P-T CONSTRAINTS FROM PHYLLOSILICATES OF THE LIGURIDE COMPLEX OF THE POLLINO AREA (SOUTHERN APENNINES, ITALY): GEOLOGICAL INFERENCES

Francesco Cavalcante*,✉, Claudia Belviso*, Salvatore Laurita** and **Giacomo Prosser****

* *Istituto di Metodologie per l'Analisi Ambientale, IMAA-CNR, Potenza, Italy.*
** *Dipartimento di Scienze, Università della Basilicata, Potenza, Italy.*
✉ *Corresponding author, e-mail: francesco.cavalcante@imaa.cnr.it*

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ABSTRACT

In this paper a mineralogical study of pelite and metapelite samples collected in the Pollino area (Southern Apennines, Basilicata, Italy) was performed by X-ray diffraction (XRD), with the aim to define in detail the thermobaric conditions of the ophiolite-bearing Liguride Complex during subduction. The two main tectonic units of the Liguride Complex, namely the metamorphic Frido Unit and the non-metamorphic North Calabria Unit, have been sampled in this study. Results indicate that in the Pollino area the metamorphic grade show an overall decrease from the SW to the NE. The Frido Unit it is characterized by HP/LT metamorphism. The highest values of temperature (280-330°C) and pressure (11-13 kbar) were detected in the southern sector of the area. The intermediate values (T = 250±30°C and P = 8-10 kbar) were observed in the central sector, whereas lowest values (T = 180±20°C and P = 7±0.5 kbar) were registered in the northern sector. These thermobaric conditions and the inferred geothermal gradient (≈ 8°C/km) are in accordance with the lawsonite-blueschist mineral assemblage shown in associated metabasite and with the presence of aragonite in the carbonate levels. Data obtained from pelites of the North-Calabria Unit indicate high diagenetic thermobaric conditions with temperatures of 110-150°C and pressures of 2-3 kbar. More in detail, temperature values of 130-150°C and of 110-140°C are obtained in the Crete Nere and the Saraceno Formations, respectively. These moderate variations in the diagenetic grade might be influenced by differences in the bulk rock composition. The wide range of temperature and pressure conditions documented within the Liguride Complex indicates that samples have been collected in different thrust sheets characterized by variable metamorphic overprint. Systematic variations in thermobaric conditions are particularly evident within the metamorphic Frido Unit, which is probably made up of some thrust sheets and/or slices derived from different portions of the accretionary wedge.

INTRODUCTION

The Southern Apennine chain is a crucial sector for understanding the geodynamic evolution of the western-central Mediterranean. It is made up of a complex system of tectonic units derived from different paleogeographic domains of the Jurassic Tethys Ocean and its southern continental margin. In this area contractional deformation, resulting from the interaction between African and European Plates, migrated from the West to the East (e.g., Menardi Noguera and Rea, 2000; Patacca and Scandone, 2007), starting from the Cretaceous (e.g., Dewey et al., 1989; Cello and Mazzoli, 1999; Turco et al., 2012). The ophiolite-bearing Liguride Complex (Ogniben, 1969) represents the highest tectonic unit of the Southern Apennines and it is interpreted as a relic of an accretionary wedge developed between the Late Cretaceous and the Oligocene times (Knott, 1994). This wedge was substantially modified when it overthrust the northern continental margin of Africa (Apulian Plate) during the Early Miocene, giving rise to the present-day Apennine chain. For this reason, study of the metamorphic features of the Liguride Complex may provide hints on the early evolutionary stages of the western-central Mediterranean area.

Typically, the Liguride Complex is divided into non-metamorphic successions (the Crete Nere and Saraceno Formations) and a metamorphic portion (the Frido Unit). According to several studies (Spadea, 1976; 1982; Knott, 1987; 1994; Monaco and Tortorici, 1995; Sansone et al., 2011; 2012) the Frido Unit underwent a polyphase HP/LT to greenschist facies metamorphism developed in the deeper parts of the Liguride accretionary wedge. However, literature data on the P-T evolution of this unit are contradictory, especially when mafic rocks and metasediments are compared. According to some authors (Beccaluva et al., 1982; Knott, 1994) blueschist metamorphism in mafic rocks developed at peak pressure conditions of 6-8 kbar and temperatures of 350°C, whereas the subsequent greenschist facies overprint took place at P = 4 kbar and T = 300-350°C. Higher values for the P-T conditions of the blueschist metamorphism (P = 8-10 kbar; T = 400-450°C) are indicated by Monaco et al. (1991).

In metasediments, Di Leo et al. (2005) suggest strikingly different thermobaric conditions, with temperatures ranging between 140-180°C and 200°C, associated with a tectonic load of 4-5 and 6-7 km, for shales and metalimestones of the Frido Unit, respectively. However, Spadea et al. (1976) reported the presence of aragonite in the metalimestones, which is consistent with pressure conditions higher than 6 kbar. Invernizzi et al. (2008) indicate temperatures of 200-300°C and pressures of 6-8 kbar for the Frido Unit, whereas for the non-metamorphic portion temperatures of 200°C (Crete Nere Formation) and of 110°C (Saraceno Formation) were estimated. These values have been determined taking into account the metapelite mineralogy, the vitrinite reflectance, the fluid inclusions and by comparing these parameters with the mineral assemblage of metabasites from the Frido Unit.

In this work, detailed study on the thermobaric condition of metasedimentary rocks from the Liguride Complex has been carried out. An extensive sampling in the Lucanian sector of the Pollino area (Southern Apennines, Basilicata, Italy) permitted to determine the Kübler Index (KI), the illite-muscovite b_0 parameter and the percentage of $2M_1$ polytype, thus estimating the temperature and pressure at which the investigated units were metamorphosed. Since strongly discordant estimates of the thermobaric conditions were achieved by the previous studies, we have tried to improve the method for the determination of the Kubler Index (KI) to obtain more reliable values, taking into account the different calibrations available in literature (e.g., Leoni, 2001; Kisch et al., 2004).

GEOLOGICAL SETTING AND PREVIOUS WORK

The study has been carried out in the Lucanian sector of the Pollino area (Southern Apennines; Fig. 1). This chain results from the passive margin inversion of the Apulian Plate, with a northeastward vergence, during the Neogene (Patacca and Scandone, 2007, and references therein; Fig. 1). Structurally, the sector of the chain investigated in this paper represents a thick pile of tectonic units, derived from different paleogeographic domains overthrusting the carbonates of the Apulia platform. The lower portion of this pile consists of Meso-Cenozoic sedimentary rocks and, more specifically, of deep-sea sedimentary rocks of the Lagonegro basin, tectonically overlain by the neritic limestones of the Apennine platform. The Liguride Complex (Ogniben, 1969), also defined as Liguride Units (Bonardi et al., 1988) or North Calabria Nappes (Selli, 1962), is located in the highest position in the tectonic edifice of the Southern Apennines. In the investigated area, this complex represents a thrust sheet with a thickness of about 1 km (Fig. 2), as documented by the Francavilla sul Sinni 1 well (available in the VIDEPI web site: http://unmig.sviluppoeconomico.gov.it/videpi/). It is covered by thrust top basin deposits (Fig. 2) consisting of siliciclastic and calciclastic sediments of the Albidona Formation (Burdigalian-Langhian), the Perosa Formation (middle-upper Tortonian) and, finally, by siliciclastic deposits of the Sant'Arcangelo Basin (Pleistocene).

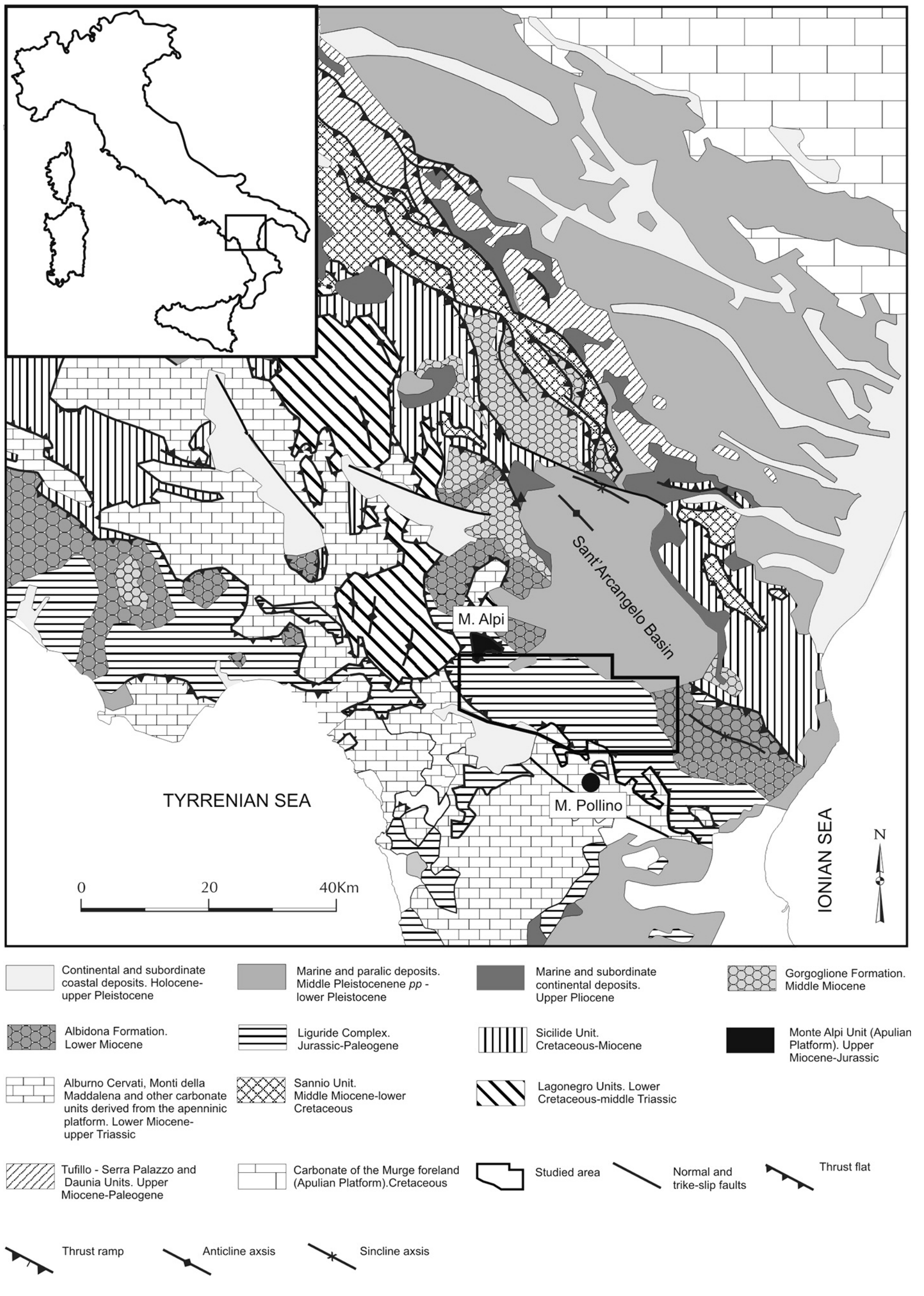

Fig. 1 - Regional geological map of the Southern Apennines; the box indicates the location of the studied area. Modified after Patacca and Scandone (2007).

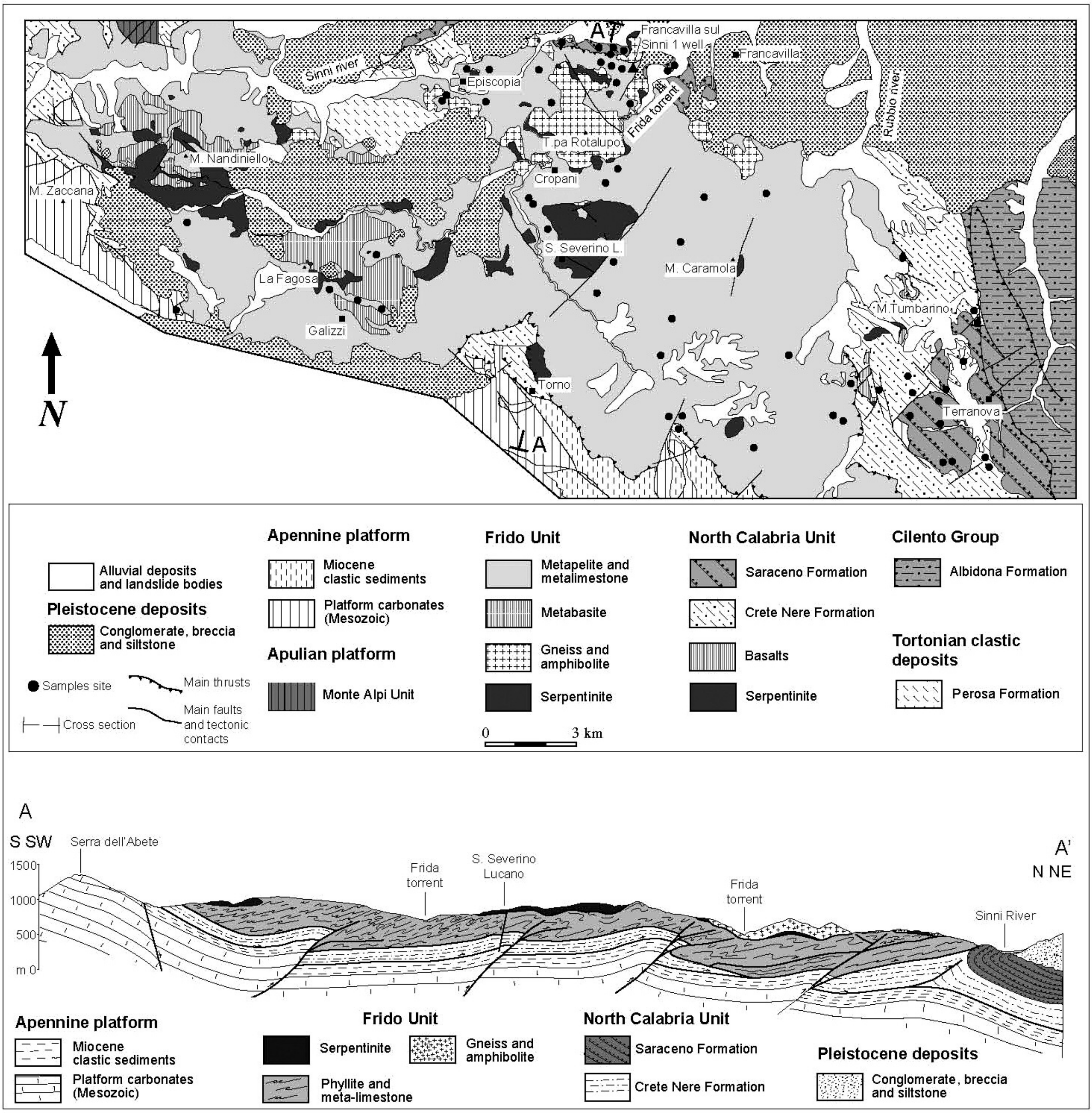

Fig. 2 - Geological sketch map of the studied area with sampling sites [a], simplified after Cavalcante et al. (2009). A regional cross-section through the Pollino Massif illustrating the internal structure of the Liguride Complex [b], is shown.

In the studied sector (Fig. 1) carbonates of the Apulia platform, generally covered by the above described allochthonous sheets, are exposed only in the Monte Alpi area (Monte Alpi Unit, according to Patacca and Scandone, 2007). Here, Jurassic-Early Cretaceous platform limestones and Late Miocene ramp carbonates are unconformably overlain by a terrigenous sequence of late Messinian - Early Pliocene(?) age (Van Dijk et al., 2000; Patacca and Scandone, 2007) made up of polygenic conglomerates, shales and subordinate hybrid calcarenites. Clasts of the conglomerates are representative of both the internal metamorphic units and the external units of the Southern Apennines. This succession is of great importance for dating the exhumation of the Liguride Complex and the thrusting of the allochthonous units over the Apulian platform.

The Liguride Complex cropping out in the Pollino area derived from a Jurassic oceanic domain (Ligurian Ocean) originally separating the European and the Apulian continental margins (e.g., Tortorici et al., 2009 and references therein). It represents a relic of an accretionary wedge developed during the Cretaceous-Oligocene subduction, that collided with the passive margin of the Adria Plate during the Early Miocene (Knott, 1987; 1994). The accretionary process involved the sedimentary cover, portions of the oceanic crust and mantle and fragments of continental crust. During the accretionary evolution and the later collision with the Adria Plate different units were stacked as thrust sheets. After emplacement in the Apennine chain, the Liguride Complex has been involved into high angle out of sequence thrusts, strike-slip and normal faults (Turco et al., 1990; Schiattarella, 1996; 1998).

The geometric relationships between different Units of the Liguride Complex are very difficult to decipher, due to their polyphase deformation history. Several authors formulated different structural interpretations (e.g., Bonardi et al., 1988; Di Leo et al., 2005; Cavalcante et al., 2009; Tortorici et al., 2009) and stratigraphic-structural schemes.

The first reconstructions (Vezzani, 1968; Ogniben, 1969) interpreted the Liguride Complex as a nearly continuous Jurassic-Miocene stratigraphic sequence overprinted a very low-grade metamorphism and showing Jurassic ophiolitic rocks and limestones at the base (Limestone of Mezzana, Bousquet, 1973).

More recent studies (Bousquet, 1971; 1973; Scandone, 1972; Amodio Morelli et al., 1976; Spadea, 1976) allowed recognizing a tectonic contact between the very low-grade metasediments of the Frido Unit below and the non-metamorphic Crete Nere Formation or North Calabria Unit (Bonardi et al., 1988) above (Fig. 3a). Bonardi et al. (1988) considered part of the metasediments, including slices of continental crust rocks and ophiolitic rocks, as a mélange zone (Episcopia-San Severino mélange), reflecting the presence of the tectonic contact. In the same reconstruction, the North Calabria Unit (Fig. 3a) is made up of the Timpa delle Murge ophiolites, overlain by the radiolarites and shales of the Timpa delle Murge Formation, the Crete Nere and the Saraceno Formations. The synorogenic sediments of the Albidona Formation (Early Miocene) are recognized upwards.

An alternative interpretation indicates the Liguride Complex as a stack of thrust sheets characterized by different lithology and metamorphic overprint (Fig. 3b; Monaco and Tortorici, 1995; Monaco et al., 1991; 1995). According to this interpretation, the Frido Unit makes up the uppermost thrust sheet (Fig. 3b), as it tectonically overlies the North Calabria Units (Flysch calabro-lucano in Fig. 3b), which in turn is split in a number of thrust sheets characterized by different lithologies (Monaco, 1993a; 1993b). The same authors consider the Frido Unit as subdivided in two subunits: calcschists and shales. The first one is made up of metalimestones and, subordinately, of shales. It overthrusts the second one, which consists of shales, subordinate quartzarenites, quartzites and metalimestones (Monaco and Tortorici, 1993; 1995; Monaco et al., 1995; Di Leo et al., 2005).

Several authors discussed the age of the HP/LT metamorphic event in the Frido Unit. Spadea (1982) refers the event to the upper part of the Early Cretaceous (Albian), taking into account regional geological-structural studies and biostratigraphic data on the Frido Unit and the Crete Nere Formation (Vezzani, 1969). Other studies, based on biostratigraphic data on the Frido Unit (Bonardi et al., 1993), in combination with geological-structural considerations, date the metamorphic event to the Late Oligocene (Monaco et al., 1991; Monaco and Tortorici, 1995; Bonardi et al., 2001). Radiometric dating with the K-Ar method on metabasites of the Frido Unit indicate Oligocene ages (Delaloye et al., 1984), whereas zircon fission track dating of continental crust rocks provided Cretaceous-Paleocene ages (65±5 Ma, Invernizzi et al., 2008; 56-65 Ma, Laurita et al., 2007).

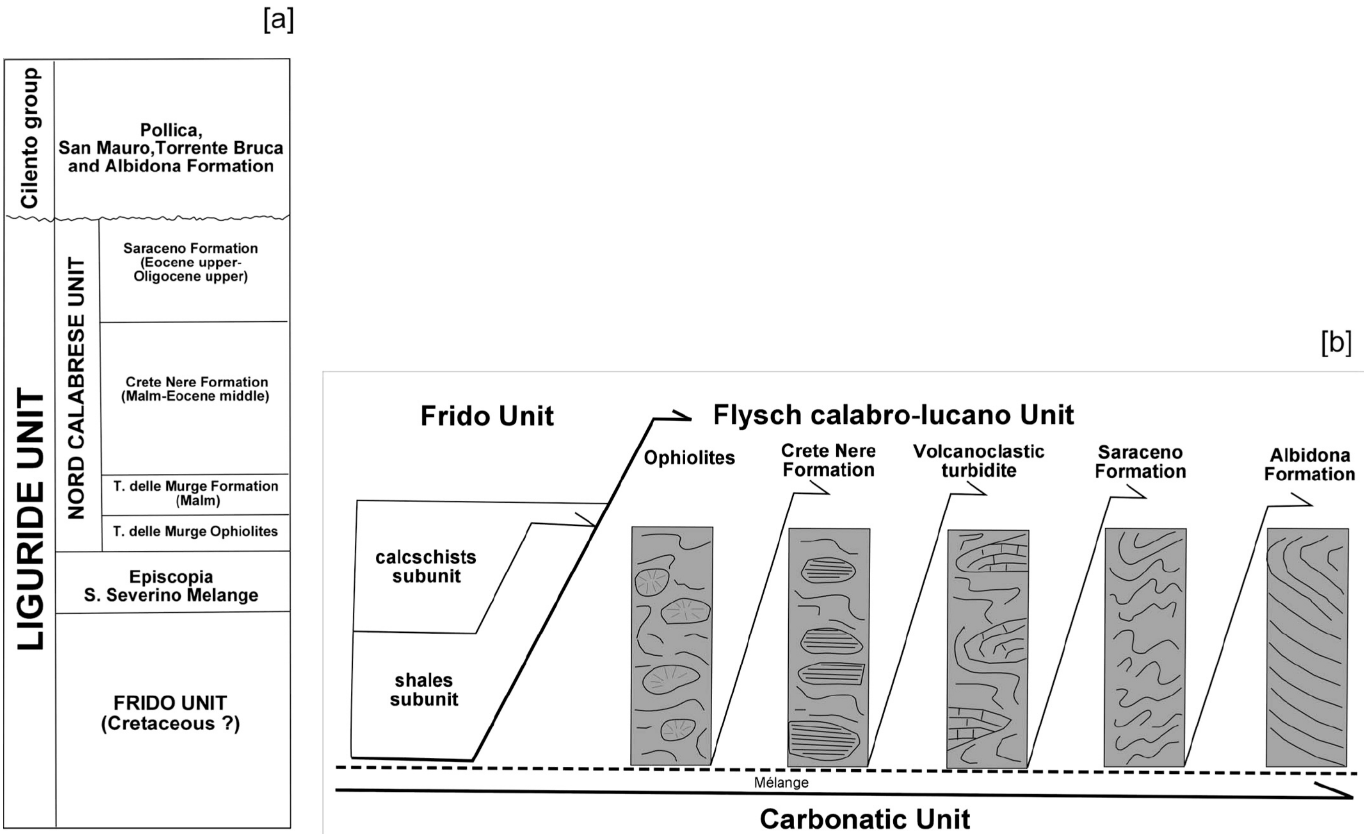

Fig. 3 - Structural-stratigraphic interpretations of the Liguride Complex according to [a] Bonardi et al. (1988) and [b] Monaco et al. (1995).

METHODS

14 samples from quartz-carbonate veins, 4 from carbonate rocks and 86 samples of pelites-metapelites have been analysed. Samples of quartz-carbonate veins, carbonate rocks and 58 samples of metapelites were collected from the Frido Unit, whereas 28 samples of terrigenous sediments were collected from the North Calabrian Units (18 from the Crete Nere Formation and 10 from the Saraceno Formation; Fig. 2).

The mineralogical composition of the whole rock and fine fractions were determined. To separate the fine fraction (< 2 μm), 25 g of the whole sample were disaggregated in an agate mortar for 50 seconds with 50 ml of distilled water and then separated by settling in distilled water.

X-ray powder diffraction analyses (XRD) were carried out using a Rigaku D/MAX-2200 powder diffractometer (CuKα radiation; graphite secondary monochromator; sample spinner) at the laboratories of IMAA-CNR. The qualitative analysis on the < 2 μm fraction were performed both on random and oriented mounts. Oriented mounts were prepared by settling a suspension (concentration: 4 mg/cm^2; Lezzerini et al., 1995) on a glass slide after being saturated with Sr^{++} cations using a 0.1 N $SrCl_2$ solution (Eberl et al., 1987). Each specimen was analysed in an air-dried state, glycolated at 60°C for 8 h and heated at 375°C for 1 h (Moore and Reynolds, 1997).

The Kübler Index (KI, Kübler, 1967), polytype ratio $2M_1/(2M_1 + 1M_d)$ (Velde, 1965), the illite-muscovite b_0 parameter (Sassi and Scolari, 1974) as well as illite/smectite (I/S) and chlorite/smectite (Chl/S) mixed layers (Moore and Reynolds, 1997) were also studied.

The KI was determined on oriented mounts of < 2 μm fraction. The Full Width at Half Maximum (FWHM) of the10 Å illite-muscovite basal peak has been obtained by decomposing the XRD pattern using WINFIT computer program (Krumm, 1996), which applies the Pearson VII asymmetric function (Warr and Rice, 1994; Battaglia et al., 2004). The measured KI values were calibrated using regression line obtained with the international standards proposed by Warr and Rice (1994) for determining a standardized scale, the Crystallinity Index Standards (CIS), to which to refer the crystallinity index.

The < 2 μm fraction of the standards analysed in the IMAA-CNR laboratories were also processed in the XRD-laboratories of the University of Pisa (Department of Earth Science) where the FWHM values were re-calibrated with respect to Kübler's standards (samples 32, 34, 35) (Leoni, 2001). Combining the data obtained from University of Pisa and IMAA-CNR, a new calibration line was obtained (Fig. 4a). It showed a good correlation coefficient (R^2 = 0.99), a sub-parallel trend comparable to that obtained with the values by Warr and Rice (1994) and a lower intercept value. Difference between the intercept values obtained from the two sets of standards is about 0.04 - 0.05°2θ, in agreement with literature data (Fig. 4a) (Leoni, 2001; see also Kisch et al, 2004). Since the Kübler's standardised KI data exhibit, in general, a good agreement with the thermal metamorphic conditions (Leoni, 2001) KI values determined using this calibration curve were used to estimate the thermobaric conditions recorded by the Liguride Complex in the studied area.

The $2M_1$ polytype was analysed taking into account the ratio between 2.80 Å and 2.58 Å peak area (Maxwell and Hower, 1967; Dalla Torre et al., 1994).

The illite/mica b_0 parameter was estimated on random specimens of fine fraction (< 2μm) of the samples collected from the metamorphic unit. The position of the peak d(060, $\bar{3}$31) was measured considering the 211 quartz peak as internal standard (Wang et al., 1996).

The % of end-members of I/S and Chl/S mixed layers and the Reichweite (R) stacking order were determined according to Moore and Reynolds (1997) and comparing the measured XRD patterns with the pattern calculated using NEWMOD© program (Reynolds, 1985).

The following assumptions were considered to estimate the thermobaric conditions of the investigated sedimentary and meta-sedimentary rocks: i) the presence of I/S ordered R1 suggests thermal conditions of high diagenesis corresponding to T = 100-120°C (Hoffman and Hower, 1979;

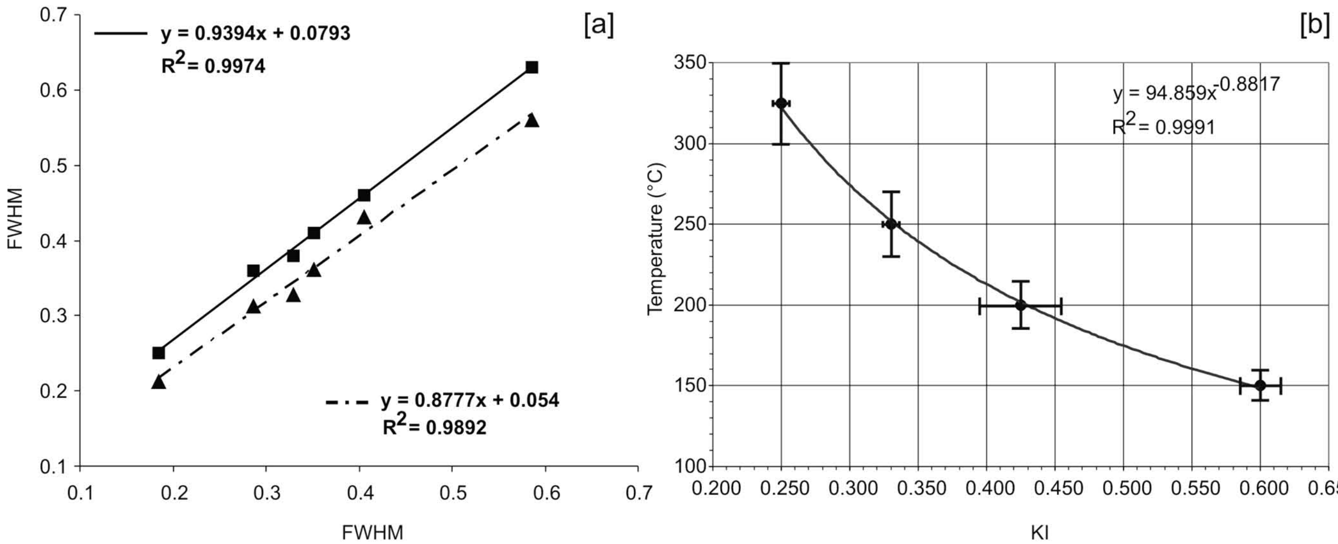

Fig. 4 - [a] Calibration lines obtained using Warr and Rice (1994; continuous line) and Kübler (1967; dotted line) standards. [b] Curve relating main value KI with corresponding main temperature value. The KI standard deviation values and the temperature variations from literature data are also reported.

Pollastro, 1993; Merriman and Peacor, 1999, and references therein) whereas I/S ordered R3 shows slightly higher temperatures (Merriman and Peacor, 1999); ii) KI = 0.6°Δ2θ indicates intermediate zone of high diagenesis and T = 150°C (Franceschelli et al., 1994; Merriman and Frey, 1999); iii) KI = 0.42°Δ2θ indicates boundary conditions between diagenesis and the anchi-metamorphism and T = 200°C (Kübler, 1984; Merriman and Frey, 1999); iv) KI = 0.34-0.30 (Franceschelli et al., 1994; Merriman and Frey, 1999) indicates low-high anchizone boundaries and T = 250°C; v) KI = 0.25°Δ2θ refers to the limits between the anchi-metamorphism and epi-metamorphism (Kübler, 1984; Merriman and Frey, 1999) and T = 300°C (Kisch, 1987) or 300-350°C (Weaver and Broekstra, 1984; Niedermayr et al., 1984).

According to these considerations a curve that relates KI *vs* temperature has been constructed (Fig. 4b). The equation $y = a/x^b$ has a good coefficient ($R^2 = 0.999$) for the following couple of values: 0.6°Δ2θ and 150°C; 0.42°Δ2θ and 200°C; 0.33°Δ2θ and 250°C; 0.25°Δ2θ and 325°C (Fig. 4b). This curve is the same type of Scherrer function (Klung and Alexander, 1974) that shows a good correlation between the sizes of the illite crystals measured by TEM and the values of KI (Merriman and Frey, 1999).

Since the mineralogical composition of the samples studied includes aluminium rich minerals such as paragonite and K/Na-mica we indicate that the investigated rocks are rich in aluminium, following Leoni (2005). In order to define the baric condition the diagram of Guidotti and Sassi (1986) and D'Amico et al. (1987; fig. 17.7 pag. 449), which is generally used in Al-rich systems (Fig. 5), has been adopted.

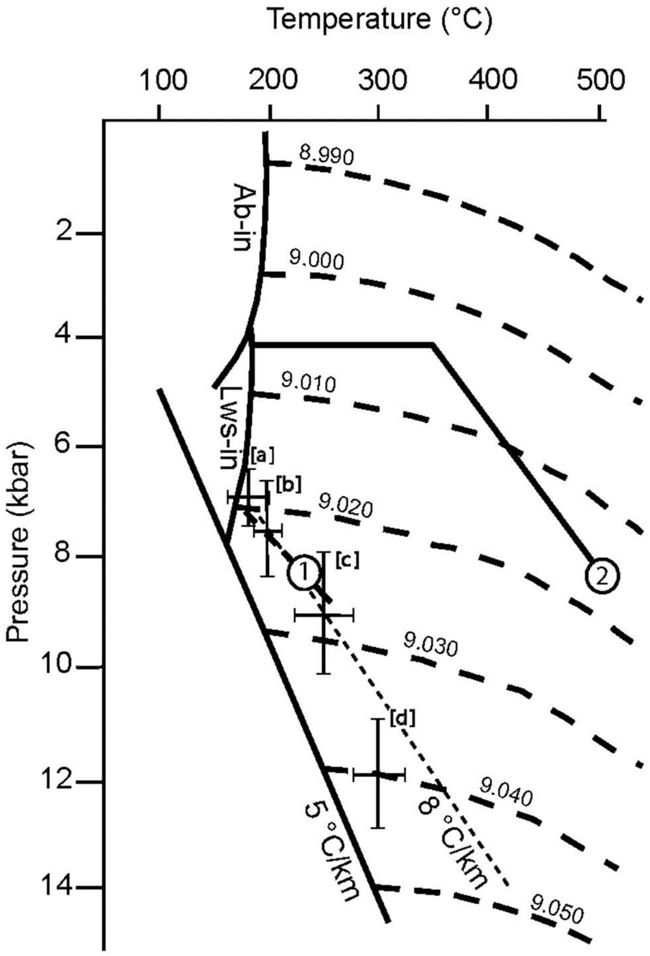

Fig. 5 - P-T diagram reporting the b0 isopleths after Guidotti and Sassi (1986). The reaction curve: glaucophane + lawsonite = pumpellyite + chlorite + albite + quartz + fluid (1) and the glaucophane stability field (2) are from Liou et al. (1985). Ab-in and Lws-in indicate the lower stability limits of Albite and Lawsonite, respectively.

RESULTS

Frido Unit

The Frido Unit consists of two main lithotypes, namely, slate/phyllite and metalimestone. Slate and phyllite are characterized by a grey colour and by intercalations of cm- to dm-thick layers of grey-green metalimestone and grey yellowish quartzite. Metalimestone is associated to calcschist and show intercalations of thin metapelite layers and rare quartzite. Carbonate and quartz veins frequently crosscut these lithologies.

In the southern sector of the studied area, near Galizzi (Fig. 2), the Frido Unit mainly consists of phyllite characterized by evident white mica that determine a silver colour. The main foliation is a well-developed S2 schistosity, almost completely erasing the previous S1 foliation (Fig. 6b). Folded veins made up of dynamically recrystallized quartz are frequently observed. The mineralogical composition of the bulk rock includes abundant quartz, phyllosilicates and feldspar traces. In detail, the phyllosilicates are represented by K-mica and chlorite (Fig. 6a). The average values of KI and b_0 are 0.27 ± 0.02°Δ2θ and 9.042±0.006 Å, respectively. Coherently, only the $2M_1$ polytype has been recognized. The above values indicate T = 280-330°C and P = 11-13 kbar.

Samples collected from the central sector of the investigated area (Fig. 6d) are characterized by a well-developed S1 and a superimposed S2 crenulation cleavage. The phyllosilicates are represented by K-mica (illite-muscovite), chlorite and Na-mica (paragonite) (Fig. 6c). In several samples also K/Na-mica mixed layer is recognized. The carbonate veins are characterized by quartz and calcite; in some samples the presence of aragonite has been detected (Fig. 7b). The average KI and b_0 values are of 0.34±0.05°Δ2θ and 9.028±0.004 Å, respectively. The percentage of $2M_1$ polytype is 83±13. These values indicate T = 220-280°C and P = 8-10 kbar.

In the northern sector of the studied area (between Cropani and Episcopia, Fig. 2) the phyllosilicates are represented by K-mica, Na-mica, chlorite and traces of mixed layer R1 Chl (75-80%)/S (Fig. 7a). Average values of the KI and b_0 are 0.43±0.02°Δ2θ and 9.023±0.006 Å, respectively. Percentage of $2M_1$ polytype is 78±16. These values are consistent with T = 190-210°C and P = 7-8 kbar.

Some samples from the northern sector (Francavilla area, North of Cropani, Fig. 2) have been collected in a tectonic slice at the base of the Frido Unit (Fig. 2), attributed to the Crete Nere Formation by previous authors (e.g., Monaco et al., 1995). Here grey metapelites show frequent intercalations of cm-thick carbonate levels and rare layers of yellowish quartzite, characterized by a S1 foliation, nearly parallel to the still recognizable sedimentary layering (S0), and an incipient crenulation locally developing a spaced S2 cleavage (Fig. 6f). The mineralogical composition of the bulk sample includes mainly quartz and phyllosilicates; feldspar is present in traces. Aragonite has been detected only in one sample coming from a carbonate layer. The phyllosilicates are represented by K-mica, chlorite, R3 illite (85-90%)/S and R1 chl (75-80%)/S (Fig. 6e). Traces of Na-mica and

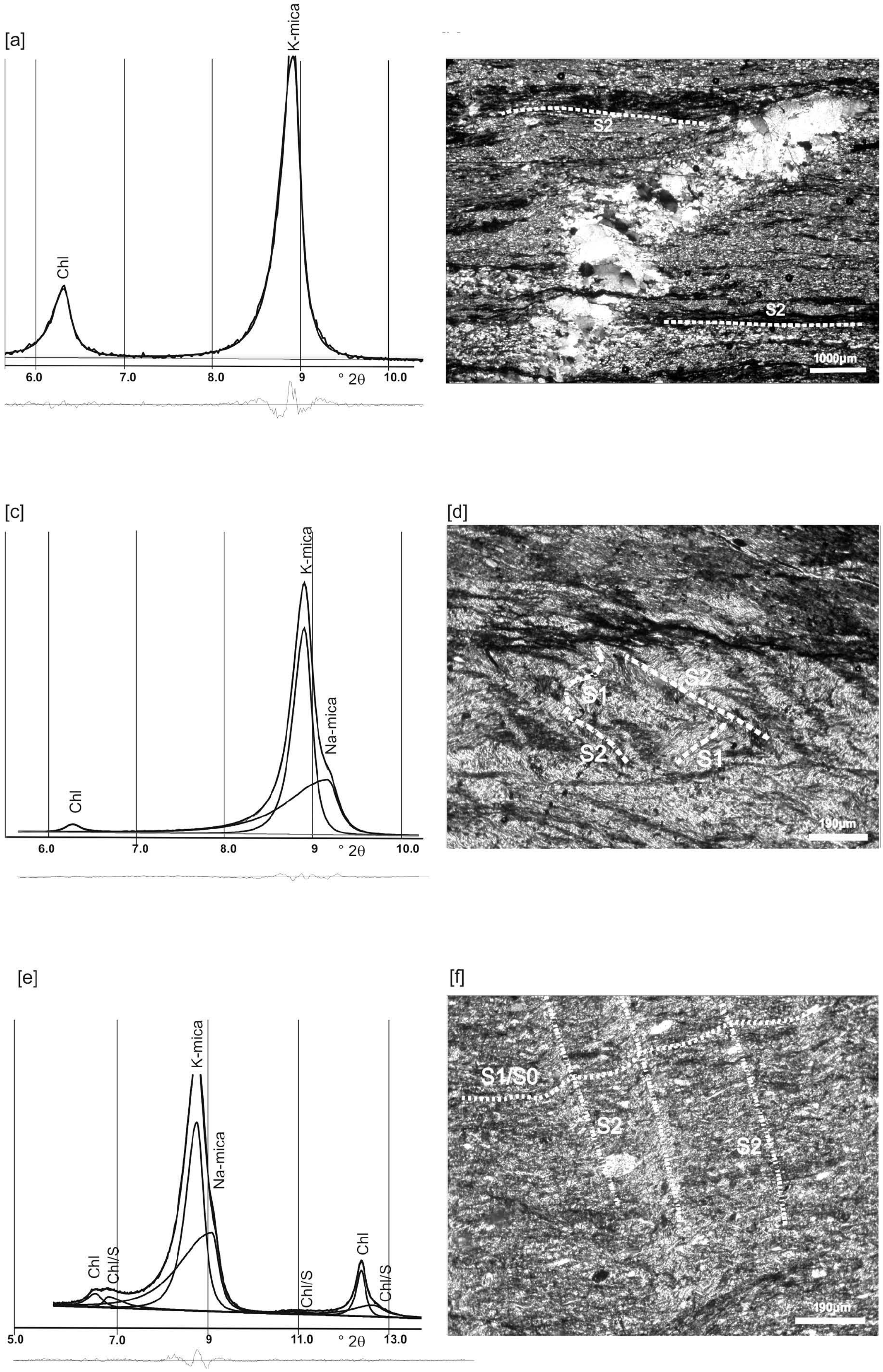

Fig. 6 - Diffraction profiles and thin section micrographs of typical metapelites of the Frido Unit. [a] and [b] Galizzi area (southern sector); [c] and [d] central sector of the Frido Unit; [e] and [f] Francavilla area (northern sector).

K/Na mica mixed layers are also present. The average KI and b_0 values are 0.47±0.05°2θ and 9.019±0.0034 Å, respectively. Percentage of the $2M_1$ polytype is 72±14. These values suggest T = 160-200°C and P = 7±0.5 kbar. The presence of aragonite is in accordance with the high pressure indicated by the b_0 values.

North-Calabria Unit

Saraceno Formation

The analysed shale samples were collected in the Terranova area and along the Sinni River (Fig. 2). The mineralogical composition includes mainly quartz and phyllosilicates. The feldspars (K-feldspar and plagioclase) occur as minor or trace components. Variable amount of calcite is present in some samples. The clay minerals are represented by illite, chlorite, R1 illite (70-80%)/S and R3 illite (85-90%)/S. In some samples the presence of R1 with chlorite (70-80%)/S was also detected (Fig. 7c). Average KI value is 0.71±0.08°2θ and the percentage of polytype $2M_1$ is 44±25. These values are coherent with temperatures of 110-140°C.

Crete Nere Formation

The Crete Nere Formation (Selli, 1962) is represented by an alternance of quartzarenite and dark grey shales followed upwards by black shales, with interbedded quartzarenite and lithoarenite layers, for a thickness of about 500 m. Upwards, the shales are less rich in organic matter and are interbedded with fine-grained calcareous turbidites, marls and layers of volcaniclastic arenites (Critelli and Monaco, 1993). According to Bonardi et al. (1988) the upper-middle part of the succession is Middle Eocene in age, whereas the lower portion should be dated to the Aptian-Albian. The mineralogical composition includes mainly quartz and phyllosilicates. The feldspar (K-feldspar and plagioclase) is poorly represented and/or in traces. Calcite has been found in some samples and in varying amounts. The clay minerals are represented by illite and R3 illite (85-90%)/S. Some samples are also characterized by the presence of R1 illite (70-80%)/S and R1 chl (75-80%)/S (Fig. 7d). Average KI value is 0.61±0.04°2θ, with percentage of the $2M_1$ polytype of 66±14. These values indicate a T = 130-150°C.

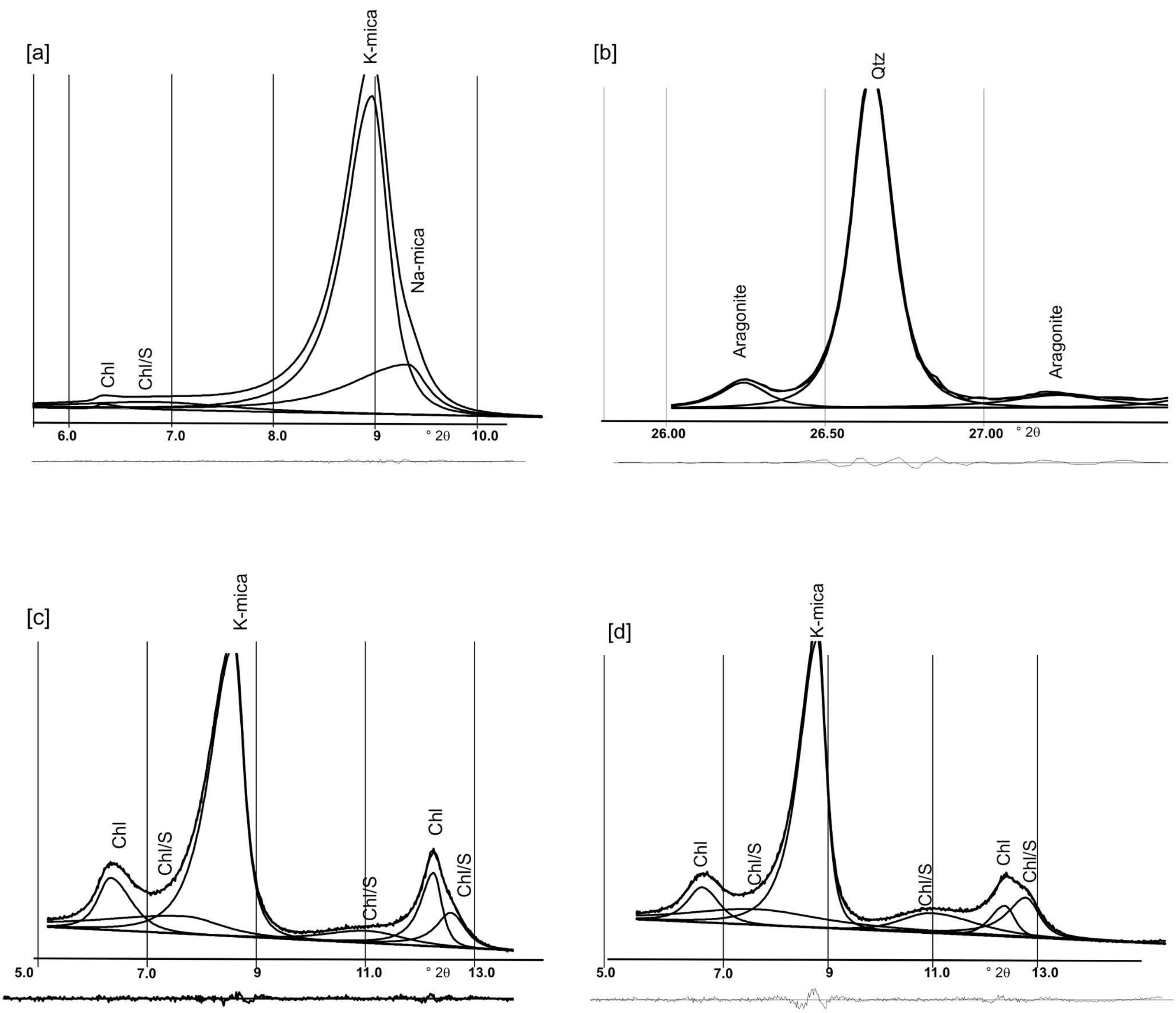

Fig. 7 - Typical diffraction profiles from: [a] the northern sector of the Frido Unit (Cropani-Episcopia area); [b] Quartz-carbonate veins of the Frido Unit; [c] Saraceno Formation; [d] Crete Nere Formation.

DISCUSSION

Our data indicate that the Frido Unit was subjected to variable HP/LT overprint. In particular the lowest temperatures (180-210°C) were estimated in the northern sector of the study area (between Cropani and Episcopia). Higher temperatures (280-330°C) and pressures (about 12 kbar) were determined in the southern sector (Galizzi). KI values determined for the central sector of the Frido Unit indicate temperatures spanning from 220 to 280°C. The thermal conditions are confirmed by the presence of mineralogical phases typical of the anchizone such as paragonite and K/Na mica mixed layers (Frey, 1987) as well as by the presence of high percentage of $2M_1$ polytype (Merriman and Peacor, 1999). The b_0 parameter suggests that the Frido Unit underwent pressure conditions in the range of 7-12 kbar. This is in agreement with the presence of aragonite in metalimestones and glaucophane in the metabasites from the same area (Beccaluva et al., 1982; Sansone et al., 2011). In addition, looking at the P-T diagram in Fig. 5 it results that three out of four datapoints are aligned along a geothermal gradient of about 8°C/km, which is typical of subduction environments.

The presence of I/S mixed layers R1 and R3 and the KI values indicate a temperature of about 110-140°C for the Saraceno Formation and a slightly higher temperature for the Crete Nere Formation (130-150°C). These low differences in the diagenetic grade might be influenced by differences in the bulk rock composition and suggest that the Crete Nere and Saraceno formations are part of the same tectonic unit. Taking into account a maximum geothermal gradient of about 15-20°C at the front of the accretionary wedge, it is possible to estimate minimum pressures of 2-3 kbar for these formations.

Summarizing, our data indicate that the Frido and North Calabria Units make up two main thrust sheets, due to the strong differences in P-T conditions. As shown by the cross section in Fig. 2, the Frido Unit overthrusts the North Calabria Unit, in agreement with the scheme proposed by Monaco and Tortorici (1995). However, considering the distribution of P-T conditions in more detail, two main differences with respect to the previous interpretations arise:

1) The North Calabria Unit may be interpreted as a single major tectonic unit, consisting mainly of the Saraceno and Crete Nere Formations, and it is not divided into several thrust sheets, as previously proposed by Monaco et al. (1995). This result is in agreement with the scheme proposed by Di Leo et al. (2005);

2) The significant difference observed for the thermobaric conditions of the Frido Unit, and in particular for the P estimates (5 kbar), cannot be explained with the presence of a single thrust sheet. Rather, our data indicate that the Frido Unit consists of staked slices and/or thrust sheets derived from different portions of the Liguride accretionary wedge.

The development of the accretionary wedge took place between the Cretaceous-Paleocene boundary to the Late Oligocene (Knott, 1994; Cello and Mazzoli, 1999). This seems consistent with zircon fission track age determinations, indicating maximum ages spanning between the Late Cretaceous and the Paleocene for the low temperature overprint of continental crust slices in the Frido Unit (Laurita et al., 2007; Invernizzi et al., 2008). A younger age (Late Oligocene) has been obtained by micropaleontological studies carried out in the northern and central sectors of the Frido Unit (Bonardi et al., 1993), where the metamorphic overprint ranges between the upper part of the high diagenesis and lower anchizone. This age probably refers to the latest deformation stages of the Liguride accretionary wedge. Summing up, thrust sheets in the Liguride Complex may have formed either during the evolution of the accretiorary wedge, when subduction of the oceanic crust took place, and/or when the wedge collided with the African continental margin during the Late Oligocene - Early Miocene.

Preservation of aragonite suggests that the different portions of the Frido Unit underwent fast exhumation after the maximum burial in the accretionary wedge. Exhumation of the Liguride Complex continued after deposition of the Saraceno Formation and before deposition of the Albidona Formation (Early Miocene), since this latter unit covers unconformably the North Calabria Unit. Most of the exhumation was completed during the Late Miocene, when the Perosa Formation (middle Tortonian) deposited unconformably on Frido Unit (Vezzani, 1966). This is confirmed by the results of apatite fission track age determinations suggesting that at about 5-6 Ma the Crete Nere formation cooled below 100°C (Invernizzi et al., 2008).

The Liguride Complex overthrust the Apennine carbonate platform in a time interval spanning between the deposition of the Albidona and the Perosa Formations. Some further uplift and exhumation probably took place also during the deposition of late Messinian - Early Pliocene clastic sediments on top of the Monte Alpi Unit, where elements coming from the Liguride Complex are observed in polygenic conglomerates (Patacca and Scandone, 2007).

CONCLUDING REMARKS

In this study detailed data on the thermobaric conditions of the Liguride Complex cropping out in the Pollino area (Southern Apennines, Basilicata, Italy) have been obtained. This analysis has proved very useful for discriminating rock bodies characterized by different P-T evolution within an accretionary wedge. The main results can be summarized in the following points:

1) The Frido Unit underwent variable HP/LT overprint, with a geothermal gradient of about 8°C/km, whereas the Crete Nere and Saraceno Formations (North Calabria Unit) are characterized by very low-grade conditions, corresponding to the lower part of high diagenesis.

2) The Crete Nere and the Saraceno Formations belong to the same tectonic unit as suggested by the similar very low-grade metamorphism.

3) A wide variation of P-T condition has been detected within metapelites of the Frido Unit. Temperatures and pressures vary from 280-330°C and 11-13 kbar (southern sector) to 185±15°C and 7 kbar (northern sector). This suggests that the Frido Unit is composed of different thrust sheets or slices characterized by a southward increase in temperatures and pressures related to the HP/LT metamorphism.

4) Widespread preservation of aragonite indicates that different thrust sheets of the Frido Unit underwent fast exhumation after the pressure and temperature peak.

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