Pertusati 1981 Structural and palaeogeographic lineaments of the Variscan cycle in Sardinia. *In:* H. J. Zwart & U. F. Dornsiepen (eds.): The Variscan Orogen in Europe – Geol. Mijnbouw 60: 171-181.

Nell'orogeno ercinico sardo è possibile distinguere:
(1) Una Fascia sud-occidentale (avampaese), limitata a NE dal Graben terziario del Campidano, poco metamorfica e con tettonica plicativa ma senza importanti sovrascorrimenti.
(2) Una Fascia centrale con sovrapposizione di falde e con un metamorfismo abbastanza uniforme in facies scisti verdi, che verso NE passa gradualmente alla successiva fascia più metamorfica.
(3) Fascia nord-orientale (zona di radice) con una tettonica polifasata complessa, granitizzazione e metamorfismo generalmente in facies anfibolitica.

Il limite convenzionale tra queste ultime due fasce può essere posto in corrispondenza di un allineamento, diretto NW-SE, che congiunge Stintino a Dorgali. Queste fasce tettono-metamorfiche sembrano coincidere con i domini paleogeografici post-cambrici.

L'assenza di ofioliti, il magmatismo acido ordoviciano, quello silurico con affinità alcalina continentale e il metamorfismo di pressione bassa e intermedia fanno ritenere che il ciclo orogenetico ercinico si sia svolto interamente su crosta continentale.

Lo stile strutturale delle diverse fasce, la asimmetria della catena, la zonazione metamorfica e i rapporti tra cristallizzazione e deformazione fanno ritenere inoltre che la catena si sia originata lungo zone di taglio immergenti a NE, le quali hanno interessato tutto lo spessore della crosta continentale.

[1] Istituto di Geologia, Via S. Maria 53, 56100 PISA, Italy.
[2] Istituto di Geologia, Via delle Cerchia 3, 53100 SIENA, Italy.
[3] Istituto di Mineralogia, Corso Ercole I° D'Este 32, 44100 FERRARA, Italy.

INTRODUCTION

In Italy, the most complete Palaeozoic succession that has not been overprinted by the Alpine orogeny crops out in Sardinia. Even though deformations occurred also between the Middle Cambrian and the Early Ordovician (Sardinian phase) and in the Ordovician (pre-Caradoc), the most important metamorphic and tectonic lineaments of the region are produced by the Hercynian orogeny (CARMIGNANI ET AL., 1978-a).

The age of the main phase of the Variscan orogeny falls between the early Tournaisian, the last intensely deformed fossiliferous sediment (OLIVIERI, 1970), and the late Westphalian (VAI & COCOZZA, 1974), which overlies the Palaeozoic folded sediments with a marked unconformity. This age, established on stratigraphic grounds, is confirmed by the radiometric age of metamorphism in northeastern Sardinia (344-300 Ma: FERRARA ET AL., 1978) and of late Variscan granitoids (297-279 Ma: DEL MORO ET AL., 1975).

Because of structural, metamorphic, and lithostratigraphic affinities, it is likely that the Variscan belt of southern France extended into Sardinia (WESTPHAL ET AL., 1976; MATTE, 1976; ARTHAUD & MATTE, 1977-a, b; RICCI & SABATINI, 1978). Nevertheless, the exact connection between Sardinia and the South-European Variscan belt, still remains one of the most challenging problems since its reconstruction is complicated by the late-Variscan strike-slip faults (ARTHAUD & MATTE, 1975) and the rotation of the Sardo-Corsican massif beginning in the Early Cenozoic (ALVAREZ, 1972; WESTPHAL ET AL., 1976).

Our research, especially in Sardinia northeast of Campidano, as part of Working Group 9, 'The Variscan Orogen of Europe', has revealed three different zones parallel to the trend of the Sardinian segment of the Variscan orogeny. Despite the lack of continuity of the Palaeozoic outcrops due to the large granitoid intrusions and post-Variscan sediments, these three zones can be traced across the entire island. In central and northern Sardinia they run NW-SE, and in southern Sardinia, N-S; they nearly parallel to the axial trends of the main phase of deformation. The subdivision in three parallel zones is not only connected with the Variscan syntectonic events but is also in relation with the post-Cambrian palaeogeographical evolution. This situation is not unique in the South-European Variscan belts; in Spain palaeogeographic and structural zones are parallel for hundreds of kilometres (MATTE, 1968).

The three zones into which we subdivide the Sardinian Variscan Orogen are as follows:

(1) *The Southwestern zone* is restricted to the area SW of the Tertiary graben of Campidano, including Iglesiente-Sulcis. This is the zone with the lowest grade of metamorphism, where intense folding has occurred without important overthrusts (ARTHAUD, 1970).

(2) *The Central zone* cuts across the entire island from Nurra to Sarrabus. It is characterized by a rather uniform metamorphism that never exceeds the greenschist facies, and by tangential tectonics with recumbent folds and important overthrusts. Towards the NE it grades into the most metamorphic zone. A conventional boundary between the two may be drawn along the NW-SE line joining Stintino and Dorgali (the so-called 'Linea Stintino-Dorgali': DI SIMPLICIO ET AL., 1975).

(3) *The Northeastern zone* includes the northern tip of the island. It is characterized by a higher metamorphic grade and may be an area where the pre-Variscan basement has been intensively remobilized.

According to the literature, the tectonics of the Southwestern zone seems to lack a clearly defined polarity, whereas in the other two zones the belt shows a clear asymmetry towards the W and SW. Thus the orogenic polarity indicates that the southwestern-most zone is also the more external one.

LITHOSTRATIGRAPHIC CHARACTERISTICS OF THE THREE ZONES

The succession in the Southwestern zone

The Iglesiente-Sulcis area is characterized by a thick epicontinental Cambrian succession consisting of sandstone with Archeocyathid-bearing dolomite and limestone lenses (Nebida Formation), overlain by dolomite and limestone (Gonnesa Formation) of the Early Cambrian, and, lastly, by nodular limestone and *Paradoxides*-bearing slate (Cabitza Formation) of the Middle Cambrian (COCOZZA & LEONE, 1977).

The Cambrian succession is unconformably overlain by polygenic conglomerate ('Puddinga') and sandstone, passing at the top into siltite and slate, both containing basic volcanites and, sometimes, lenses of encrinite-bearing Caradocian fossils. This sequence continues with the Silurian and Devonian rocks.The former consists of graptolite-bearing carbonaceous slate, while the latter is made up of limestone lenses embedded in slate. The Devonian is the last fossiliferous level and is overlain by a thick detritic formation ('Postgotlandiano' AUCT.), which has been interpreted as a synorogenic Variscan deposit and attributed to the Early and Middle Carboniferous (VAI & COCOZZA, 1974). In southern Sulcis at the base of the Matoppa Member (COCOZZA, 1979) there is a succession consisting of slate and siltite with subordinate sandstone, limestone and microconglomerate lenses, the latter containing orthogneiss clasts. This succession is probably attributable to the Precambrian (COCOZZA & LEONE, 1977; COCOZZA, 1979).

The succession in the Central zone

Northeast of Campidano there is no direct evidence of Cambrian sediments[4]. The succession begins with a thick formation of volcanite and volcanoclastic or arkosic metasediments of pre-Caradocian age ('porphyroids'), overlain without perceptible unconformity by another thick series dated as Early Ordovician to Carboniferous.

The 'porphyroids' often form the base of the nappes in the central zone and are frequently exposed from Gerrei to Sarcidano. It is a composite formation consisting of sometimes stratified detrital rocks characterized by quartz and, especially, feldspar 'eyes', which are sometimes as much as 10 cm long, with occasional siltite and quartzite intercalations. The origin of this formation still has not been clarified. It is likely that most of it is derived from acidic volcanites or the products of their subaerial reworking. Whatever the origin of this formation, it is lithologically strikingly similar to the Precambrian porphyroids ('Ollo de Sapo') exposed at the base of the Cambrian and the Lower Ordovician in central Spain (CAPDEVILA ET AL., 1964; PARGA-PONDAL ET AL., 1964; ANTHONIOZ & FERRAGNE, 1967; MATTE, 1968; HERNANDEZ ENRILE, 1971; BARD ET AL., 1972; FERRAGNE, 1972). Thus we feel justified in concluding that, like the analogous Spanish formations, it is older than the Cambrian.

In Sardinia, outcrops of the 'porphyroids' are almost entirely restricted to the area northeast of Campidano (COCOZZA & MINZONI, 1977) and they are overlain by formations attributed to the Early Ordovician.

The absence of the Cambrian in the Central zone may be attributed to the complete erosion of these sediments after the 'Sardinian phase', or else to a lack of deposition, throughout the whole Central zone as in the case of the epicontinental facies of the Lower and Middle Cambrian in Iglesiente (COCOZZA, 1979).

In the Grighini Mountains, the base of Palaeozoic succession consists of 'porphyroids' overlying orthogneiss and polymetamorphic garnetiferous micaschists. The contact between the 'porphyroids' and the underlying rocks is not tectonic (Fig. 1). This is the only point in the Central zone where the pre-Variscan basement may be exposed. The 'porphyroids' would seem to be confirmed as the 'basal conglomerate' of the Palaeozoic sequence by their position in this succession.

The Palaeozoic successions overlying the 'porphyroids' show clear traces of 'Caledonian movements' during the Ordovician: the pre-Caradocian sequences have a marked lateral variability both in facies and in thickness. The recognition of important nappe structures of eastern and northeastern provenance (CARMIGNANI & PERTUSATI, 1977; CARMIGNANI ET AL., 1978-a) has made possible a palaeogeographic reconstruction with a gradual transition into the post-Cambrian successions of Iglesiente-Sulcis. The highest tectonic units in the structural pile are of northeastern provenance and contain a much thicker Ordovician sequence than in the Southwestern zone (Iglesiente- Sulcis) (Fig. 1).

In these units the 'porphyroids' are overlain by alternating siltite, sandstone and quartzite attributable to the Ordovician partly by analogy with South-European formations such as the 'Armorican quartzites' of the Arenig and the '*Calymena tristani*-bearing slate' of the Llandeilo (SCHNEIDER, 1974-b)[4]. These formations may be more than 1000 m thick ('S. Vito sandstone' formation in southeastern Sardinia and the 'Solanas sandstone' formation in central Sardinia) and are overlain by thick formations of acidic and basic subaerial volcanites and products of their reworking.

In the structurally lower units, these formations are drastically reduced in thickness, and the Early Ordovician sandstones contain coarse-grained reddish particles that resemble the transgressive conglomerate overlying the Cambrian of Iglesiente. The volcanism of the Late Ordovician is represented only by thin layers of volcanoclasts, and a few small outcrops in northermost Iglesiente (COCOZZA & MINZONI, 1977).

All these successions pass up through levels of coarse quartzite and conglomerates into greywacke and olive-green siltite with Caradocian fossils, sometimes with encrinite lenses. The Caradocian sediments are particularly homogeneous throughout the Central zone.

The Silurian is represented by characteristic graptolite-bearing carbonaceous slate and limestone lenses with *Orthoceras*. The Devonian is usually marly at its base while the top is composed of *Clymenia*-bearing limestone laid down in continuous sedimentation lasting as late as the Tournaisian (OLIVIERI, 1970).

Even though the lateral variability of the Silurian-Devonian formations is much less pronounced than in the Ordovician ones, some distinctions can still be made. Silurian gabbro and basalt with alkaline continental affinity are found only in the northwesternmost side of the Central zone (RICCI & SABATINI, 1978). The Silurian-Devonian successions in this part are thicker and the limestone tends to disappear so that the succession becomes much less varied. One such sequence is at Nurra, where the Silurian-Devonian consists of a monotonous succession of phyllites.

In the environs of M. Gennargentu, a thick, detrital sequence without fossils overlies the youngest part of the above-described succession, sometimes with a tectonic contact (BOSELLINI & OGNIBEN, 1968). Here, as in the Southwestern zone, this formation is attributed to the early Middle Carboniferous and does not seem analogous to the Culm facies, which close the Variscan sedimentary cycle in other Mediterranean massifs (BOURROUILH, 1975).

The succession in the Northeastern zone

Our information on the original lithostratigraphic successions of the most metamorphic zone is far from complete. The outcrops of metamorphic rocks are isolated from the late-Variscan granitoids, and have often undergone contact metamorphism in addition to the intense regional metamorphism.

[4] While this paper was in print, Acritarchs were found in the 'Arenarie di S. Vito' in southeastern Sardinia; they are attributed to the Late (possibly Middle) Cambrian and the Early Ordovician (see Barca et al., in press).

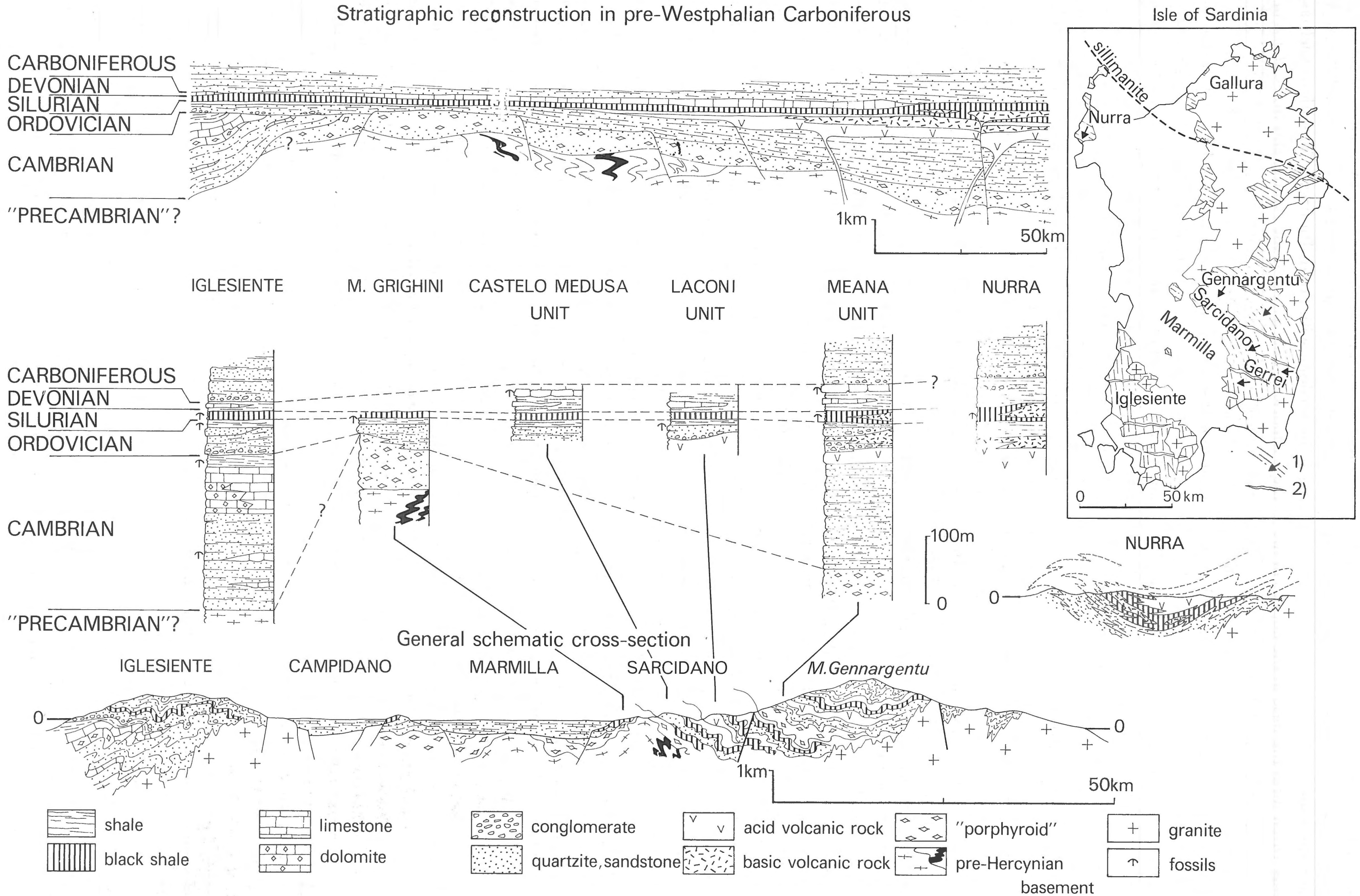

Fig. 1
Stratigraphic and structural schematic pattern of the Variscan cycle in Sardinia. 1 = Main fold axial traces and overturning direction of the first phase; 2= Fold axial traces of second phase.

According to the geological-petrographical map of the Sardinian crystalline basement (DI SIMPLICIO ET AL., 1975), two metamorphic complexes can be distinguished: one in its southwestern and the other in its northeastern part. Originally monotonous pelitic, psammo-pelitic or volcanic rocks were metamorphosed in the SW into an amphibolite facies, while along the northeastern coast of the island, metamorphism ranged from migmatite to amphibolite.

In the ultrametamorphic facies, relics of eclogites (MILLER ET AL., 1976) have been found and, most recently, granulites retrograde into amphibolite facies (GHEZZO ET AL., 1979). In Nurra it has been possible to ascertain that the metamorphism of amphibolite facies, characteristic of the Northeastern zone affects the same Palaeozoic successions that are exposed in the Central zone (CARMIGNANI ET AL., 1979). Therefore we consider it likely that most of the original pelitic or psammo-pelitic rocks, metamorphosed to an amphibolite facies, were derived from a Palaeozoic sequence that was probably monotonous but essentially coeval with that of the central zone. The presence of graphite, slate and marble also seems to confirm this assumption. In contrast, the metamorphic rocks with eclogite and granulite relics from the extreme northeast of the island may be remnants of a deeply reactived pre-Variscan basement.

Even though many problems remain unsolved, especially in the Northeastern zone, certain fundamental aspects of the Palaeozoic palaeogeography emerge from a comparison of the various successions (Fig. 1):

(1) The successions in the various zones can be compared only with regard to the Early Ordovician. The thick epicontinental Early and Middle Cambrian succession in Iglesiente probably corresponds to a hiatus lasting until the Early Ordovician.

(2) As early as the Early Ordovician the Central zone can be identified as an area with greater subsidence with thick deposits of sandstone, pelite and quartzite with a maximum thickness in the northeasternmost side.

(3) In the Central zone, the Late Ordovician is a period of particular instability evidenced by levels of conglomerates and substantial outflows of basic and acidic volcanites of which there are only slight traces in the Southwestern zone.

(4) The greater subsidence of the Northeastern zone continued in the Silurian and Devonian. The presence of basalt with continental alkaline affinity in the northeastern Silurian sediments of the Central zone indicates that in this period the continental crust was fracturing, thus forming an abortive rift where, in place of the *Clymenia*-bearing Devonian limestone of the more southwesterly zones, pelitic deposits were laid down (CIAMPI, 1913).

TECTONIC AND METAMORPHIC FRAMEWORK IN THE THREE ZONES

The Southwestern zone

It has long been known that the axis of the main Variscan tectonism in this zone runs roughly N-S and cuts across the earlier Caledonian folds running E-W (Sardinian phase) giving rise to typical 'dome and basin' structures (LAMARMORA DE FERRERO, 1857; GRAULICH, 1953; POLL & SWART, 1964; VALERA, 1967; BRUSCA & DESSAU, 1968; ARTHAUD, 1970; COCOZZA ET AL., 1974). According to CONTI ET AL. (1978) low regional metamorphism is present in the 'Cabitza slate' (Middle Cambrian) and not in the Early Ordovician sequences. According to some geologists the main (N-S) Variscan phase was preceded by weak folding along an E-W axis retracing the Caledonian structures, which was followed by a final weak folding phase with a NE-SW axis.

Regarded as a whole, Iglesiente and northern Sulcis are characterized by N-S folds that may be accompanied by fracture or strain-slip cleavage and rarely slaty cleavage. Nappe structures and important metamorphic recrystallization are lacking (ARTHAUD, 1970).

On the other hand, in southern Sulcis the Variscan cleavage becomes sub-horizontal and is associated with recumbent isoclinal folds (ARTHAUD, 1970). There is a larger degree of synkinematic recrystallization, which, however, never exceeds the greenschist facies.

A particular problem is posed by the rocks exposed at the base of the Lower Cambrian (Matoppa Member), near Capo Spartivento. In fact their microscopic fabric is complex: the Variscan schistosity refolds and transposes an older foliation. The age of the phase that produced these old deformations is unclear, though efforts are underway to solve the problem. However, since the 'Caledonian events' (Sardinian phase) that deformed the Cambrian sediments into gentle open folds with an E-W orientation seem to have produced an over-all shortening (ARTHAUD, 1970; SCHNEIDER, 1974-a), it is likely that the pre-Variscan foliation of the rocks underlying the fossiliferous Lower Cambrian (Punta Manna Member) is attributable to the Assyntic orogeny. In fact the presence of pebbles of orthogneiss in the conglomerate in the lower part of the sequence, near Capo Spartivento, probably indicate their proximity to the basal unconformity of the Palaeozoic succession of Iglesiente (COCOZZA & LEONE, 1977; COCOZZA, 1979).

The Central zone

Three Variscan deformational phases can be recognized in this area. The first produced sub-horizontal cleavage (S_1) and nappes; two later ones involved much less shortening.

Only the first phase is accompanied by synkinematic metamorphism, generally of greenschist facies, with biotite appearing in the deepest tectonic units[5]. This phase produced

[5] In the Grighini Mountains micaschists with garnets and staurolite are also present. These amphibolite-facies rocks are associated with orthogneiss and retrograde-metamorphic rocks in greenschist facies which, as mentioned above, may be a fragment of the old pre-Variscan basement.

synkinematic metamorphic isoclinal recumbent folds covering as much as several kilometres. While the folds in Gerrei run N-S, their direction is NW-SE in the centre and north of the island, thus displaying broad virgation (Fig. 1). The polarity of the sediments and the geometry of the folds indicate that the direction of overturning was towards the west or southwest. The most important structural lineaments are nappe structures of eastern or northeastern provenance. The superposition of three tectonic units which have been palaeontologically proven in Sarcidano (Central Sardinia) have their tectonic correlations in Gerrei, SE Sardinia (CARMIGNANI ET AL., 1978-a). The overthrusts run for tens of kilometres.

The emplacement of the allochthonous units in the more internal zones of the Central zone (Nurra) differs from that in the external zones (Sarcidano-Gerrei). In the external zone the overthrust surfaces are sub-parallel to the general allignment of the S_1, but cut across the folds of the first phase, and the basal cataclasites show an early schistosity. The grade of metamorphism sometimes increases abruptly as one moves down to the deeper tectonic units. Taken together, these facts suggest that at least part of the displacement occurred when most of the metamorphism was already accomplished, and that the tectonic superpositions represent a late development of the first phase. The more internal part of the Central zone displays a style characteristic of deeper structural levels. The nappe structures consist of large recumbent folds with their inverted limbs preserved; the displacement along the late sliding planes was much less important. A good example of this type of deformation is found in the central and southern zones of the metamorphic basement in Nurra (CARMIGNANI ET AL., 1979).

Throughout the Central zone, the folds and nappe structures of the first phase are refolded into antiforms and synforms (second phase) with axial directions ranging between E-W and N 140. Even though the shortening involved in the second phase is slight, the lineations, which are cartographically most evident NE of Campidano, are largely due to these antiforms and synforms. The largest structures, whose axial planes are, on the whole, sub-vertical are accompanied by minor structures (crenulations, kinks, chevron folds etc.) typical of late phases. Axial-plane cleavage (S_2) is of strain-slip or fracture cleavage type and is rarely associated with recrystallization.

The shortening in the third phase is negligible. It is evidenced mostly in the less competent rock by open folds or kinks that are spaced out and oriented N-S. These structures are always related to strike-slip fractures. The most important effect of this phase can be observed on the map: affecting the second-phase folds it produced axial depressions, in which the uppermost tectonic units are preserved, and culminations, in which the deepest and most metamorphic units are exposed.

The Northeastern zone

This is the zone with the highest-grade metamorphism and the most widespread granitization. Metamorphism remains low-grade (greenschist facies) up to the NW-SE line that crosses the entire island from the promontory of Stintino to Dorgali (the 'Stintino-Dorgali line'). To the northeast of this line, the metamorphism gradually increases, and biotite, garnet, kyanite-staurolite and sillimanite isograds succeed eachother rapidly (Fig. 1).

On the northeastern coast, migmatites and metabasites are also exposed. Whether or not the higher-pressure metamorphism of these rocks should be attributed to a pre-Variscan cycle will be discussed later. It is possible that all the other metamorphites are derived from Palaeozoic successions which underwent syntectonic Variscan metamorphism in amphibolite facies. The structural framework of this zone is still unclear both because of the high grade of metamorphism and the lack of continuity among these outcrops, which are often completely isolated by late-Variscan granitoid intrusions.

Usually the most evident foliation almost completely transposes an older schistosity, which can be distinguished only in thin sections. However, the presence of orthogneiss at the core of the recumbent folds testifies strong shearing with remobilization of the deep parts of the basement.

The metamorphic basement of Nurra (NW Sardinia) provides a significant example of the structural and metamorphic evolution of the Northeastern zone (CARMIGNANI ET AL., 1979). In fact, moving from the south to the north of this region, there is a progressive increase of the grade of metamorphism from the greenschist facies of the Central zone to the amphibolite facies typical of the Northeastern zone. The main characteristics of the first phase resemble those of the central zone: a tangential phase with isoclinal folds overturned towards SW. The relationship between crystallization and deformation shows that a syntectonic crystallization never exceeding the greenschist facies is ubiquitous.

The amphibolite facies was attained in northern Nurra during an episode of static recrystallization after the first-phase deformation. This period was responsible for the crystallization of the plagioclase which is the most striking mark of metamorphism ('gneiss di Stintino').

In comparison with the Central zone, the most important structural differences are the effects of the second phase. Moving northward, the second-phase deformation gradually becomes more and more intense, until the folds are isoclinal and recumbent. At the northern tip of Nurra the S_2 is the most evident schistosity and is accompanied by syntectonic recrystallization of biotite. Thus, in addition to the difference in metamorphic grade, it would seem that the following differences exist between the Central and Northeastern zones:

(1) In the Central zone the higher-grade metamorphism occurs during the first phase, while in the Northeastern zone it is later than the first phase.

(2) In the Northeastern zone the second phase also involves a great shortening, which is evidenced by isoclinal folds and pervasive cleavage that often eradicates all traces of older deformations. Thus the northeasternmost zone has a Variscan metamorphic history and a deformational evolution that is more complex with two important tangential phases. This makes the reconstruction of its overall geometry and the succession of its tectonic phases difficult. Undoubtedly the deepest part of the belt is exposed in this area.

From the above discussion it is evident that there is a clearcut contrast between an external domain (Iglesiente), with slight shortening and metamorphism, and a more metamorphic internal domain where shortening was presumably higher. The Central zone forms an area of intermediate structural and metamorphic characteristics.

At present definite proof that the Variscan deformation is coeval throughout the island is lacking. In the southwestern zone, the exact age of the last deformed sediment ('Postgotlandian') is unkwown, and stratigraphic data only restrict the orogeny to a time interval between the Tournaisian and the late Westphalian. ARTHAUD & MATTE (1977-a) propose a pre-Visean age for the orogeny in the internal zones and a post-Visean age in the external one throughout the segments of the Variscan belt around the north Balearic basin. But since radiometric ages of metamorphism in the Northeastern zone (441-300 Ma: FERRARA ET AL., 1978) agree with the stratigraphic data of the Southwestern zone, we prefer to consider the orogenic events in the various parts of the island as essentially coeval.

TWO UNSOLVED QUESTIONS

The existence of a pre-Variscan orogenic cycle accompanied by penetrative deformation and metamorphism in Sardinia is still under discussion. The 'porphyroids' underlying the Ordovician sequence in Central Sardinia can be taken as an indirect evidence of a previous Assyntic cycle. If the assignment of the 'porphyroids' to the Precambrian is correct, this thick series of volcanic, volcanoclastic and arkosic rocks must have been derived from the erosion of a Precambrian belt, together with products of postorogenic volcanism. In addition to the above-mentioned orthogneiss and micaschist of M. Grighini and the repeatedly deformed phyllites in Sulcis, the relicts of eclogitic and/or granulite facies assemblages in the northeastern coast may constitute direct evidence of a pre-Variscan basement. They underwent a higher-pressure metamorphism before the recrystallization into amphibolite facies typical of the Northeastern zone had occurred. Furthermore, their rare earth content proves their derivation from tholeiitic basalt, while the geochemical data available in the basic volcanites of the Palaeozoic indicate a continental alkaline affinity (RICCI & SABATINI, 1978). In the Assyntic massifs of eastern Galicia peridotite, gabbro and basic lava are found which underwent higher-pressure metamorphism previous to Variscan events (DEN TEX ET AL., 1972; ENGELS, 1972; ENGELS ET AL., 1974; DEN TEX, 1977).

For the present the possibility that the metamorphites in the northeasternmost part of Sardinia may also be derived from Palaeozoic successions recrystallized during distinct episodes of Variscan metamorphism cannot be excluded.

The other unsettled question regards the geodynamic significance of Ordovician and Silurian magmatic events. Whole-rock Rb/Sr isochron analyses yield an age of 442 ± 30 Ma for the granodioritic orthogneiss of Siniscola-Mamone (DI SIMPLICIO ET AL., 1975), recalculated on the basis of the new constants as 458 ± 31 Ma, and of 441 ± 33 Ma for the 'augengneiss' of rhyolitic composition of the same area (FERRARA ET AL., 1978). A slightly different radiometric age has been obtained for the orthogneiss at the opposite side of the island (Capo Spartivento): 413 ± 33 Ma (COCOZZA ET AL., 1977), recalculated by FERRARA ET AL. (1978) as 427 ± 34 Ma. According to various authors (GHEZZO & RICCI, 1970; DI SIMPLICIO ET AL., 1975; GHEZZO & RICCI, 1977; FERRARA ET AL., 1978), these acidic magmatic products together with the volcanism of the Late Ordovician suggest a late-orogenic magmatic-anatectic association of the Caledonian cycle. However, the main obstacle in accepting this interpretation lies in the absence of major tectonism in 'Caledonian times'.

(1) In the Ordovician sediments there is no penetrative deformation previous to the Variscan folding (CARMIGNANI & PERTUSATI, 1977). We maintain that the Ordovician deformations, which are attested to by the sudden variations in thickness of the succession or by conglomerate levels, consisted of vertical displacements probably associated with tensional tectonics (CARMIGNANI ET AL., 1978-a).

(2) In the Cambrian sediments of Iglesiente too, the main deformations are attributable to the Variscan cycle. The deformations here of the 'Sardinian phase' are, as throughout southwestern Europe, so slight, that SCHNEIDER (1974-a) has proposed to group them togheter under the term 'Sardinian movements'. On the other hand it is likely that this phase represents the end of the Assyntic orogenic cycle rather than the beginning of the Caledonian one (COCOZZA, 1969). In Spain too, the tectonic phase between the Cambrian and the Ordovician is considered to be the last, weak event of the Assyntic orogeny (CAPDEVILA, 1965).

(3) At present no proof of a Sardinian regional metamorphism definitely referable to the Caledonian orogenic cycle has been obtained, excepted for Iglesiente (CONTI ET AL., 1978).

The contrast between the conformity of the Ordovician-Silurian-Devonian succession, or even from the Cambrian through the Devonian, in the various Variscan massifs of southern Europe (ZWART, 1976) on the one hand, and the radiometric data substantiating the intrusion of granitoids and sometimes even the presence of metamorphism during the Ordovician and Silurian on the other hand, has been a matter of discussion throughout Europe for years (a bibliography for this question can be found in ZWART & DORNSIEPEN, 1978). In order to explain the abundance of granitoids and volcanites of anatectic-crustal origin during a non-orogenic period VAN CALSTEREN (1977) recently proposed a high heatflow regime in the mantle during the Caledonian. DEN TEX (1977) considers the calc-alkaline and hyperalkaline granitoids of Galicia (radiometric age ranging from 460 to 430 Ma) as originated by diapiric bodies moving up from the subcontinental mantle at a time of crustal tension.

In Sardinia too, the geological data indicate an analogous tensional phase during the Ordovician and Silurian, but, no orthogneiss derived from alkaline granitoid has yet been found, and the basic volcanism with continental alkaline affinity seems to be restricted to the Silurian (COCOZZA & MINZONI, 1977).

The geodynamic significance of the magmatism of the Late Ordovician should become clearer when research on trace elements like that done by RICCI & SABATINI (1978) on the Silurian metabasites will be extended to the whole Palaeozoic magmatism.

DISCUSSION AND CONCLUSIONS

Considering only Variscan events along a section running SW-NE, a tectono-metamorphic division into zones analogous to those of the 'alpine belt' can be made. In fact, the weakly metamorphosed Southwestern zone can be identified as a domain with structural characteristics of a foreland; the Central zone as an accumulation area of nappes originating more internally, and, lastly, the Northeastern zone as a granitized 'root zone', characterized by the superimposition of several metamorphic episodes. Furthermore, there seems to be a parallelism between post-Cambrian palaeogeographic domains and Variscan tectono-metamorphic zones.

An analogous situation is found in many south European Variscan massifs from the Maures massif to Spain, where important tangential tectonics have been described (DEMAY, 1952; GUITARD, 1960, 1964; ARTHAUD & MATTE, 1966, 1977-b; MATTE, 1968; ARTHAUD ET AL., 1969; ARTHAUD, 1970; WESTPHAL ET AL., 1976; etc.) as well as a certain parallelism between tectono-metamorphic lineaments and palaeogeographic zones (MATTE, 1968, 1976; ARTHAUD & MATTE, 1977-a).

The absence of ophiolite associations, the Ordovician acidic magmatism, that of the Silurian with continental alkaline affinity and the Variscan metamorphism of low or intermediate pressure (RICCI & SABATINI, 1978) and the abundance of late-tectonic granitoids have led to the long-established supposition that the Variscan orogeny in Sardinia involved only the continental crust. This entirely ensialic evolution is not necessarily in contrast to the structural style described here, and is analogous to that of collisional belts along continental margins.

In the Himalayas, the 'Main Central Thrust' and the 'Main Boundary Thrust' are respectively about 100 and 200 km away from the suture zone of the old continental margins showing that large shear zones can develop even within the continental crust. Recently many Cenozoic belts that mainly developed in the continental crust have been interpreted as mobile belts originating along prevailing simple shear zones and involving the entire thickness of the continental crust (HAYNES & MCQUILLAN, 1971; BIRD & TOKOSÖZ, 1975; LE FORT, 1975; PECHER, 1975; MATTAUER, 1975; MILNES, 1978; CARMIGNANI ET AL., 1978-b; KLIGFIELD, 1979; etc.).

This model has also been proposed for the Variscan belt of the French Central Massif (MATTAUER, 1974; CARME, 1974; MATTAUER & ETCHECOPAR, 1976), and we find this a satisfactory explanation of the structural style and zonality of the Variscan belt in Sardinia too.

The relationship between crystallization and deformation in the Northeastern zone seems to confirm this geodynamic model. In the basement of Nurra, the most intense metamorphism is attained after the end of the tangential tectonics of the first phase (CARMIGNANI ET AL., 1979). The thermal model proposed by BIRD & TOKOSÖZ (1975) for cases of overlapping continental crust, in addition to explaining the zones with inverted metamorphic gradient connected with the large Himalayan overthrusts (PECHER, 1975; LE FORT, 1976; THAKUR, 1977) and those recently reported by BRIAND (1978) and by BRIAND & GAY (1978) in the French Central Massif, offers a key for interpreting the time gap between crystallizations and tangential tectonics.

In fact, according to BIRD & TOKOSÖZ (1975), the subduction of the continental crust along a shear zone causes a downward inflexion of the isotherms in the subducted slab. In the subducted zone, the maximum metamorphism is reached only after the end of the main shortening phase when the negative thermal anomaly has been dissipated.

In our opinion the Northeastern zone of Sardinia represents the portion of the crust most deeply subducted along an intracontinental shear zone dipping towards the NE. This concept provides a coherent explanation for the nature of the overthrust, the style of the belt, the overall division into metamorphic zones, and the chronological relationship between crystallization and deformation.

The relationship between the tensional tectonics connected with the volcanism of alkaline continental affinity in the Silurian and the Hercynian structural lineaments has already been discussed by RICCI & SABATINI (1978).

We agree with these authors that the parallelism between Variscan structural lineaments and palaeogeographical zones may result from the evolution of the basement starting in Ordovician times. The greater thickness of the post-Cambrian successions in the internal zone, the thick intercalations of acidic and basic volcanites possibly accompanied by granitoid intrusions of the Late Ordovician, and lastly, the basalt with continental alkaline affinity of the Silurian suggest a long period of crustal thinning culminating in the formation of an 'abortive rift' in 'Caledonian times'. These zones of weakness in the crust may have been reactivated during the Variscan shortening, becoming the site of the shear zone. The belt could thus have been born and shaped along old palaeogeographical lineaments.

This type of evolution, as has already been mentioned, seems to be common to the South-European Variscan belts. The acidic and basic volcanism of the Ordovician and Silurian appears in many successions from the Maures Massif to the Iberian Meseta (MATTE, 1964; SAUPÉ; 1971; ROBERT & THIEBAUT, 1976; RICCI & SABATINI, 1978), and in some cases (BARD, 1977) an origin from intracontinental rifting is proposed. Tensional tectonics throughout Europe during 'Caledonian times' may have created zones with a thinned crust with complicated fault patterns. The reactivation of these weakened zones during compressional phases from the Devonian onwards may be an explanation of the intricate structural framework with narrow virgations and branching of the chain. Perhaps this is another reason for the difficulty of fitting the Variscan orogeny into classical schemes of plate tectonics, as is shown by the sometimes completely conflicting interpretations offered over the past years (BURRET, 1972; NICOLAS, 1972; LAURENT, 1972; BADHAM & HALLS, 1975; BOILLOT & CAPDEVILA, 1977; COGNE, 1977; etc).

ACKNOWLEDGEMENTS

This work has been supported by a grant of Progetto Finalizzato – Geodinamica, N. 309 and the 'Centro di Geologia strutturale e dinamica', CNR, Pisa.

REFERENCES

Alvarez, W. 1972 Rotation of the Corsica-Sardinia microplate – Nature Phys. Sci. 235: 103-105.

Anthonioz, P. M. & A. Ferragne 1967 Sur la présence d'orthogneiss en Galice moyenne (Nord-Ouest de l'Espagne) – C. R. Acad. Sci. Paris 265: 848-851.

Arthaud, F. 1970 Etude tectonique et microtectonique comparée de deux domaines hercyniens: les nappes de la Montagne Noire (France) et l'anticlinorium de l'Iglesiente (Sardaigne) – Publ. U.S.T.E.L.A. Sér. Géol. Struct. 1: 175 pp.

Arthaud, F., M. Mattauer & Ph. Matte 1969 La direction des plis couchés penniques de la phase majeure hercynienne et subméridienne dans les Cévennes méridionales – C. R. Acad. Sci. Paris 269: 556-559.

Arthaud, F. & Ph. Matte 1966 Contribution à l'étude des tectoniques superposées dans la chaîne hercynienne: étude microtectonique des séries metamorphiques du Massif des Maures (Var.) – C. R. Acad. Sci. Paris 262: 436-439.

——1975 Les décrochements tardi-hercyniens du Sud-ouest de l'Europe. Géométrie et essai de reconstitution des conditions de la déformation – Tectonophysics 24: 139-171.

——1977-a Synthèse provisoire sur l'évolution tectonique et les raccords entre les segments Hercyniens situés autour du bassin nord-Baléare (Sud de la France, Espagne, bloc corso-sarde) – Coll. int. CNRS (Rennes) 243: 497-513.

——1977-b Détermination de la position initiale de la Corse et de la Sardaigne à la fin de l'orogenèse hercynienne grâce aux marqueurs géologiques anté-mésozoïques – Bull. Soc. Géol. France 19: 833-840.

Badham, J. P. N. & C. Halls 1975 Microplate tectonics, oblique collision and evolution at the Hercynian orogenic systems – Geology 3: 373-376.

Barca, S., M. del Rio & P. Pittau (in press) Acritarchs in the 'Arenarie di S. Vito' of southeastern Sardinia: stratigraphical and geological implications – Boll. Soc. Geol. It.

Bard, J. P. 1977 Signification tectonique des métatholéïtes d'affinité abyssale de la ceinture métamorphique de basse pression d'Aracena (Huelva, Espagne) – Bull. Soc. Géol. France 19: 385-393.

Bard, J. P., R. Capdevila & Ph. Matte 1971 La structure de la Chaîne hercynienne de la Meseta Ibérique: comparaison avec les segments voisins. In: Histoire structurale du Golfe de Gascogne – Symp. I. F. P. – C.N.E.X.O. 1: 1-68.

Bard, J. P., R. Capdevila, Ph. Matte & A. Ribeiro 1972 Le Précambrien de la Meseta Ibérique. In: Actes du Colloque sur les corrélations du Précambrien (Agadir-Rabat, 1970) – Notes Mém. Serv. géol. Maroc 236: 315-335.

Bird, P. & M. Tokosöz 1975 Thermal and mechanical model of continent – continent convergences zones – J. Geophys. Res. 80: 4405-4416.

Boillot, G. & R. Capdevila 1977 The Pyrenees: subduction and collision? – Earth Planet. Sci. Lett. 35: 151-160.

Bosellini, A. & G. Ogniben 1968 Ricoprimenti ercinici nella Sardegna centrale – Ann. Univ. Ferrara, 1: 1-15.

Bouchez, J. L. & A. Pecher 1976 Plasticité du quartz et sens de cisaillement dans les quartzites du grand chevauchement central himalayen – Bull. Soc. Géol. France 18: 1377-1385.

Bourrouilh, R. 1975 Flysch dévonien et Culm de Minorque (Baléares, Espagne): essai de reconstitution des zones de dépôt et première comparaison avec le Sud-Ouest de la Sardaigne – IX^{e} Congr. Int. Sédiment. (Nice) 5: 97-101.

Briand, B. 1978 Métamorphisme inverse et chevauchement de 'type himalayen' dans la série de la vallée du Lot – C. R. Acad. Sci. Fr. 286 D: 729-731.

Briand, B. & M. Gay 1978 La série inverse de Saint-Geniez-d'Olt: évolution métamorphique et structurale – Bull. B.R.G.M. (2e serie) 1: 167-186.

Brusca, C. & G. Dessau 1968 I giacimenti piombo-zinciferi di S. Giovanni (Iglesias) nel quadro della geologia del Cambrico sardo – Industria Min. (ser. 2) 19: 470-494, 533-556, 597-609.

Burret, C. F. 1972 Plate tectonic and the Hercynian orogeny – Nature 239: 155-157.

Capdevila, R. 1965 Sur la géologie du Précambrien et du Paléozoique dans la région de Lugo et la question des plissements assyntiques et sardes en Espagne – Notas Comm. Inst. Geol. Min. España 80: 157-174.

Capdevila, R., Ph. Matte & I. Parga-Pondal 1964 Sur la présence d'une formation porphyroïde infracambrienne en Espagne – C. R. somm. S.G.F.: 249-250.

Carme, F. 1974 Idées nouvelles sur le style et l'ampleur de la tectonique hercynienne à la marge sud de la zone arverne (Massif Central) – C. R. Acad. Sci. Paris 278: 2613-2616.

Carmignani, L., T. Cocozza, N. Minzoni & P. C. Pertusati 1978-a The Hercynian orogenic revolution in Sardinia – Z. dt. geol. Ges. 129: 485-493.

Carmignani, L., M. Franceschelli, P. C. Pertusati & C. A. Ricci 1979 Evoluzione tettonico-metamorfica del basamento ercinico della Nurra (Sardegna NW) – Mem. Soc. Geol. It. 20: 57-84.

Carmignani, L., G. Giglia & R. Kligfield 1978-b Structural evolution of the Apuane Alps: an example of continental margin deformation in the Northern Apennines, Italy – J. Geol. 86: 487-504.

Carmignani, L. & P. C. Pertusati 1977 Analisi strutturale di un segmento della catena ercinica: Il Gerrei (Sardegna) – Boll. Soc.

Geol. It. 96: 339-364.
Ciampi, A. 1913 Fossili della Nurra – Ass. Min. Sarda 18 (7): 7-9.
Cocozza, T. 1969 Slumping e brecce intraformazionali nel Cambriano medio della Sardegna – Boll. Soc. Geol. It. 88: 71-80.
——1979 The Cambrian of Sardinia – Mem. Soc. Geol. It. 20: 163-187.
Cocozza, T., L. Conti, D. Cozzupoli, G. Lombardi, S. Scharbert & G. Traversa 1977 Rb/Sr age and geo-petrologic evolution of crystalline rocks in southern Sulcis (Sardinia) – N. Jb. Geol. Paläont. Mh. 2: 95-102.
Cocozza, T., A. Jacobacci, R. Nardi & I. Salvadori 1974 Schema stratigrafico-strutturale del massiccio sardo-corso e minerogenesi della Sardegna – Mem. Soc. Geol. It. 13: 85-186.
Cocozza, T. & F. Leone 1977 Sintesi della successione stratigrafico paleozoica della Sardegna sud-occidentale In: Escursione in Sardegna 1977 – G.B. VAI GLP 2-1977 Suppl.: 15-23.
Cocozza, T. & N. Minzoni 1977 Osservazioni sul vulcanismo paleozoico sardo. In: Escursione in Sardegna 1977 – G. B. VAI GLP 2-1977 Suppl.: 25-29.
Cogné, J. 1977 La chaîne hercynienne ouest-européenne correspond-elle à un orogène par collision? Proposition pour une interpretation géodinamique globale. Ecologie et géologie de l'Himalaya – Coll. int. CNRS 268: 111-129.
Conti, L., B. Di Sabatino, G. Negretti & R. Tucci 1978 Aspetti petrografici comparativi tra gli scisti di Cabitza (Cambrico medio) e le sequenze dell Ordoviciano inferiore (Sardegna meridionale) – Period. Mineral. 47: 73-81.
Del Moro, A., P. Di Simplicio, C. Ghezzo, G. Guasparri, F. Rita & G. Sabatini 1975 Radiometric data and intrusive sequence in the Sardinian Batholith – N. Jb. Miner. Abh. 126: 28-44.
Demay, A. 1952 Sur les relations stratigraphiques structurales et magmatiques entre le Massif Central Français et l'Armorique méridionale – C.R. Int. Geol. Congr. 13: 52-62.
Den Tex, E. 1977 Le socle poly-cyclique et son rôle dans l'évolution de la chaîne varisique en Galice (Espagne du NW) In: La chaîne varisque d'Europe moyenne et occidentale – Coll. int. CNRS (Rennes) 243: 441-451.
Den Tex, E., J. P. Engels & D. E. Vogel 1972 A high pressure-intermediate temperature facies series in the Precambrian et Cabo-Ortegal (Northwest Spain) – 24th Int. Geol. Congr. (Montreal) Sect. Rept. 2: 64-73.
Di Simplicio, P., G. Ferrara, C. Ghezzo, G. Guasparri, R. Pellizer, C. A. Ricci, F. Rita & G. Sabatini 1975 Il metamorfismo e il magmatismo paleozoico nella Sardegna – Rend. Soc Ital. Miner. Petrol. 30: 979-1068.
Engels, J. P. 1972 The catazonal polymetamorphic rocks at Cabo Ortegal (NW Spain). A structural and petrofabric study – Leidse Geol. Meded. 48: 83-133.
Engels, J. P., J. J. M. W. Hubregtse, P. Floor & E. Den Tex 1974 Precambrian complex in the Hercynian Orogen of the Northwestern Iberian peninsula – Progr. Conf. Int. Corrél. Géol. Précambrien des zones mobiles de l'Europe (Liblice, 1972): 163-174.
Ferragne, A. 1972 Le Précambrien et le Paleozoïque de la province d'Orense (nord-ouest de l'Espagne), Stratigraphie – Tectonique – Métamorphisme – Thèse doct. Univ. Bordeaux: 249 pp.
Ferrara, G., C. A. Ricci & F. Rita 1978 Isotopic ages and tectonometamorphic history of the metamorphic basement of North-Eastern Sardinia – Contrib. Mineral. Petrol. 68: 99-106.
Ghezzo, C., I. Memmi & C. A. Ricci 1979 Un evento granulitico nel basamento metamorfico della Sardegna nord-orientale – Mem. Soc. Geol. It. 20: 23-38.
Ghezzo, C. & C. A. Ricci 1970 Relazioni fra rocce granitiche e metamorfiche nella Sardegna centro-settentrionale. Nota II – I porfiroidi della regione Bolotona – Illorai – Rend. Soc. It. Miner. Petrol. 26: 109-146.
——1977 Aspetti petrologici del basamento cristallino della Sardegna. In: Escursione in Sardegna 1977 – G. B. VAI GLP 2-1977 Suppl.: 41-51.
Graulich, J. M. 1953 Osservazioni sulla scistosità nei terreni paleozoici dell'Iglesiente (Sardegna). Significato dell'anagenite – Boll. Soc. Geol. It. 72: 3-6.
Guitard, G. 1960 Linéations, schistosités et phases de plissement durant l'orogenèse hercynienne dans les terrains anciens des Pyrénées orientales – Bull. Soc. Géol. France 2: 862-887.
——1964 Un exemple de structure en nappe de style pennique dans la chaîne hercynienne: le gneiss stratoïdes du Canigou (Pyrénées orientales) – C.R. Acad. Sci. Paris 258: 4597-4599.
Haynes, S. & H. McQuillan 1971 Evolution of the Zagros suture zone, Southern Iran – Geol. Soc. Amer. Bull. 85: 739-744.
Hernandez Enrile, J. L. 1971 La rocas porfiroides del limite Cambrico- Precambrico en el flanco meridional del anticlinorio Olivenza-Monesterio (Badagoz) – Bol. Geol. Miner 82-84: 359-370.
Kligfield, R. 1979 The Northern Apennines as a collisional orogen – Amer. J. Sci (in press).
Laurent, K. 1972 The Hercynides of South Europe, a model – 24th Int. Geol. Congr. (Montreal) 3: 363-370.
Lamarmora de Ferrero, A. 1857 Viaggio in Sardegna III: Descrizione geologica – Ediz. il Nuraghe (Cagliari, 1927).
Le Fort, P. 1975 Himalayas: the collided range. Present knowledge of the continental arc. – Amer J. Sci. 275-A: 1-44.
——1976 A thermal model of intracontinental subduction. Explanation of the Himalayan inverted metamorphism – Atti dei convegni dell'Acc. nazionale dei Lincei, 21.
Mattauer, M. 1974 Existe-t-il des chevauchements de type himalayen dans la chaîne hercynienne du Sud de la France? – Rév. Ann. Sci. Terre: 279.
——1975 Sur le mécanisme de formation de la schistosité dans l'Himalaya – Earth Planet. Sci. Letters 28: 144-154.
Mattauer, M. & A. Etchecopar 1976 Argument en faveur de chevauchements de type himalayen dans la chaîne hercynienne du Massif central français. In: Ecologie et géologie de l'Himalaya – Coll. Int. CNRS 268.
Matte, Ph. 1964 Sur le volcanisme silurien du synclinal de Truchas (NW de l'Espagne) – C.R. Somm. Soc. Géol. France 2: 57-58.
——1968 La structure de la virgation hercynienne de Galice (Espagne) – Géol. Alpine 44: 157-280.
——1976 Raccord des segments hercyniens d'Europe sud-occidentale. In: Beiträge zur Kenntnis der europäischen Varisziden (Franz-Kossmat Symposium) – Nova Acta Leopoldina 45: 239-262.
Miller, C., F. P. Sassi & G. Armari 1976 On the occurrence of altered eclogite rocks in north-eastern Sardinia and their implications – N. Jb. Geol. Paläont. Mh. 11: 683-689.
Milnes, A. G. 1978 Structural zones and continental collision, Central Alps – Tectonophysics 47: 364-392.
Nicolas, A. 1972 Was the Hercynian orogenic belt of Europe of the Andean type? – Nature 236: 221-223.
Olivieri, R. 1970 Conodonti e zonatura del Devoniano superiore e riconoscimento di Carbonifero inferiore nei calcari di Corona Mizziu (Gerrei – Sardegna) – Boll. Soc. Paleont. It. 8: 63-152.
Parga-Pondal, I., Ph. Matte & R. Capdevila 1964 Introduction à la géologie de l' 'Ollo de Sapo' formation porphyroide antésilurienne du Nord-Ouest de l'Espagne – Not. Comm. Inst. Geol. Min. España 76: 119-153.
Pecher, A. 1975 The Main Central Thrust of the Nepal Himalaya and the related metamorphism in the Modi-Khola cross–section (Annapurna Range) – Himalayan Geol. 5: 115-131.
——1977 Geology of the Nepal Himalaya: deformation and petrography in the Main Central Thrust Zone. In: Ecologie et géologie de l'Himalaya – Coll. int. CNRS 268: 302-318.
Poll, I. J. H. & H. J. Zwart 1964 On the tectonics of the Sulcis area, Sardinia – Geol. Mijnbouw 43: 144-146.

Ricci, C. A. & G. Sabatini 1978 Petrogenetic affinity and geodynamic significance of metabasic rocks from Sardinia, Corsica and Provence – N. Jb. Mineral. Mh. 1: 23-38.

Robert, J. F. & J. Thiebaut 1976 Découverte d'un volcanisme acide dans le Caradoc de la région de Ribas de Freser (Province de Geronc) – C. R. Acad. Sci. Paris 282 D: 2049-2050.

Saupé, F. 1971 Stratigraphie et pétrographie du 'Quartzites du Criadero' (Valentien) à Almaden (Province de Ciudad Real, Espagne) – Colloque Ordovicien – Silurien – Mém. B.R.G.M. 73: 139-147.

Schneider, H. H. 1974-a Revision of the Lower Paleozoic in Sardinia especially of the Sardinian Conglomerate – N. Jb. Geol. Paläont. Abh. 146: 78-103.

——1974-b Lithostratigraphy of the San-Vito formation at San Nicolò Gerrei (SE – Sardinia) and some tectonic considerations on the Villasalto-Fault – Boll. Soc. Geol. It. 93: 927-936.

Thakur, V. C. 1977 Divergent isograds of metamorphism in some parts of the Higher Himalaya zone. In: Ecologie et géologie de l'Himalaya – Coll. int. CNRS 268: 433-441.

Vai, G. B. & T. Cocozza 1974 Il 'Postgotlandiano' sardo, Unità sinorogenetica ercinica – Boll. Soc. Geol. It. 92: 61-72.

Valera, R. 1967 Contributo alla conoscenza dell'evoluzione tettonica della Sardegna – Ass. Min. Sarda 72: 3-95.

Van Calsteren, P. W. C. 1977 A mantle plume model interpretation for the Paleozoic geology with emphasis on the Cabo Ortegal (NW Spain) – Proc. Kon. Ned. Akad. Wetensch. B 80: 156-168.

Westphal, M., J. Orsini & P. Vellutini 1976 Le microcontinent corsosarde, sa position initiale: données paléomagnétiques et raccords géologiques – Tectonophysics 30: 141-157.

Zwart, H. J. 1976 Relazione conclusiva (relazione ufficiale) – Mem. Soc. Geol. It. 13: 419-421.

Zwart, H. J. & U. F. Dornsiepen 1978 The tectonic framework of Central and Western Europe. In: A. J. van Loon (ed.): Keynotes of the MEGS-II (Amsterdam, 1978) – Geol. Mijnbouw 57: 627-654.