Editorial
Structure, Evolution, and Present Dynamics of the Calabrian Arc

The Calabrian Arc occupies a central and crucial position in the Mediterranean area. It is the threshold between two deep basins (Tyrrhenian and eastern Mediterranean) and connects the Apennine Chain to Maghrebian Chain of North Africa and Sicily.

The geologic structure of the Arc, as it has been progressively unveiled since the pioneering works of Novarese, Cortese, Limanowski, Quitzow, and the more recent studies by Italian, French, German, English, Dutch scientists, is extremely complicated. Most authors agree on the presence of a large number of nappes, usually thin skinned, made of rocks of various ages and nature and including also materials from deep crustal layers. Such framework is quite different from that of the adjacent southern Apenninic and Maghrebian Chains, deformed essentially in Neogene time, and indicates a great tectonic mobility of the area during the whole post-Cretaceous Alpine cycle.

Geological and geophysical evidence, moreover, point to a high tectonic activity of the area also in present times. Strong earthquakes (more than 100,000 persons were killed in 1908 by a large magnitude shock located in the Strait of Messina area), volcanic activity, large Pleistocene subsidence and uplift rates indicate the occurrence of peculiar tectonic mechanisms in this sector of the Mediterranean.

These aspects make the Calabrian Arc a sort of natural laboratory suitable for an integrated study of its geodynamic evolution and of the related environmental and social impact (seismic and volcanic risks, landslides prevention, mineral resources). A better understanding of the ongoing processes can only be achieved by coordinated studies of geologists, geophysicists, and geodesists.

Italy has produced a considerable effort in this direction during the past five years, thanks to the "Progetto Finalizzato Geodinamica" (1976–1981), funded by C. N. R. In addition, integrated Groups of research are still actively working in the area (Gruppo Arco Calabro-Peloritano), as are French and German Institutions.

This collection of original papers presents the most recent data and interpretations gathered on the geodynamic problems of the Calabrian Arc, mostly by Italian scientists. This should hopefully result in an up-to-date set of data and in a modern discussion of interpretations and of still open problems.

The first group of papers deals with the geological constitution of the arc. It includes the geological history, paleomagnetic data, and genetic aspects of the mineral resources of the region. Two papers deal with the Neogene evolution of the area and with the current tectonic activity both on land on the marine areas adjacent to the arc. The volcanic activity and products are then described in relation to tectonic processes. Neotectonic data are followed by some structural information on the Crust and upper Mantle, based on surface wave dispersion studies and on interpretation of gravity anomalies. There follows an analysis of seismicity – both in the Crust and in the Mantle – and of the regional stress field, as derived by seismological and geological data. The results of ten years of geodetical measurements within the most mobile portions of the arc are then discussed in relation to seismicity. The final paper attempts a review on the adequacy of the geodynamical models proposed so far for the Arc and discusses the problem of the driving forces of the tectonic processes.

It is our hope that this volume may give a general picture of the geodynamic problems of the Calabrian Arc, and may contribute to turn more scientists to the study of a region that has been fascinating and appealing since the blooming of the ancient greek civilisation, more than 2,000 years ago.

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Structure and Evolution of the Calabrian Arc

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Key Words

Calabrian Arc
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Abstract

The Calabrian Arc is a complex structure resulting from the progressive bending and splitting of a previous continent-continent collisional belt. Most of the units outcropping in northern and central Calabria represent the southward continuation of the eo-Alpine chain, constituted by ophiolite-bearing nappes of oceanic derivation and by crystalline nappes derived from the southern continental margin of the Tethys. The units forming the eastern Sila and the southern Peloritani mountains are considered as derived from a paleogeographic belt located between the Alpine and the Apenninic realms. The original position of the crystalline units forming the bulk of the Serre-Aspromonte-northern Peloritani region, on the contrary, is still unknown. The present dynamics of the Calabrian Arc is supposed to result from a passive sinking in the asthenosphere of a residual slab, an active spreading in the south-eastern Tyrrhenian Sea and from an increase in the bending of the arc, while the Europe-Africa collision is still persistent.

Introduction

The Calabrian Arc is an intriguing piece of the Mediterranean puzzle, representing a sort of "foreign" element set in the Apenninic Maghrebian scenery. The Appennines and the Maghrebides form two distinct segments (Scandone, 1979) of the Neogene Africa-verging chain mainly constituted by décollement nappes made up of Mesozoic and Tertiary sedimentary rocks. The Calabrian Arc, on the contrary, is chiefly constituted by pre-Triassic crystalline rocks partly affected by Alpine metamorphism (Fig. 1).

The geometric relationships between the crystalline masses of the Calabrian Arc and the sedimentary units of the Apennines and Maghrebides are quite complex. Two principal fault zones – the Sangineto and the Taormina lines – have been recognized at the northern and southern edges of the Calabrian Arc; they have been interpreted (Amodio Morelli et al., 1976) as transcurrent faults (respectively sinistral and dextral) which allowed differential movements towards east and south-east of the most convex part of the arc. In reality, the Sangineto line does not represent a deep-seated transcurrent fault, since the two highest Apenninic units crop out south of the line in several tectonic windows as far as the Catanzaro fault zone without showing a considerable offset with respect to the northern outcrops. Moreover, several Klippen of Calabrian units overlying the Apenninic nappes occur in Northern Calabria and Southern Lucania. On the other hand, it is a remarkable fact that very thick crystalline units widespread just south of the Sangineto line (Sila) are not at all represented north of this lineament.

In my opinion, the Sangineto line can be more likely interpreted as a fault with predominant dip-slip motion in the depth and strike-slip motion (tear in the Calabrian nappes) near the surface.

No data on the deep structure of the Taormina line are available; at the surface, the line corresponds to the front of the Calabria-Peloritani units thrust over a Cretaceous flysch sequence which in turn tectonically overlies the Sicilian Maghrebian nappes.

The crustal structure of the Calabrian Arc has been investigated by DSS experiments in 1970, 1972 and 1979 (Morelli et al., 1975; Schütte, 1978; Guerra et al., 1981). The data reveal crustal thicknesses of 35–40 km along the Ionian side of Calabria and of 20–25 km along the Tyrrhenian side; the identification in Central Calabria of two discontinuities marked by high velocities and high velocity gradients suggests a possible crustal doubling.

Central and Southern Calabria form a narrow bridge separating the Tyrrhenian from the Ionian sea. The Tyrrhenian Sea, interpreted as a Neogene oceanic basin, is characterized by high values of Bouguer gravity anomalies (250mgal), thinned crust and lithosphere (respectively 10–15km and 30km), high heat flow and anomalous seismic wave propagation, with attenuation of S waves in the mantle and crust. The crust of the Ionian area is still poorly known. High positive Bouguer anomalies (310mgal), low heat flow values and depths of about 4000 metres suggested the hypothesis of an ancient oceanic-type crust (Erikson et al., 1977) overlain by a thick sedimentary sequence (Hinz, 1974; Weigel, 1974; Giese and Morelli, 1975). Results of surface-wave dispersion, on the contrary, point to a continental structure (Farruggia and Panza, 1981; Mantovani and Boschi, this volume) with a crust 30–35km thick.

The Tyrrhenian border of the Calabrian Arc is characterized by the occurrence of intermediate and deep earthquakes suggesting the existence of a high velocity body in the mantle (Caputo et al., 1972). The existence of a Benioff zone is also confirmed by the presence of Quaternary, still active, calc-alkaline volcanoes in the Aeolian Islands. The reloca-

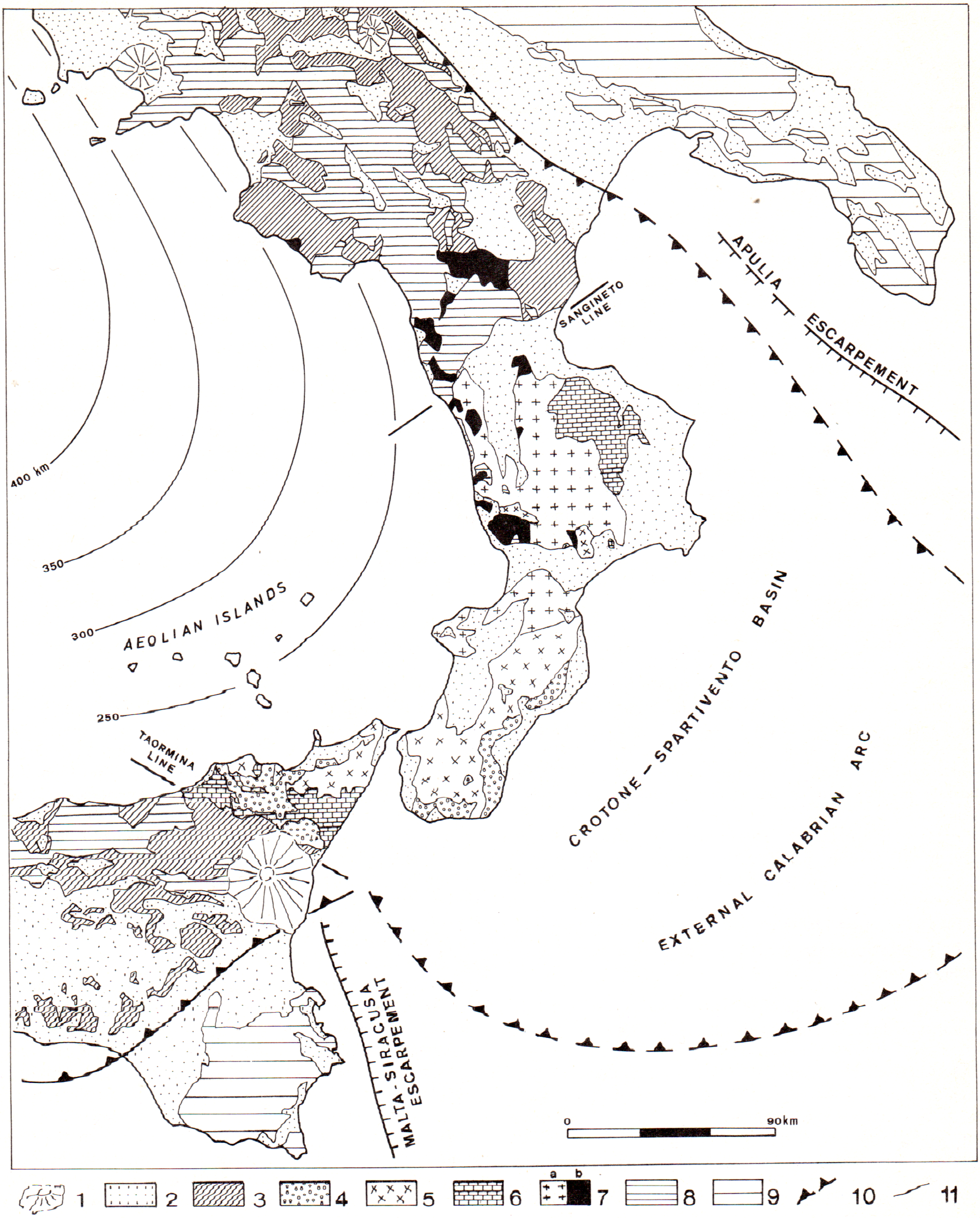

Fig. 1
Structural sketch of the Calabrian Arc. **1** main Quaternary volcanoes on land; **2** uppermost Miocene-Quaternary deposits; **3** Cretaceous-Eocene flysch (Sicilide and Cilento units); **4** uppermost Oligocene-lowermost Miocene terrigenous deposits of Serre-Aspromonte-Peloritani); **5** crystalline units of Serre-Aspromonte-Peloritani (including the Stilo sequence); **6** Longobucco and Longi-Taormina units; **7** Calabrian Alpine units (**7a** Austroalpine nappes; **7b** Penninic and Ligurian ophiolite-bearing nappes); **8** Apenninic and Maghrebian units; **9** Mesozoic-Tertiary deposits of the Apulia and Southern Sicily foreland; **10** front of the Pliocene compression; **11** isobaths of the subducted lithosphere beneath the Tyrrhenian Sea.

tion of deep earthquake hypocentres by the JHD method (Gasparini et al., 1982) allowed a quite detailed reconstruction of the isobaths of the subducted slab. The latter dips towards the Tyrrhenian Abyssal Plain following the bending of the arc, with concentration of earthquake energy in the area of maximum concavity and at a depth of 250–340 kilometres. Fault plane solutions show predominant down-dip compression in the most concave part of the slab and strike-slip motions in the northern and southern parts. Along the Ionian border of Calabria crustal earthquakes show focal mechanisms with horizontal P axes directed normally to the trend of the arc. A compressional pattern in the north-eastern Ionian Sea has also been recognized in the External Calabrian Arc, a complex structure characterized by very recent thrusts, reverse faults and gravity flows. (Rossi and Sartori, 1981; Barone et al., this volume).

The main problems concerning the Calabrian Arc can be summarized in a set of questions. The principal ones, in my opinion, are the following:

– what do the crystalline units of the Calabrian Arc represent in reality? How are they geometrically arranged and which relationships occur between them and the Apenninic-Maghrebian units?

– which is the most reliable palinspastic restoration of the Calabrian paleogeographic domains during Alpine times? What is the meaning and which was the original location of the Cretaceous-Eocene flysch sequences (Sicilide and Cilento nappes) which widely crop out in Northern Calabria-Southern Lucania and in North-Eastern Sicily?

– does the shape of the arc result from the bending of a previous straight segment, involving lithospheric distortion, or is it the inheritance of primary paleogeographic features? Does an active Benioff zone actually exist beneath the Calabrian Arc? Which relationships do exist between the surface geology, the crustal structure and the lithospheric one?

We are able to answer satisfactorily only few questions, which reduce only partially the freedoms of the system. Consequently, a wide space is still left for interpretation.

The Crystalline Units of Calabria-Peloritani and Their Relationships with the Apennines and the Maghrebides

Leaving out the obsolete interpretation of the Calabria-Peloritani belt as an authochtonous crystalline massif, (Cortese, 1895; De Lorenzo, 1896), I would like to mention here Lugeon and Argand (1906) who were pioneers of the nappe theory in the region. The major evidence for nappe identification was the occurrence of granites and high grade metamorphites geometrically overlying slightly metamorphosed metapelites in Central Calabria (Coastal Range and Sila).

For many years the Calabria-Peloritani belt was considered the "African front" (Staub, 1951) overthrust on the Southern Apennines; the latter were considered a slightly deformed part of the mythical Mesogeide. Severe crustal shortening should have been responsible for the "squeezing" of an oceanic area located further south of Sangineto which divided the Mesogeide realms from the African craton (Glangeaud, 1951). Dubois (1976) is the last supporter of this theory.

There exists today a large agreement among the authors (Dietrich and Scandone, 1972; Alvarez et al., 1974; Amodio Morelli et al., 1976) that at least a part of the Calabrian Arc is a fragment of the Cretaceous-Paleogene Europe-verging Alpine chain which overthrust *in toto* over the Apennines during Early Miocene times. This hypothesis was clearly expressed for the first time by Haccard, Lorenz and Grandjacquet in 1972. Strong disagreements concern the kinematic model; I shall discuss the main points in next pages.

Analyzing the Calabrian units we must divide the Calabria-Peloritani belt in two sectors: a northern sector which extends southwards to the northern margin of the Serra S. Bruno, and a southern one which includes the greatest part of the Serre, Aspromonte and Peloritani mountains.

Most of the rock units present in the northern sector are strictly comparable to the eo-Alpine units of the Western Alps and north-eastern Corsica. They can be divided in two groups:

– a lower group, consisting of Cretaceous terrigenous deposits and of Jurassic ophiolites with their sedimentary cover;

– an upper group, consisting of plutonites and several types of metamorphites (deriving from a pre-Alpine crystalline basement) with or without a Mesozoic sedimentary cover.

Both groups of units are affected by Alpine metamorphism. The geometrical relationships among the different units are schematically given in Fig. 2. Table I summarizes the main characteristics of the recognized units. The lower group has been correlated with the Penninic and Ligurian units of the Western Alps and Northern Apennines (Frido unit = (?) pre-Piedmontese units; Diamante-Terranova U. = HP/LT Piedmontese ophiolitic units; Gimigliano and Malvito units = metamorphosed and unmetamorphosed Ligurian ophiolitic units). The upper group has been correlated with the Austroalpine nappes of the Western Alps (markedly, Polia-Copanello Unit = "II Dioritic-kinzigitic zone" and Valpelline "series").

Along the Ionian side of Central Calabria is widely developed an other tectonic unit (the Longobucco unit) whose relationships with the Calabrian Alpine nappes and with the Apenninic ones are not wholly clarified. This unit consists of Hercynian low-grade metamorphites and intrusive granitic rocks unconformably overlain by Mesozoic-Tertiary deposits not affected by Alpine metamorphism. At least three subunits have been distinguished, which are separated by thrust contacts and are characterized by different sedimentary covers (Patacca and Scandone, unpublished data). The upper one shows continental quartz-conglomerates and quartzarenites grading upwards to shallow water limestones of lower Liassic age. The limestones, in turn, are overlain by marls and sandstones which form a turbiditic sequence up to 700 metres thick (middle Liassic). The sedimentary cover in the middle unit consists of bioclastic limestones (lower Liassic) followed by condensed pelagic

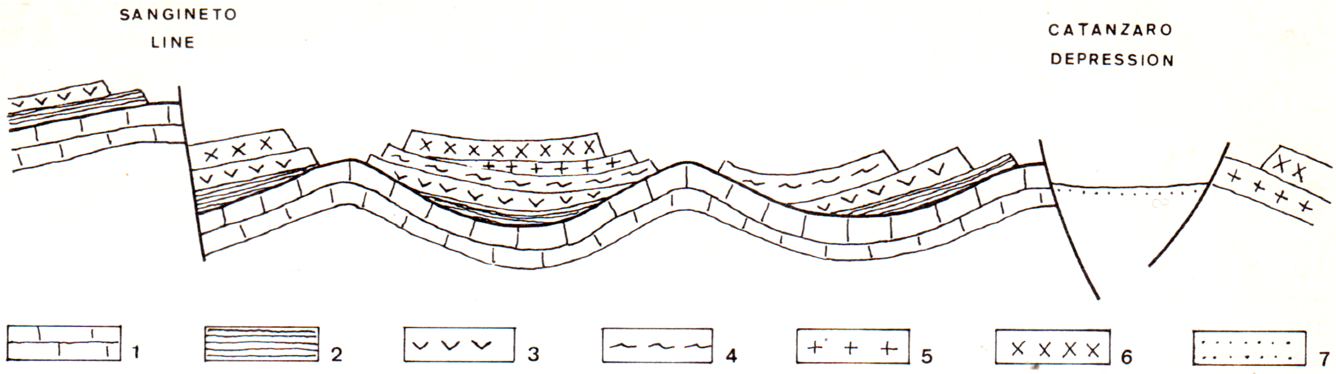

Fig. 2
Geometrical relationships among the Calabrian Alpine units in the Coastal Range. **1** Apenninic units; **2** Frido unit; **3** ophiolitic units; **4** Bagni unit; **5** Castagna unit; **6** Polia-Copanello unit; **7** Neogene and Quaternary deposits of the Catanzaro depression.

Table I: Main characteristics of the Alpine and Apenninic units in the Calabrian Coastal Range. After Amodio Morelli et al. (1976), slightly modified.

<table>
<tr><td rowspan="5">Alpine Units</td><td colspan="3">Polia-Copanello Unit
Lithology: biotite-garnet gneisses with sillimanite and cordierite, metabasites and subordinate peridotites, marbles
Thickness: several hundred metres
Metamorphism: pre-Alpine amphibolite-granulite facies; subordinate Alpine overprint indicative of moderately high pressure (lawsonite)</td></tr>
<tr><td rowspan="2">Malvito Unit
Sequence: slightly metamorphosed Calpionella limestones and radiolarian cherts; metabasites, gabbros and serpentinites
Age of the sequence: Jurassic-Lower Cretaceous
Max. thickness: 350 m
Metamorphism: from prehnite-pumpellyite facies to albite-lawsonite facies</td><td rowspan="2">?</td><td>Castagna Unit
Lithology: gneisses and migmatites; micaschists
Max. thickness: around 700 m
Metamorphism: from greenschists to amphibolite facies (pre-Alpine), with Alpine overprint indicative of HP/LT (glaucophane and lawsonite)</td></tr>
<tr><td>Bagni Unit
Sequence: crystalline limestones, cherts and metapelites; metaconglomerates and quartzites unconformably overlying metapsammites and phyllites with occasional intercalations of volcanites
Age of the sequence: Hercynian basement and Triassic-L. Cretaceous sedimentary cover
Max. thickness: several hundred metres
Metamorphism: low-grade of the greenschist facies (Hercynian metamorphism); Alpine overprint indicative of moderately high pressure (lawsonite)</td></tr>
<tr><td>Diamante-Terranova Unit
Sequence: calcareous schists and phyllites; metabasites, serpentinites
Age of the sequence: Jurassic-Lower Cretaceous
Max. thickness: 200–250 m
Metamorphism: blueschist facies with superimposed greenschist facies</td><td>?</td><td>Gimigliano Unit
Sequence: metapelites, quartzites and crystalline limestones; metabasites and serpentinites
Age of the sequence: Jurassic-L. Cretaceous
Max. thickness: around 500 m
Metamorphism: low-grade of the greenschist facies with relics of a HP/LT event (glaucophane and lawsonite)</td></tr>
<tr><td colspan="3">Frido Unit
Sequence: slates and subordinate limestones, quartzites
Age of the sequence: Upper Cretaceous
Thickness: some hundred metres
Metamorphism: very low-grade of the greenschist facies, at the boundary with the diagenesis</td></tr>
<tr><td rowspan="2">Apenninic Units</td><td colspan="3">Verbicaro Unit
Sequence: slightly metamorphosed cherty limestones and breccias; dolomites. Locally mafic lavas
Age of the sequence: Upper Triassic-Lower Miocene
Max. thickness: 1500 m
Metamorphism: very low-grade of the greenschist facies, with moderate effects of high pressure
Age of the metamorphism: Lower Miocene (Burdigalian)</td></tr>
<tr><td colspan="3">S. Donato Unit
Sequence: crystalline limestones, dolomites and evaporites; phyllites with intercalations of metalimestones and occasional mafic lavas
Age of the sequence: Middle Triassic-Lower Miocene
Max. thickness: 1500–2000 m
Metamorphism: low-grade of the greenschist facies
Age of the metamorphism: Lower Miocene (Burdigalian-Langhian)</td></tr>
</table>

deposits of middle Liassic-Lower Cretaceous age (ammonite bearing nodular limestones, red marls with pelagic bivalves, radiolarites and Calpionella limestones). The lower sub-unit shows a condensed sequence similar to the previous one, but including also Eocene red marls with globigerinids. The succession ends with terrigenous deposits of Eocene age representing a typical wildflysch with blocks of radiolarites, Calpionella limestones and red marls. It is interesting to remark the occurrence in the terrigenous sequence of andesitic products testifying a calc-alkaline volcanic activity coheval with the deposition of the wild-flysch (Zuffa and De Rosa, 1978).

The pile of the Calabrian Alpine nappes grows thinner and thinner towards the north; in northern Calabria-Southern Lucania it is reduced to small lenticular bodies of metapelites and quartzites, ophiolites and high grade metamorphites tectonically overlying the Apenninic units and underlying a Cretaceous-Eocene allochthonous flysch (Cilento unit). In the south, on the contrary, the Calabrian Alpine nappes reach some thousand metres in thickness, but just north of Serra S. Bruno they abruptly disappear below (and against?) the crystalline units of the Serre-Aspromonte region (southern sector of the Calabrian Arc). The relationships between the Calabrian Alpine nappes and the crystalline units of Southern Calabria-Northern Peloritani need to be investigated more in detail. The whole southern sector of the Calabrian Arc, moreover, still remains an unsolved problem. The southern margin of the Peloritani mountains is constituted by a number of thrust sheets (Longi Taormina unit) made up of Hercynian low grade metamorphites unconformably overlain by Mesozoic-Tertiary sediments comparable to those of the Longobucco unit. The main difference is represented by the absence of Eocene wild-flysch deposits, being the uppermost part of the sequence in this region constituted by marls and siltstones attributed to the uppermost Eocene-lowermost Oligocene.

In the Southern Peloritani mountains, the Longi-Taormina unit is thrust over a Cretaceous allochthonous flysch (Monte Soro Unit), while in the north it is tectonically covered by high-grade Hercynian metamorphites showing no Alpine metamorphic overprint.

The Serre-Aspromonte-Northern Peloritani region is chiefly constituted by pre-Triassic crystalline rocks including low-grade to high-grade metamorphites, as well as plutonites mainly developed in the northern part of the area. A Mesozoic sedimentary cover is well exposed along the south-eastern flank of the Serre. The sequence consists of Jurassic and Cretaceous shallow-water carbonates unconformably over-lying slightly metamorphosed nodular limestones and metapelites of Devonian age which have been intruded by Carboniferous granites (Stilo sequence). Small outcrops of Mesozoic limestones strictly comparable with those of the Stilo sequence have also been recognized in southern Aspromonte between Capo dell'Armi and Capo Spartivento. In Northern Calabria, several Klippen made up of pre-Triassic crystalline rocks and of Mesozoic-Tertiary deposits referable to the Stilo sequence overlie the Calabrian Alpine nappes just north of the Catanzaro depression. In southern Calabria the Paleozoic rocks of the Stilo sequence tectonically overlie gneisses and micaschists of amphibolite facies widely developed in the Aspromonte and Peloritani. A small tectonic window near Africo Vecchio revealed that the latter, in turn, tectonically cover low-grade metamorphites (Bonardi et al., 1979). Whether the Stilo sequence belongs to a tectonic unit of Alpine age distinct from the bulk of the Aspromonte-Northern Peloritani crystalline masses, and whether the latter represent a tectonic edifice built up during Hercynian times (Lorenzoni and Zanettin Lorenzoni, 1979) or during alpine times (Bonardi et al., 1979) is a controversial matter. Moreover, there is no general agreement among the authors (see Bonardi et al., 1979; Lorenzoni and Zanettin Lorenzoni, 1979; De Vivo et al., 1980) about the geometrical relationships among the different crystalline units.

According to Lorenzoni and Zanettin Lorenzoni (1979) the Aspromonte and the Eastern Sila form a single tectonic unit of Alpine age deriving from the deformation of a continuous Hercynian thrust belt. In my opinion there are no elements in the Alpine tectonic history of these regions which support such correlation founded only on striking similarities between some crystalline rocks in Sila and Aspromonte. What is sure, is that the Southern Calabria-Peloritani region constituted a unique undivided belt at the end of the Oligocene. All crystalline units, in fact, are stratigraphically overlain by Lower Miocene terrigenous deposits which crop out without interruption from Stilo to the Taormina line, suturing also the contact between the Northern Peloritani gneisses and the Longi-Taormina unit.

The terrigenous sequence is represented by Aquitanian coastal conglomerates and litharenites which grade upwards into turbiditic sandstones (Stilo-Capo d'Orlando Flysch) of Burdigalian-Langhian age (Bonardi et al., 1980). The top of the sequence is truncated by large slides of chaotic varicoloured clays containing olistolithes of Oligocene (?) quartzarenites strongly resembling the wellknown Numidian Flysch. No traces of this sequence are present in the area where the Longobucco unit crops out.

In conclusion, we may distinguish in the Calabria-Peloritani Arc four groups of units:

– Alpine nappes, exposed in Central and Northern Calabria. They extend southwards as far as the northern margin of the Serra S. Bruno;

– the Longobucco unit, cropping out in Eastern Sila and whose relationships with the Calabrian Alpine nappes need to be investigated more in detail;

– the Longi-Taormina unit, which is the lower tectonic element of the Peloritani mountains. This unit surely derives from the same paleogeographic realm of the Longobucco units; it is not clear whether the Longi-Taormina and the Longobucco units constitute a unique kinematic element or not;

– the Serre-Aspromonte-Northern Peloritani units, including the Stilo sequence, whose Alpine tectonic history before Oligocene is so poorly known that it is still an open question whether this structural edifice was piled up during Hercynian or during Alpine times.

Palinspastic Restoration

If we accept that at least a part of the Calabrian units belongs to the Europe-verging Alpine chain, we see clearly that the latter from Western Alps to Corsica, to Southern Italy appears split up, and the single fragments are separated by areas which have been oceanized during Tertiary times. We cannot explain a gap like the Tyrrhenian Sea admitting that it was formed in the wake of a small "Calabrian plate" as it moved south-eastwards from the Corsica-Sardinia border (Alvarez et al., 1974), since the Calabrian Alpine nappes overthrust the highest Apenninic units during Burdigalian times (Scandone, 1979), that is, before the opening of the Tyrrhenian basin. When we try to align northern Calabria with the Alpine nappes of eastern Corsica, closing the Tyrrhenian Sea, we are obliged to rotate the Italian peninsula clockwise and to shift Sicily westwards. A counter-clockwise rotation of the Italian peninsula is supported also by paleomagnetic results (see Manzoni and Vanderberg, this volume). If we assume a rotation pole further north of Elba Island, by smoothing out the Neogene compression we obtain the picture of Fig. 3 which seems to be quite consistent with the available geological information. Fig. 4 is a schematic palinspastic cross section from Sardinia to the Adria zone during Burdigalian.

In this reconstruction the Europe-verging Alpine chain was back-thrust towards the Apenninic domains during Eocene-Oligocene times, partially overriding the Longobucco unit. The latter overthrust the highest Apenninic units, together with the Alpine chain, during the Early Miocene.

The original domain of the Cilento Flysch and a part of the Sicilide units (Helmintoid flysch comparable with the calcareous flysch of the external Ligurides in the Northern Apennines) has been tentatively placed between the already built-up Alpine chain and the Longobucco domain. We cannot exclude, however, that a part of the Sicilide units derives from a belt located between the Longobucco domain and the Apenninic realms. The Longobucco domain is hypothetically correlated with the "Insubric Ridge" of the Northern Apennines (Elter et al., 1966; Baldacci et al., 1972).

The picture is more confused in the southern sector of the arc, where the palinspastic relationships between the basin of the Monte Soro Flysch and the Longi-Taormina domain are not yet solved. Moreover, the original position of the Northern Peloritani-Aspromonte crystalline units, as well as that of the Stilo sequence, are presently unknown. We can only say that the Northern Peloritani crystalline nappes overthrust the Longi-Taormina unit before the end of the Oligocene; both groups of units were finally tectonically transported over the Maghrebian Numidian Flysch during the Early Miocene, together with the Monte Soro Flysch and the other Sicilide units.

I must underline here that no systematic work has been carried out as yet on the Monte Soro Flysch and, in general, on the Sicilide units. The latter, indeed, represent a real "rubbish-bin" where a lot of rock units have been discharged which have in reality different ages and different geological meaning.

Going back in time, additional complications occur, the first one being represented by the opening of the Western Mediterranean basin. Fig. 5 shows the trend of the Eocene Alpine chain obtained by a clockwise rotation of the Corsica-Sardinia "block" and by smoothing out the Oligocene and the Neogene deformation. A schematic palinspastic cross section at this time is given in Fig. 6. The HP/LT metamorphism in the Austroalpine Calabrian nappes should be related to the rapid burial of crustal slices during the active subduction of the African lithosphere, whose margin was consumed together with the Tethys ocean floor.

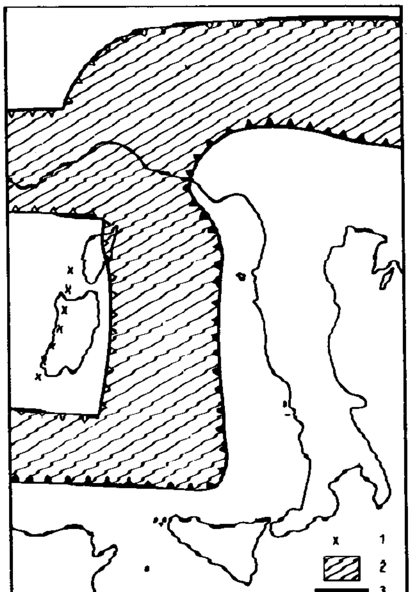

Fig. 3
Palinspastic restoration of the central Mediterranean area during Early Miocene (after Scandone, 1979). 1 Oligocene-lower Miocene calc-alkaline district of Western Sardinia; 2 nucleus of Paleogene deformation between the African and European forelands; 3 Front of the Europe-verging Paleogene-lower Miocene nappes; 4 front of the Africa-verging Paleogene-lower Miocene nappes.

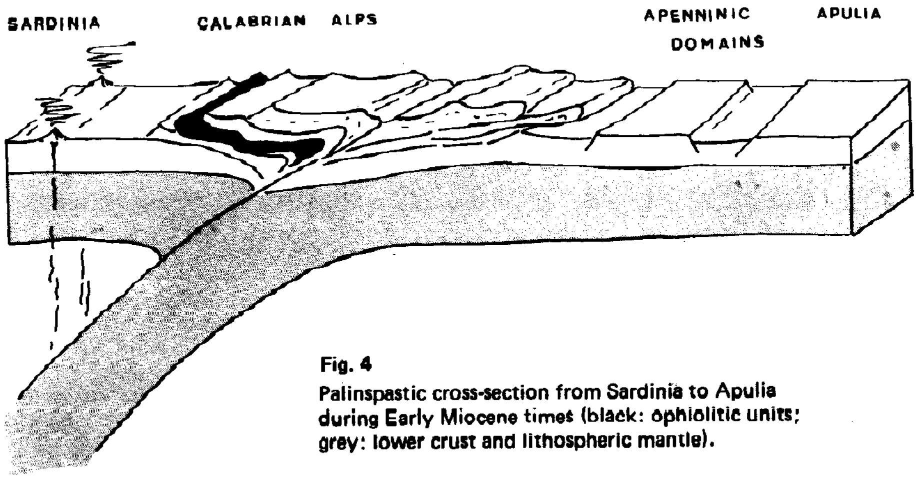

Fig. 4
Palinspastic cross-section from Sardinia to Apulia during Early Miocene times (black: ophiolitic units; grey: lower crust and lithospheric mantle).

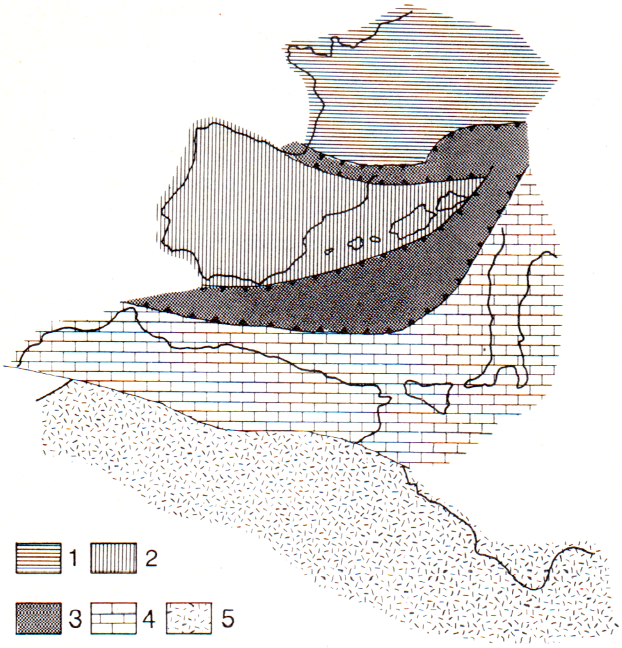

Fig. 5
Palinspastic restoration of the central and western Mediterranean area during Eocene. 1 „stable" Europe; 2 Iberian „microplate"; 3 deformed belts; 4 „mobile" part of the African continental margin; 5 „stable" Africa.

By removing the Alpine nappes we obtain the palinspastic reconstruction shown in Fig. 7, referred to the Jurassic-Cretaceous boundary.

It is interesting to underline that although the Jurassic Tethys was a kinematic counterpart of the Jurassic Southern Atlantic, the former was probably a narrower oceanic area, dissected by numerous fracture zones.

The paleogeographic pattern of the southern sector of the Calabrian Arc during late Jurassic-Early Cretaceous times is still obscure. The Longi-Taormina domain had to be connected with the Longobucco domain, and both had to be part of the African continental margin. The westwards continuation of this realm is well documented in the Kabylies. The original location of the northern Peloritani-Aspromonte-Serre crystalline units, on the contrary, as well as the location of the basin of the Monte Soro Flysch is an open problem. Amodio Morelli et al. (1976) proposed an European derivation for the Southern Calabria-Peloritani units. Indeed, I think that a rigid cilindrism must be taken with due caution, since the disappearance of the Alpine units, and in particular of the Jurassic ophiolites just south of Catanzaro could be interpreted as a consequence of a first-order kinematic boundary corresponding to the end of the Tethys ocean against the major transform fault.

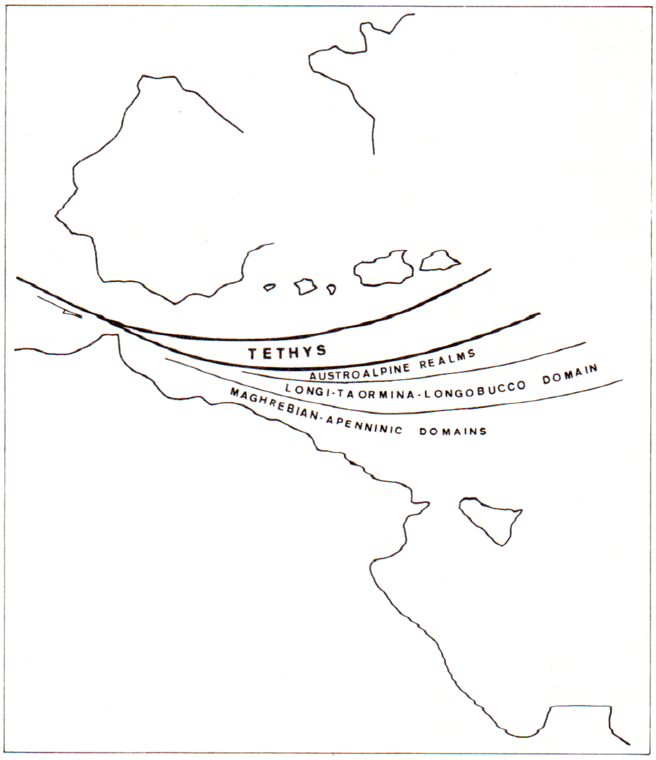

Fig. 7
Paleogeographic realms of the southern continental margin of Tethys during Late Jurassic-Early Cretaceous times.

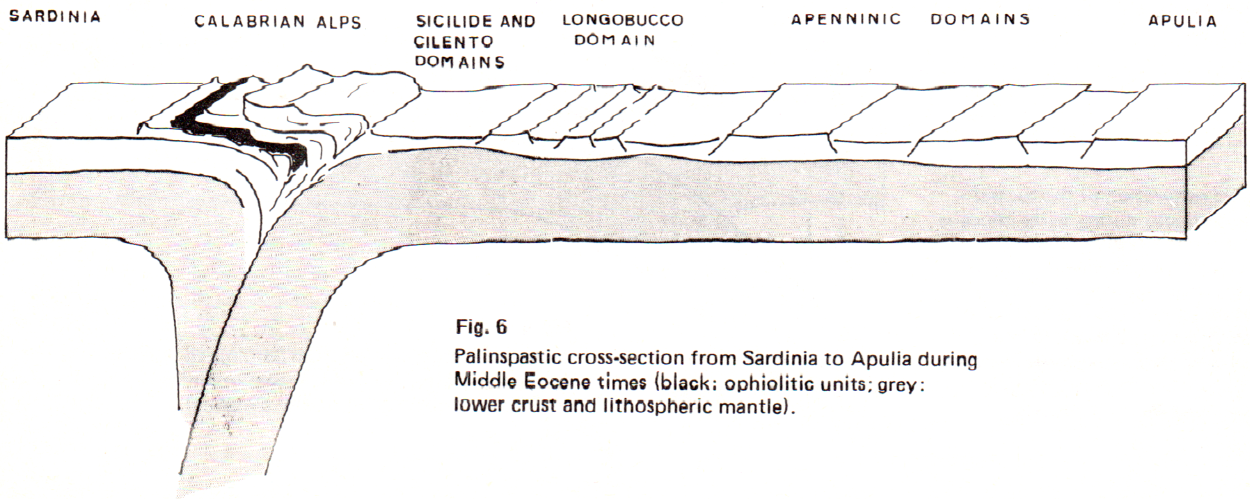

Fig. 6
Palinspastic cross-section from Sardinia to Apulia during Middle Eocene times (black: ophiolitic units; grey: lower crust and lithospheric mantle).

The Curvature of the Calabrian Arc

The convexity of the Calabrian Arc has been interpreted by some authors as due to the south-eastwards migration of an arc-trench system generated by the subduction of an oceanic "Ionian plate". The migration should also have been responsible for the opening of the Tyrrhenian basin in a back arc position. (Boccaletti and Guazzone, 1972; Barberi et al., 1973; Görler and Giese, 1978).

If we accept that the Calabrian Alpine nappes costitute the southward continuation of the Alpine chain, and if we assume that the trend of this belt during Eocene was like that represented in Fig. 5, then we must conclude that the present shape of the arc results from a severe distortion of a previously straight or at least less arcuate lithospheric segment. The southern Tyrrhenian area is characterized, as said before, by intermediate and deep-focus earthquakes. The maximal length of the slab is around 650 kilometres, requiring a large time span for subduction. Palinspastic restorations in the Southern Apennines allow to calculate an average subduction rate of the African margin of about 2.5 cm/year for the Neogene time; if we extrapolate the same velocity to the past, we obtain a value of 26 MY before present. This is of course only an approximative value, but indicative enough to establish that the present Benioff zone consists of a lithospheric body which began to subduce a long time ago and in any case before the generation of the Tyrrhenian Sea. The latter, therefore, opened not in a back arc position, but in a fore-arc one, being the volcanic arc during Oligocene-Lower Miocene located along the western margin of the Corsica-Sardinia "block". Anticlockwise rotations of the system accompanied by megashears during Late Oligocene-Early Miocene and during Middle-Upper Miocene should have been responsible for the distortion, fragmentation and splitting of the Alpine chain, as well as of the opening of the Western Mediterranean and Tyrrhenian basins. The Calabrian Arc, therefore, represents a sort of orocline, and the present Benioff zone may be interpreted as a remnant of a larger slab, chiefly consisting of African continental lithosphere subducted during and after the continent-continent collision.

Whether subduction processes are still active or not beneath the Calabrian Arc is questionable. The last considerable orogenic transport happened during middle Pliocene, with an amount of horizontal displacement of the nappe building not lower than 30 kilometres. The non-existence of a trench and the lack of free-air gravity anomalies along the Ionian side of the arc do not favour the occurrence of a present subduction, although evidences of neotectonic activity are widespread (Barone et al.,; Ghisetti and Vezzani, this volume). Fault-plane solutions of intermediate and deep-focus earthquakes (Gasparini et al., 1982) reveal sinistral strike-slip motions in the northern part of the slab and dextral ones in the southern part; down-dip compression, on the contrary, is predominant in the concave part of the arc. Crustal earthquakes show strike-slip motion in Sicily (P axes oriented approximately N–S or NE–SW) and along the Ionian coast (P axes oriented normally to the trend of the structures on land), while prevalent dip-slip motion with T axes normal to the main trend of the chain have been inferred in the Southern Apennines. This complex pattern cannot be explained in a simple way. Probably several concurrent phenomena act on the system such as a passive sinking in the asthenosphere of the residual slab, an active spreading in the south-eastern Tyrrhenian Sea and an increase in the torsion of the Calabrian Arc, while the Europe-Africa convergence is still persisting.

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