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Pre-Triassic history recorded in the Calabria-Peloritani segment of the Alpine chain, southern Italy. An overview

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ABSTRACT. — Clockwise P-T-(t) trajectories are generally recorded in the pre-Triassic basement rocks of the Calabria-Peloritani segment of the Alpine chain.

Geochronological data point to a synchronism of T-peak and emplacement of huge masses of granitoids at about 300 Ma. Decompression and heat supply from the granitic intrusions mark the transition from Barrovian to low P/high T metamorphism. When the preserved characters allow to trace prograde trajectories, a strong P increase and a moderate T increase, sometimes with T peak delayed relatively to the P peak.

These features are consistent with orogenic evolution in which crustal thickening in early-middle-Hercynian contractional stages was followed by crustal thinning in late-Hercynian extensional stages.

Moreover, in the Calabria-Peloritani segment of the Alpine chain, pre-Hercynian metamorphic and magmatic evidence also occurs.

RIASSUNTO. — Traiettorie P-T-(t) in senso orario sono generalmente registrate nelle rocce metamorfiche pre-triassiche, presenti nel segmento calabro-peloritano della catena alpina.

I dati geocronologici indicano un sincronismo, a circa 300 Ma, tra il picco termico e la messa in posto di grandi masse di granitoidi. La decompressione e il calore fornito dalle intrusioni granitiche segnano la transizione dal metamorfismo di tipo Barroviano a quello di bassa pressione/alta temperatura. Un forte incremento di P e un moderato incremento di T, a volte con picchi diacroni, sono registrati.

Questi aspetti sono coerenti con una evoluzione orogenica in cui l'ispessimento crostale, avvenuto durante il raccorciamento eo- meso-ercinico, fu seguito dall'assottigliamento crostale, durante l'estensione tardo-ercinica.

Inoltre, nei basamenti calabro-peloritani, sono documentati anche eventi metamorfici e magmatici pre-ercinici.

KEY WORDS: *Calabria-Peloritani, Pre-Triassic, metamorphic evolution.*

INTRODUCTION AND GEOLOGICAL BACKGROUND

The Calabria-Peloritani segment of the Alpine chain connects the NW-SE-trending Apennines and the E-W-trending Sicilian Maghrebides (Amodio-Morelli *et al.* 1976; Bonardi *et al.*, 2001, for a review). It consists of pre-Triassic metamorphic and plutonic basement rocks, Mesozoic to Cenozoic

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sedimentary covers and Alpine metamorphic rocks. The basement rocks are mainly exposed in Catena Costiera, Sila Massif, Serre Massif, Capo Vaticano Promontory, Aspromonte Massif, in Calabria, and in the Peloritani Mts., in Sicily (Fig. 1).

The Calabria-Peloritani orogenic belt consists of tectonic units stacked during the Alpine orogenesis. These units are represented, from the top, by: a) pre-Triassic continental crust with remnants of its sedimentary cover, b) Jurassic - Lower Cretaceous Tethyan oceanic crust and c) Mesozoic sedimentary rocks (Dubois, 1970; Amodio-Morelli *et al.*, 1976; Bouillin, 1984). South of the Cenozoic Catanzaro Graben (Fig. 1), only units of the Hercynian continental crust and Meso-Cenozoic sedimentary cover are exposed.

The provenance of the pre-Triassic rocks forming the Alpine tectonic units in Calabria and Peloritani Mts. is still debated. They have been interpreted as fragments of: a) the African continental margin (e.g. Amodio-Morelli *et al.*, 1976; Alvarez, 1976; Grandjacquet and Mascle, 1978), b) the European continental margin (Ogniben, 1973; Knott, 1987; Bouillin *et al.*, 1986; Dietrich, 1988), c) a micro continent (Mesomediterranean Terrane) between the European and the African continental margins (Guerrera *et al.*, 1993; Bonardi *et al.*, 1996; Perrone, 1996; 2004). Two distinct interpretative models have been proposed: (i) building of a Cretaceous – Paleogene Europe-verging chain, which was thrust onto Africa-verging Apennine units during early Miocene (e.g. Haccard, *et al.*, 1972; Alvarez, 1976; Amodio-Morelli, *et al.*, 1976), (ii) stacking of European and Tethyan units which were subsequently thrust onto the African continental margin in early Miocene (e.g. Ogniben, 1969; 1973; Bouillin, 1984). On the whole, the continental crust units are polydeformed and, sometimes, polymetamorphic.

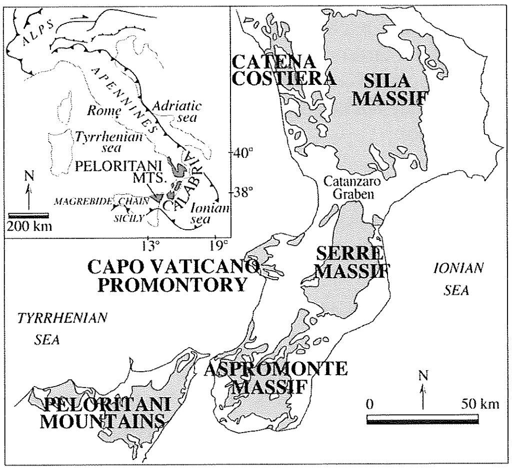

Fig. 1 – Map of Calabria and the Peloritani Mts. showing the main outcrops of the pre-Triassic continental crust rocks (grey areas).

According to Bonardi *et al.* (1980; 1996; 2001) and Messina *et al.* (1996a; 2002a) the Calabria-Peloritani orogenic belt can be considered a terrane, in which Northern (Sila Massif, Catena Costiera, Capo Vaticano Promontory and Northern Serre Massif) and Southern (Central and Southern Serre Massif, Aspromonte Massif and Peloritani Mts.) sub-terranes are distinguished. Both sub-terranes became kinematically independent during the Upper Cretaceous to Paleogene tectonic events. These tectonic events were responsible for an early Europe-vergence of the Northern sub-terrane, whereas the Southern sub-terrane remained substantially undeformed. Recent studies, however, have documented the occurrence of an Eocene deformational event in the basement-rocks of the Southern sub-terrane (Prosser *et al.*, 2003).

The pre-Triassic continental crust units bear evidence of an Alpine reworking along centimetre to kilometre thick shear zones (e.g. Dubois, 1976; Paglionico and Piccarreta, 1976; Bonardi *et al.*, 1984a; 1996; Platt and Compagnoni, 1990; Messina, 2002; Prosser *et al.*, 2003). The ophiolitic units record Alpine high-P/low-T metamorphic conditions, from albite-lawsonite to glaucophane schist facies overprinted by greenschist facies conditions. The Alpine overprint includes effects of high-P/low-T conditions with growth of prehnite, pumpellyite, lawsonite and blue amphibole (e.g. Colonna and Piccarreta, 1975; Piccarreta, 1981) as well as Barrovian metamorphism, ranging from sub-greenschist (Ferla and Azzaro, 1978) to amphibolite facies (Messina *et al.*, 1990; 1996a). Despite the Alpine orogenesis, in the pre-Triassic rocks the Hercynian metamorphism and relics of older petrogenetic events are well preserved.

The present tectonic setting of the Calabria-Peloritani segment of the Alpine chain is a consequence of pre-Hercynian to Cenozoic events, which favoured the exhumation of thick Hercynian crustal sections (Schenk, 1990; Thomson, 1994; Caggianelli *et al.*, 2000a; Del Moro *et al.*, 2000; Festa *et al.*, 2003).

In this paper, a possible pre-Triassic evolution is discussed mainly on the basis of the new data available since the review papers by Ferla *et al.* (1982) and Atzori *et al.* (1984).

STRATIGRAPHIC AND METAMORPHIC SETTING OF THE HERCYNIAN CONTINENTAL CRUST

In order to trace the tectono-metamorphic evolution, attention will be firstly focused on the most complete Hercynian continental crust sections exposed in Sila Massif, Serre Massif and Catena Costiera and, later, on the incomplete crustal ones exposed in the Aspromonte Massif and Peloritani Mts.

Sila Massif, Serre Massif and Catena Costiera

Geological evidence

More than 20 km-thick Alpine tectonic units are exposed both on the North and on the South of the Catanzaro Graben, in the Sila and Serre Massifs. They are made up of Hercynian basement rocks and Mesozoic to Cenozoic sedimentary cover (Fig. 2). The Sila and Serre sections show some similarities: they consist of lower to upper crustal segments separated by huge masses of late-Hercynian granitoids (e.g. Dubois, 1976; Schenk, 1980), emplaced at depths ranging from about 7 to 20 km, in the Serre Massif, and from 7 to 16 km in the Sila Massif (Caggianelli *et al.*, 1997; 2000b) (Fig. 3). Geochronological data indicate mineral ages ranging from 310 to 290 Ma (Schenk, 1980; Ayuso *et al.*, 1994; Graessner *et al.*, 2000). Deformations from magmatic to subsolidus conditions have been described for lower- to middle-crustal level granitoids (Caggianelli *et al.*, 2000b; Festa *et al.*, 2001-02; Liotta *et al.*, 2004). The intrusive contacts are characterized by the presence of a migmatitic border zone, in the high-grade metamorphics of the lower crust (Rottura *et al.*, 1990; 1991; Clarke and Rottura, 1994), and of a contact metamorphic aureole, in the medium- to low-grade metamorphics of the upper crust (Colonna *et al.*, 1973; Bonardi *et al.*, 1984b; Acquafredda *et al.*, 1987; Messina *et al.*, 1996a).

The upper crust consists of two Hercynian tectonic units (Borghi *et al.*, 1992; Colonna *et al.*, 1973), preserving their Mesozoic sedimentary cover (Figs. 2 and 3). In both the Serre Massif and Sila Massif sections, the lowermost grade metamorphics contain relics of Cambrian to Carboniferous fossils (Bouillin *et al.*, 1987). Despite these similarities, the two sections are currently interpreted in different ways. The Sila section is considered as a composite Alpine unit made up of different Hercynian rocks (Dubois, 1976; Borghi *et al.*, 1992; Bonardi *et al.*, 1996; 2001; Messina *et al.*, 1996a), including the Polia Copanello and Monte Gariglione Units (lower- to middle-crustal parts) and the Longobucco Unit (upper crustal segment) of Amodio Morelli *et al.* (1976). The Serre section is considered as a continental crust pile formed either: a) during the Hercynian orogeny (Dubois, 1976; Schenk, 1984; Caggianelli *et al.*, 1991) (Fig. 2) or, b) during the Alpine orogeny (Fig. 5) (e.g. Bonardi *et al.*, 1996; 2001; Messina *et al.*, 1996a), owing to the overlapping of the Stilo Unit (upper-crust metamorphics and plutonics of the southern sub-terrane) of Amodio Morelli *et al.* (1976) and of Bonardi *et al.* (1984b) on the Polia Copanello Unit (lower crust metamorphics and plutonics of the northern sub-terrane) of Amodio Morelli *et al.* (1976),

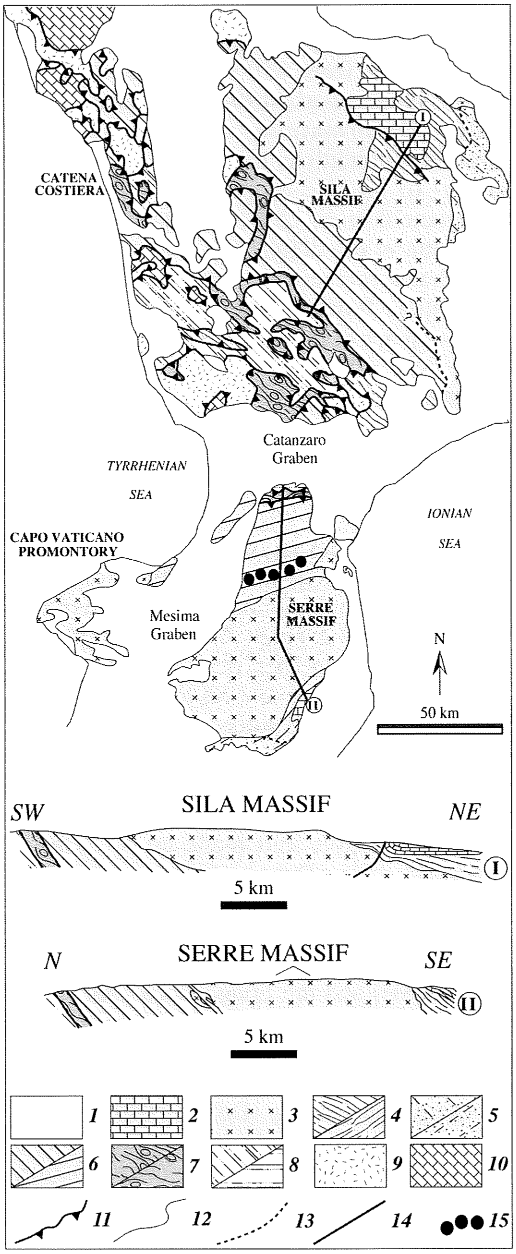

Fig. 2 – Geotectonic sketch map of Sila Massif (after Bonardi *et al.*, 2001; Caggianelli *et al.*, 2000b, modified), Serre Massif (after Schenk, 1990; Caggianelli *et al.*, 2000b; Del Moro *et al.*, 2000, modified), Catena Costiera (after Bonardi *et al.*, 2001, modified) and Capo Vaticano Promontory (after Rottura *et al.*, 1991, modified).
Legend. 1 – Oligocene to Quaternary sediments. SILA UNIT: 2 – Jurassic limestones; 3 – Carboniferous to Permian granitoids; 4 - Hercynian slates, phyllites with interbedded marbles and metavolcanites of the Bocchigliero and Stilo-Pazzano Hercynian Units, derived from Cambrian to Carboniferous protoliths; 5 – Micaschists and paragneisses of the Mandatoriccio and Mammola Hercynian Units; 6 – Metagabbros, felsic granulites, amphibolites, migmatitic paragneisses with interbedded marbles and metabasites. CASTAGNA UNIT: 7 – Gneisses and micaschists. POMO RIVER UNIT: 8 – Phyllites, metarenites and metarhyolites. OPHIOLITIC UNITS: 9 – Jurassic metabasalts, serpentinites, metahyaloclastites, quartzites, calc-schists, phyllites and metalimestones. APENNINIC UNIT: 10 – Middle Triassic – Lower Miocene mostly platform to basin carbonatic successions with a weak metamorphic overprint. Symbols: 11 - Alpine thrust traces; 12 - Stratigraphic and magmatic contacts; 13 - Hercynian tectonic contacts; 14 - Traces of cross sections; 15 - Grt-Crd bathozone trace in the Northern Serre Massif.

but ascribed to the Sila Unit by Bonardi *et al.* (1996) and Messina *et al.* (1996a).

The continental crust pile of the Serre is thicker than that of the Sila, owing to the absence of basal metagabbros and felsic granulites in the Sila Massif (Fig. 3). According to Piluso and Morten (2002), however, the very-high grade rocks in contact with the mantle peridotites in the northern Catena Costiera represent the deepest part of the Hercynian continental crust exposed in the Sila Massif. In the Serre Massif, moreover, basic to acidic metaigneous rocks record Pan–African magmatic ages (U/Pb determinations) of about 550 Ma (Schenk, 1984; Senesi, 1999).

Pre-Triassic tectono-metamorphic evolution: petrological and geochronological evidence

In the lower crust cropping out in the Sila and Serre Massifs the prograde stage is poorly constrained (e.g. Paglionico and Piccarreta, 1978; Schenk, 1984; 1989; Graessner and Schenk, 2001), since the relics of the prograde path were masked as temperature and diffusion rates increased towards the T-peak. After the prograde stage, Schenk (1984) and Graessner and Schenk (2001) have reconstructed P-T-(t) paths characterized by high-T, isothermal decompression followed by isobaric cooling (Fig. 4A, paths (1) and (2)); Kruhl and

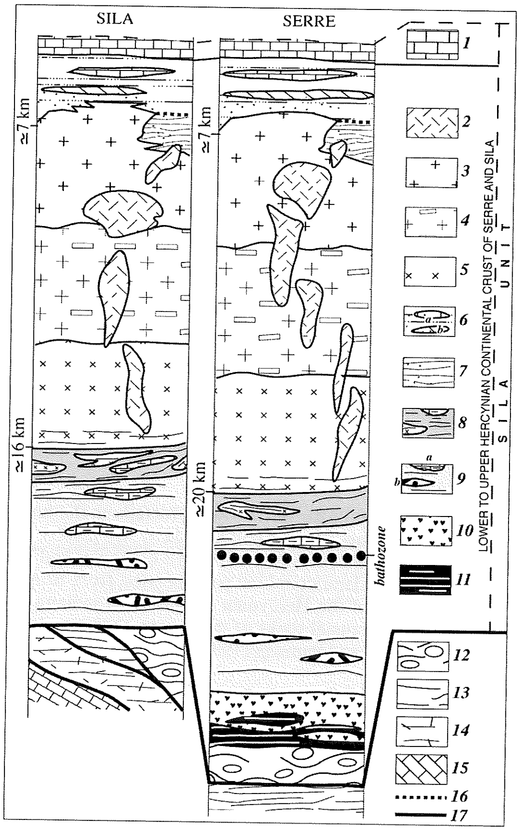

Fig. 3 – Stratigraphic sections of the Hercynian continental crust in the Serre and Sila Massifs (after Del Moro *et al.*, 2000; Caggianelli and Prosser 2002, modified), with the Alpine tectonic contacts showing relationships among Alpine units; paleodepths on the left side of each section.

Legend: 1 – Jurassic carbonatic cover; 2 - Peraluminous granitoids; 3 - Granodiorites and granites; 4 - K-feldspar megacryst-bearing granodiorites; 5 - Quartzodiorites to tonalites; 6 - Slates, phyllites with interbedded (a) marbles and (b) metavolcanites of the Bocchigliero and Stilo-Pazzano Units, derived from Cambrian to Carboniferous protoliths (dots indicate the contact aureola); 7 - Micaschists and paragneisses of the Mandatoriccio and Mammola Units (dots indicate the contact aureola); 8 - Migmatitic border zone; 9 - Migmatitic paragneisses with interbedded (a) marbles and (b) metabasites; 10 - Felsic granulites; 11 - Layered metagabbroic rocks; 12 - CASTAGNA UNIT; 13 – POMO RIVER UNIT; 14 – OPHIOLITIC UNITS; 15 – APENNINIC UNIT; 16 – Tectonic contacts predating the intrusion of the Carboniferous to Permian granitoids; 17 – Alpine tectonic contacts.

Lithotypes from 1 to 11, 2 to 11 and 2 to 5 belong to the SILA UNIT, Hercynian continental crust and Carboniferous - Permian granitoids, respectively.

Huntemann (1991) and Altemberger and Kruhl (2000) have described microstructures developed during decompression and cooling paths. The thermal peak, at about 300 Ma, is synchronous with the intrusion of granitoids, whereas the isobaric cooling is younger than 290 Ma, as inferred by U-Pb determinations on zircons and monazites from the metasediments. In the lower crust of the Serre Massif, peak metamorphic conditions at ≈ 700°C and ≈ 5.5 kbar, for the upper portion, and ≈ 800°C and ≈ 7.5 kbar, for the basal portion, have been estimated (Schenk, 1984; 1989; 1990). In the lower crust of the Sila, peak metamorphic conditions of ≈ 740°C and ≈ 4 kbar, for the upper portion, and ≈ 770°C and ≈ 6 kbar, for the basal portion, were estimated (Graessner and Schenk, 2001) (Fig. 4B, paths (1) and (2)). In the Catena Costiera, Piluso and Morten (2002) estimated P-T conditions of about 9-10 kbar and 750-800°C for the late-Hercynian metamorphic climax, followed by a decompression of ≈ 4 kbar (Fig. 4B, path (5)).

An extensive partial melting affected the lower crust metasediments, and sillimanite, garnet, biotite, cordierite residues are normal end-products of most metapelitic granulites. In the Serre Massif, the melting process initiated with H_2O-fluxed melting and continued via mica-dehydration melting (Fornelli *et al.*, 2002). In the uppermost part of the Serre Massif lower-crustal segment, the occurrence of relict kyanite, staurolite (Schenk, 1984; Paglionico and Piccarreta, 1978) and white mica (Wm) (Acquafredda *et al.*, 2003), together with textural features and the sequence of the melting stages, might yield important information about the metamorphic evolution. Wm_1 (Si/11ox = 3.18)+Chl+Bt protected in garnet, Wm_2 (Si/11Ox = 3.22) in contact with garnet and Wm_3 (Si/11Ox = 3.29) within the biotite of melanosomes, have been found in the same sample collected close to the tonalitic intrusion. The growth of kyanite after staurolite and of white mica (Si/11Ox = 3.29) in rocks containing garnet, staurolite, kyanite and biotite, occurred earlier than partial melting in

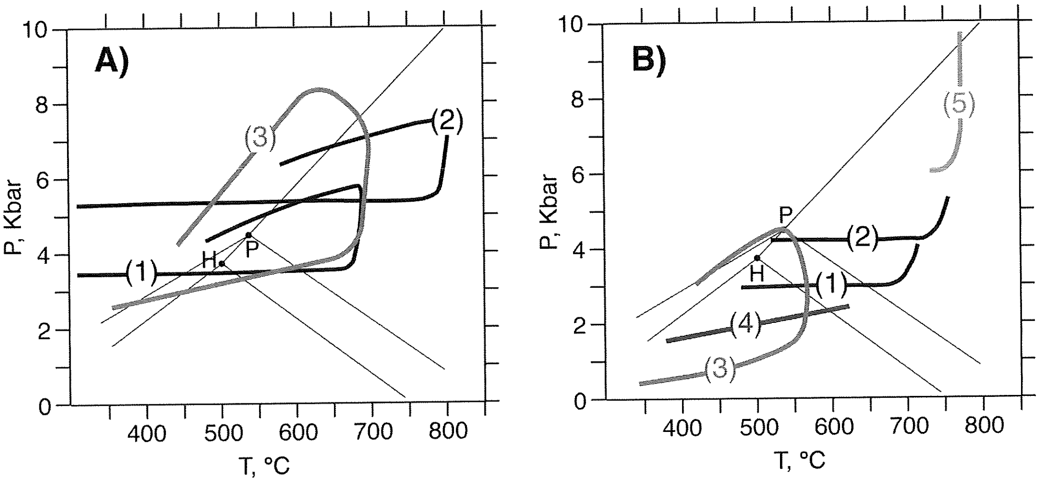

Fig. 4 – A) Clockwise P-T paths for the Hercynian lower continental crust section of the Serre Massif (details in the text): (1) upper and (2) lower part, modified from Schenk (1989); (3) uppermost part, from Acquafredda *et al.* (2003). B) Clockwise P-T paths for the Hercynian continental crust section of the Sila Massif (details in the text): (1) lower and (2) upper part of the lower crustal rocks, from Graessner and Schenk (2001); (3) Mandatoriccio Unit paragneisses, from Borghi *et al.* (1992). Clockwise P-T paths for the (4) amphibolite facies metamorphics of the Hercynian crustal rocks making up the Alpine Stilo Unit, from Graessner and Schenk (1999) and the (5) Hercynian crustal rocks of the Catena Costiera, from Piluso and Morten (2002). H and P: Al-silicate triple point after Holdaway (1971) and Pattison (1989), respectively.

the sillimanite stability field (Acquafredda *et al.*, 2003). The earliest assemblage (Wm_1+Chl+Bt) suggests T ≈ 450°C and P ≈ 4-5 kbar, whereas the latest prograde subsolidus mineral assemblage (Wm_3+Bt+Grt+St+Ky) suggests T = 700°C and P > 8 kbar (Fig. 4A, path (3)). After the P-peak the following events took place: (i) progressive heating that favoured H_2O–fluxed melting and, later, dehydration melting of micas within the stability field of garnet; (ii) decompression at high T, until the univariant reaction Bt+Sil+Qtz = Grt+Crd+Kfs+Melt, in the Grt-Crd bathozone mapped by Schenk (1990), was reached (Figs. 2 and 3; Fig. 4A, paths (1) and (2)).

High-T mylonites containing garnet, cordierite and sillimanite are present within the studied segment of the lower-crustal section. These minerals show boudinage, elongation and pull-aparts. In garnet ribbons, with inclusions of sillimanite and rutile, pull-aparts structures are filled with the low-P assemblage Crd+Spl (formed from the breakdown of Grt+Sil) and ilmenite including symplectitic Grt+Rt (Acquafredda *et al.*, 2003). Cooling and re-hydration, within the stability field of andalusite and then of kyanite, followed (Schenk, 1990; Fornelli *et al.*, 2002; Acquafredda *et al.*, 2003).

As concerns the Sila Massif lower-crustal segment, retrograde kyanite and staurolite have been reported (Graessner and Schenk, 2001). Relict kyanite, rimmed by fibrolite, however, is also present (Paglionico, 1974). Thus, the lower crust of the Sila and Serre Massifs records the Ky-Sil-And-Ky clockwise P-T path. For the prograde part of the P-T-(t) path, Schenk (1990) and Graessner and Schenk (2001) suggested a slight P increase and a strong T increase, with coeval P and T peaks (Fig. 4A, path (1)). On the contrary, the prograde metamorphic trajectory inferred by Acquafredda *et al.* (2003) for the uppermost part of the Serre Massif lower crust, implies a strong P increase reaching the peak in the subsolidus region and a progressive heating under slight decompression up to the thermal peak in the melting region (Fig. 4A, path (3)).

In the Sila Massif, the upper crust is represented by the Bocchigliero (sub-greenschist to greenschist facies) and the Mandatoriccio (greenschist to amphibolite facies) Hercynian Units, whose tectonic juxtaposition is sutured by the intrusion of late-Hercynian granitoids (Borghi *et al.*, 1992; Lorenzoni and Zanettin-Lorenzoni, 1979) (Figs. 2 and 3). Borghi *et al.* (1992) estimated peak conditions of 550-600°C and 4-4.5 kbar, for the Mandatoriccio Unit, and suggested a P-T path including a prograde stage, followed by decompression and by subsequent isobaric cooling (Fig. 4B, path (3)). The metamorphic peak in the Bocchigliero Unit was dated by Rb-Sr whole rock isochron at about 330 Ma (Acquafredda *et al.*, 1992; 1994).

In the Serre Massif, the upper crust is represented by the Stilo-Pazzano (sub-greenschist- to greenschist-facies) and the Mammola (greenschist- to amphibolite-facies) Hercynian Units, which, according to Colonna *et al.* (1973), were tectonically juxtaposed before the intrusion of Late-Hercynian granitoid plutons (Figs. 2 and 3). These metamorphics are interpreted by Crisci *et al.* (1983), Bonardi *et al.* (1984b; 1996; 2001), Messina *et al.* (1996a; 2002b) as part of the Alpine Stilo Unit (Fig. 5), which is characterized by a prograde zoning from the chlorite to the Sil+Ms zone. Instead, other authors (Dubois, 1976; Schenk, 1990; Graessner and Schenk, 1999; Del Moro *et al.*, 2000; Caggianelli and Prosser, 2002) consider the Stilo-Pazzano and the Mammola Units as the upward continuation of the Hercynian lower crust.

Graessner and Schenk (1999) estimated for the highest grade, upper-crustal rocks metamorphic conditions of ≈ 2.5 kbar and a quasi-isobaric heating up to ≈ 620°C (Fig. 4B, path(4)) (see also Messina, 2002). Monazite U-Pb dating reveals that both metamorphic peak and granitoid intrusions occurred at about 300 Ma (Graessner *et al.*, 2000), as happens in the lower crust.

Aspromonte Massif and Peloritani Mts.

Geological evidence

A complex structure and tectono-metamorphic evolution of the Aspromonte Massif and the Peloritani Mts. were suggested by Amodio Morelli *et al.* (1976) and Bonardi *et al.* (1976; 1996). On the basis of new geological, petrological and geochronological data, (Messina, 1998; 2002; Bonardi *et al.* 2001; Messina and Somma, 2002b; Messina *et al.*, 2002a; 2003a; 2003c), the Aspromonte Massif and the Peloritani Mts. (Fig. 5) are considered as a nappe pile consisting of ten tectono-stratigraphic units, whose geometrical relationships are summarized in Fig. 6. The stacking is considered as being of Alpine age and their emplacement is referred to the Africa-verging tectonics (Bonardi *et al.*, 2001; Messina, 2002, with references). Graessner and Schenk (1999) and De Gregorio *et al.* (2003), however, claim that the Stilo and the Aspromonte Units, in Calabria, and the Aspromonte and the Mandanici Units, in Sicily, have been superimposed earlier than the emplacement of the late-Hercynian granitoids. According to these authors, the peraluminous granites sealed the contact between the Stilo and the Aspromonte Units in Calabria, and an Ar/Ar age of 301 Ma has been obtained on white micas from a mylonitic augengneiss of the Aspromonte Unit overlying the Mandanici Unit in Sicily. Nevertheless, the presence of slices of Mesozoic to Cenozoic cover, interposed between nappes in Aspromonte Massif and Peloritani Mts., allows one to consider the Alpine orogenesis as the process responsible for their tectonic setting.

In order to describe the pre-Triassic evolution of this crust section the Longi-Taormina, Mela and Aspromonte Units will be considered, as they record a longer history.

Pre-Triassic tectono-metamorphic evolution: petrological and geochronological evidence

The Longi-Taormina Unit consists of a Paleozoic (Cambrian to Early-Carboniferous) metasedimentary and metaigneous sequence,

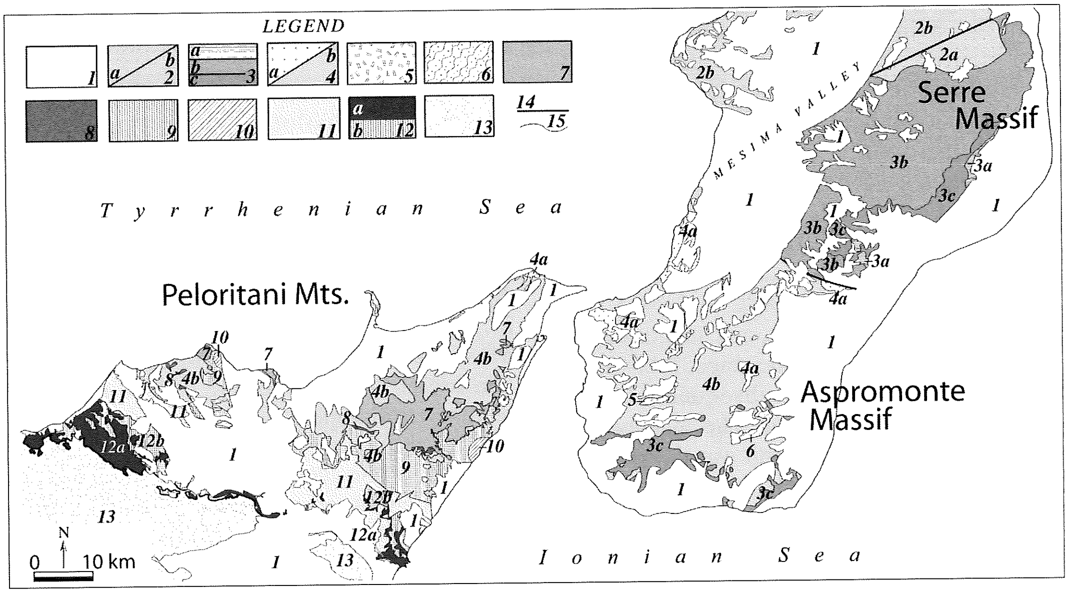

Fig. 5 – Geological sketch map of Southern Calabria and Peloritani Mts. (after Messina *et al.*, 2003b).
Legend: 1. Holocene - Pleistocene Etna volcanics and Holocene - Miocene sedimentary rocks. *Northern Calabria-Peloritani sub-terrane.* 2. SILA UNIT*: Polia-Copanello* basement - a) late-Hercynian intermediate to basic plutonites; b) Hercynian granulite- to amphibolite-facies metamorphics (pre-Paleozoic? - Paleozoic). *Southern Calabria-Peloritani sub-terrane.* 3. STILO UNIT: a) Aquitanian-Upper Triassic(?) cover; b) late-Hercynian acidic to intermediate plutonites (Stilo Batholith); c) Hercynian lower-greenschist- to lower-amphibolite-facies metamorphics (Paleozoic). 4. ASPROMONTE UNIT: a) late-Hercynian acidic to basic plutonites; b) Hercynian lower-granulite- to lower-amphibolite-facies metamorphics with pre-Hercynian upper-granulite facies relics. The Alpine upper-greenschist- to lower-amphibolite-facies overprint is localised along shear zones (pre-Paleozoic to Paleozoic protoliths). 5. CARDETO UNIT: Hercynian lower-greenschist facies metamorphics, weakly affected by Alpine metamorphism (Paleozoic protoliths). 6. AFRICO UNIT: Hercynian lower-greenschist facies overprint (Paleozoic protoliths). 7. MELA UNIT: lower-amphibolite- to upper-greenschist-facies metamorphics with early-Hercynian eclogite relics (Paleozoic protoliths). 8. PIRAINO UNIT: Early-Middle Jurassic cover. Hercynian lower-greenschist- to lower-amphibolite-facies metamorphics (Paleozoic protoliths). 9. MANDANICI UNIT: Mesozoic cover. Hercynian lower-greenschist- to upper-greenschist-facies metamorphics (Paleozoic protoliths). 10. ALI UNIT: Upper Triassic(?) to Cretaceous cover. Hercynian anchizone metamorphics (Paleozoic protoliths). Cover and basement show an Alpine anchizone metamorphic overprint. 11. FONDACHELLI UNIT: Mesozoic cover. Hercynian lower-greenschist facies metamorphics (Paleozoic protoliths). 12. LONGI-TAORMINA UNIT: a) Upper Triassic(?) to Aquitanian cover. b) Hercynian sub-greenschist- to greenschist-facies metamorphics (Paleozoic protoliths). *Maghrebid Chain* 13. MAGHREBIAN UNITS (Lower Miocene-Upper Jurassic). 14. Fault. 15. Overthrust.

affected by Hercynian sub-greenschist- to greenschist-facies metamorphism. The Carboniferous metaconglomerates of this unit contain metasedimentary pebbles (Bouillin *et al.*, 2004) showing polyphase, plurifacial metamorphism from low-T, greenschist- to medium-T, amphibolite-facies conditions. Pebbles of acidic orthoderivates, which exhibit strong cataclastic effects to weak low-T greenschist facies metamorphism, are also present.

The Mela Unit, which is tectonically interposed between the Aspromonte and either the Piraino or the Mandanici units, shows a complex pre-Triassic history characterized by two main metamorphic stages. The older stage is recorded in relict garnet amphibolites (Borghi *et al.*, 1995), and characterized by the occurrence of a) Amph+Pl and Cpx+Pl symplectites after former omphacite, and b) a corroded garnet, partly replaced by Qtz+Bt+Pl. The presence of oligoclase+clinozoisite relics

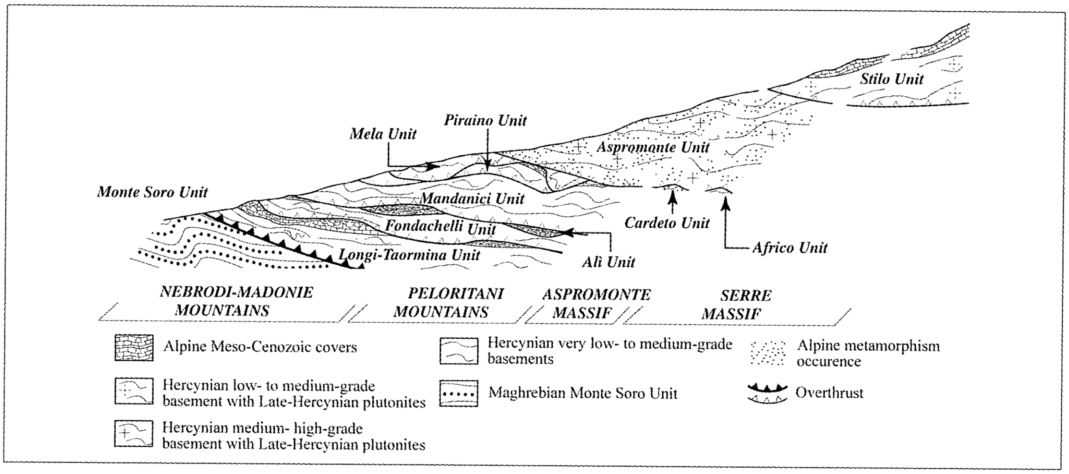

Fig. 6 – Sketch of the tectonic relationships among Alpine units in the Peloritani Mts., Aspromonte and Serre Massifs (after Messina *et al.*, 2003b, simplified).

inside the garnet indicates that this older metamorphism developed from epidote-amphibolite- to eclogite-facies conditions at ≈ 600-580°C and ≈ 16 kbar (Compagnoni *et al.*, 1998). This metamorphism is overprinted by a retrograde amphibolite- to greenschist-facies stage (Messina *et al.*, 1997; 1998).

In the metasedimentary rocks, the post-eclogite stage was characterized by the growth of kyanite, staurolite, garnet, followed by fibrolite and by the subsequent growth of low-P minerals such as cordierite, andalusite and thin rims of albite around oligoclase.

The P-T-(t) path of the Mela Unit (Messina, 1998) consists of an earlier prograde path from amphibolite- to eclogite-facies, followed: a) by decompression, first within the stability field of the Ky+St+Grt assemblage (P ≈ 7 kbar and T ≈ 600°C) and further within the stability field of the Sil+Crd+And assemblage at nearly isothermal conditions and b) by a late isobaric cooling (T < 500°C and P > 2 kbar) (Fig. 7, path (1)).

The Aspromonte Unit consists of metasedimentary and metaigneous rocks, which underwent Hercynian granulite- to amphibolite-facies conditions and were intruded by late-Hercynian granitoids. All the rocks experienced metamorphic overprint along shear zones during the Alpine orogeny (28-22 Ma, Rb/Sr ages on micas; Bonardi *et al.*, 1991). Relics of mafic granulites locally occur within the Hercynian migmatites: their Ca-rich-Grt+Cpx+Qtz assemblage, deriving from Opx+Pl, suggests P ≈ 8-10 kbar and T ≈ 700°C (Messina *et al.*, 1996b). Within the metasedimentary rock types, plagioclase, biotite, garnet, sillimanite and local retrograde muscovite show syn- to post-kinematic crystallization (Messina *et al.*, 1996a). The static growth of staurolite, cordierite and andalusite porphyroblasts occurs at the end of the Hercynian metamorphism (314 Ma, Rb/Sr ages on micas; Bonardi *et al.*, 1991). The whole P-T-(t) path is summarized in Fig. 7, path (2) (Messina, 1998). The earliest event records high-P, granulite facies conditions followed by isothermal decompression (down to ≈ 5 kbar) in the Sil+Kf+Grt stability field and by cooling and decompression (from ≈ 680 to ≈ 550°C and from ≈ 5 to ≈ 3 kbar) to reach the andalusite field. Finally, hydration under further decreasing T (up to ≈ 480°C) took place owing to the H_2O released from plutonic masses intruded at ≈ 290 Ma (Rb-Sr data on micas; Rottura *et al.*, 1990). The metaigneous rocks (mostly augengneisses), which give Pan-African U-Pb magmatic age from about 520 to 600 Ma (Schenk and Todt, 1989; unpublished data) and include xenoliths of

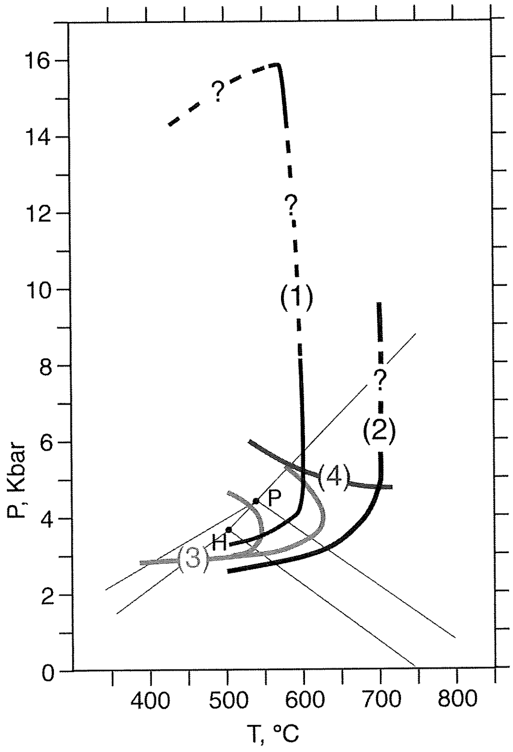

Fig. 7 – Clockwise P-T paths for the Peloritani Mts. (details in the text): (1) Mela Unit and (2) Aspromonte Unit (after Messina, 1998, modified); (3) Atzori and Ferla (1992), modified and (4) Dubois and Truillet (1970), modified. H and P: Al-silicate triple point after Holdaway (1971) and Pattison (1989), respectively.

metamorphic rocks, were intruded by the late-Hercynian granitoids.

Atzori and Ferla (1992), who did not recognise the Piraino and Mela Units (Fig. 6), proposed P-T-(t) paths showing distinct peaks for P and T for the Aspromonte and the Mandanici Units (see also Dubois and Truillet, 1970) (Fig. 7, paths (3) and (4)).

INTERPRETATION OF THE PRE-TRIASSIC METAMORPHIC HISTORY

(1) Clockwise P-T-(t) trajectories are generally recorded in the pre-Triassic basement rocks exposed along the Calabria-Peloritani Alpine orogenic segment. The available geochronological data suggest that the low-P/high-T metamorphism overprinted the Barrovian one about 300 Ma ago, approximately at the same time of the widespread granitoid plutonism. In most of the considered units, the low-P metamorphic stage was produced by a significant decompression coupled with a T increase connected to plutonism, as suggested by Graessner and Schenk (1999) and modeled by Caggianelli and Prosser (2002).

(2) In the higher-grade rocks, the prograde P-T-(t) path is usually obliterated by significant heating, occurring after the main deformation. Relics of prograde synkinematic stages, however, are locally preserved, which record a strong P increase and a moderate T increase, respectively, with the P-peak predating the thermal peak. This P-T-(t) path is consistent with a geodynamic evolution implying crustal thickening during early- and middle-Hercynian collisional stages, followed by crustal thinning and unroofing during late-Hercynian extensional stages. A similar evolution has been described for other European Hercynian segments such as, for instance, Sardinia (Carmignani *et al.*, 1992), the French Central Massif (Burg *et al.*, 1989; Malavieille *et al.*, 1991) and Western Carpathians (Janak *et al.*, 1999).

A diachronism in the exhumation of crustal rocks derived from different depth during the extension, their different residence times at given P-T conditions, as well as the distance from the granitoid intrusions, might account for the differences in the inferred P-T-(t) paths.

(3) In Calabria and in the Peloritani Mts. an earlier, most likely Pan-African metamorphic event, is also suggested by the following evidence: (i) greenschist- to amphibolite-facies metasedimentary pebbles included in the very-low grade Carboniferous metaconglomerates of the Longi-Taormina Unit; (ii) the presence of metasedimentary rocks within the augengneiss of the Aspromonte Unit, derived from pre-Hercyninan granitoid protoliths (magmatic age of 520-600 Ma); (iii) the presence within the lower crustal segment of the Serre of mafic and

felsic metaigneous rocks recording magmatic ages of about 550 Ma, similar to those documented in the augengneisses in Aspromonte. The scarcity of geochronological data on the high grade rocks of the Aspromonte does not rule out the possibility that part of the metamorphic events such as, for instance, the granulite facies relics, might be pre-Hercynian.

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