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# The Triassic rift system in the northern Calabrian-Peloritani Orogen: evidence from basaltic dyke magmatism in the San Donato Unit

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ABSTRACT - Green to gray-green metabasite dykes occur within the metasedimentary sequence of the San Donato Unit, the lowest tectonic Unit cropping out in the Mt. Pollino area (northern Calabria). These metabasites are intruded in the Anisian-Ladinian metasediments of the San Donato sequence, but not in the overlying Carnic levels, suggesting a Middle Triassic emplacement age.

The original porphyritic texture is locally preserved in weakly foliated samples affected by very low- to low-grade metamorphism during the Alpine Orogeny. The metamorphic assemblages are indicative of a polyphase evolution: an early synkinematic albite + actinolite + chlorite + epidote + quarz + Fe-Ti oxides association developed at the subgreenschist-greenschist facies transition, and a later albite + calcite + chlorite + quartz +Fe-Ti oxides mineral association, in microdomains and patches, suggests localised increase of $X_{CO_2}$ in the fluid phase.

The protolith of the metabasites has been identified in alkaline to transitional basalts with geochemical features consistent with generation by partial melting of an enriched mantle source in a within plate setting. In particular, their geochemical composition is consistent with a low degree partial melting of a enriched mantle source. Based on geological constrains and on petrological considerations, these Middle Triassic metabasites may document the initial break-up stage of the Pangea, evolving to continent rifting and subsequent oceanization processes.

RIASSUNTO - Metabasiti di probabile età medio-triassica affiorano come dicchi all'interno dei meta-sedimenti anisico-ladinici che costituiscono parte della sequenza metasedimentaria dell'Unità di San Donato, l'unità tettonica più profonda nell'area del Monte Pollino (Calabria settentrionale).

L'originaria struttura porfirica è localmente preservata in campioni debolmente foliati, affetti da metamorfismo alpino di grado da bassissimo a basso. Le paragenesi metamorfiche suggeriscono un'evoluzione polifasica: una fase precoce sin-cinematica, con blastesi di albite + actinolite + clorite + epidoto + quarzo + Fe-Ti ossidi, si sviluppa alla transizione tra la sub-greenschist e la greenschist facies, ed una fase successiva, con produzione dell'associazione albite + calcite + clorite + quarzo + Fe-Ti ossidi, in limitati micro-domini, indicativa di un localizzato aumento della $X_{CO_2}$ nella fase fluida.

Le indagini geochimiche suggeriscono per tali metabasiti, protoliti basaltici con affinità alcalina e alcalino-transizionale tipici di ambiente intraplacca; i caratteri geochimici sono compatibili con una genesi per bassi gradi di fusione parziale di una sorgente di mantello arricchita. Sulla base di vincoli geologici e di considerazioni petrologiche, le metabasiti medio-

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triassiche studiate possono documentare lo stadio iniziale di lacerazione continentale, quale precursore dello sviluppo dei processi di oceanizzazione nell'area centro mediterranea.

KEY WORDS: *Triassic dyke magmatism; Rift magmatism; Calabrian-Peloritani Orogen.*

## INTRODUCTION

Low-grade metabasites are of great importance in the unravelling of the metamorphic and geodynamic history of a chain sector since the geochemical features of the protoliths are often well preserved during the metamorphism, allowing petrological and geodynamic considerations to be made. In the studied case, the metabasites may provide the only reliable evidences for the reconstruction of the extensional regimes which mark the initial phases of continental break-up.

Metabasites intruded as dykes and sills within the Triassic metasedimentary succession of the San Donato Unit are the subject of the present paper. The emplacement age is referred to Middle Trias (Macciotta *et al.,* 1986), corresponding to the age of the initial stages of continental rifting and subsequent oceanization that affected Pangea, later leading to the formation of the North Atlantic-Alpine Tethys oceanic system. In this framework we focus the attention on the geochemical features of the San Donato metabasites, with the aim to constrain the geodynamic environment of magma generation and to elaborate a petrogenetic model for these rocks.

## GEOLOGICAL SETTING

The studied area is located in northern Calabria, at the northern termination of the Calabrian Peloritani Orogen (CPO; Fig. 1). This Orogen

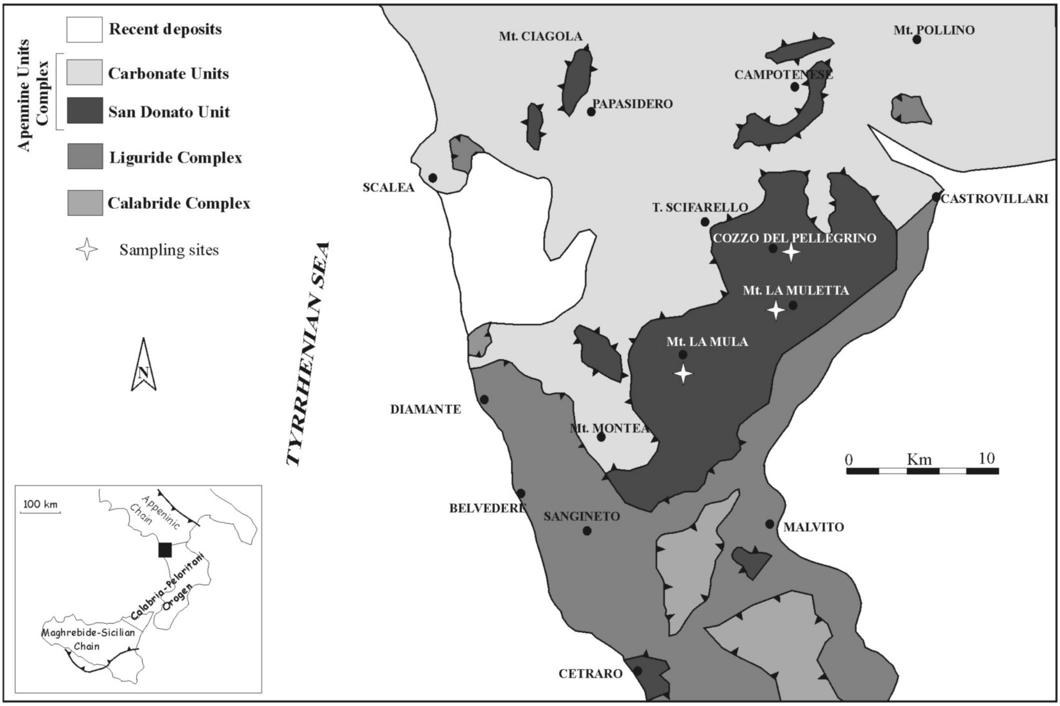


Fig. 1 - Geological sketch map of the north-western Calabria with location of the studied samples.

represents an arcuate segment, located in Central Mediterranean area, that connects the Maghrebian chain, in Sicily, and the Apennine thrust belts, in southern Italy. It is considered an Alpine orogenic belt derived from deformation of a palaeomargin during the Europa-Adria collisional event. The evolution and geodynamic significance of the Calabrian-Peloritani Orogen is still the subject of numerous and contrasting interpretations, leading to two main hypotheses: a) this domain is a fragment of the original European palaeo-margin (Ogniben, 1969; Bouillin *et al.,* 1986); b) it is a fragment of the original African domain emplaced onto the Appenninic domains during Neogene times (Haccard *et al*., 1972; Alvarez, 1976; Bonardi *et al*., 1982). The CPO has been subdivided into northern and southern sectors characterised by different geodynamic histories (Tortorici, 1982).

According to Ogniben (1973) and Morten and Tortorici (1993), the nappe system of the northern CPO can be subdivided in three main tectonic complexes: the Apennine units Complex at the base, the Liguride Complex in the intermediate position and the Calabride Complex at the top of the nappe edifice. These complexes were involved in the collision between the Iberian and Adria plates leading to the development of the present-day double vergent nappe system (Critelli, 1999 and reference therein).

In northern Calabria, the basal Apennine Unit Complex crop out in tectonic windows under the Sila and the Catena Costiera massifs and more extensively in the northernmost part of the region. It consists of low-grade Palaeozoic crystalline basement rocks and carbonate Mesozoic covers subdivided into several tectonic units (Ietto and Barilaro, 1993; Iannace *et al.,* 1995; Perrone, 1996). The San Donato Unit represents the lowermost unit of the Apennine Unit Complex cropping out in the studied area.

This unit consists of a sequence of siliciclastic and carbonate rocks with an overall thickness of 2500-3000 m and a Middle to Upper Trias age (Bousquet and Grandjacquet, 1969; Amodio Morelli *et al.*, 1976; Ietto and Barilaro, 1993). This succession was affected by several deformational phases and by Alpine metamorphism reaching greenschist facies conditions at P and T of 3-4 kbars and 300-400 °C, respectively (Dietrich, 1976). The entire succession may be subdivided in three main intervals: *1) Basal Terrigenous Complex*, composed by a thick sequence (~700-900 m) of siliciclastic sediments with limestone intercalations. Rock types are mostly represented by graphite-rich phyllites, calcschists and green to purplish quartzites; 2) *Intermediate Carbonate Complex*, consisting of a shelf margin sequence in stratigraphic and gradual contact with the underlying complex. The carbonate rocks crop out as small bodies of massive white marbles passing upwards and laterally to well layered black limestones and gray marbles ascribed to Anisian-Ladinian (Ietto and Romano, 2001); 3) *Upper Marly Dolomitic Complex*, developed in stratigraphic contact above the carbonate complex and mostly consisting in a dolomite succession, with maximum thickness of 700-800 m. The upper portions contain fossiliferous levels ascribed to Carnian (Broglio-Loriga *et al.,* 1993).

## Field and petrographic features of the metabasites

The metabasite dykes crop out extensively in the Mt. Pollino area; the dykes studied in this paper are located at Mt. La Mula (CF samples; N 39°40’50”, E 15°58’55”), Mt. La Muletta (CA samples; N 39°41’25”, E 15°58’46”) and Cozzo del Pellegrino (AF samples; N 39°42’36”, E 16°00’20”) localities (Fig. 1). They occur within the Basal Terrigenous Complex and in the Middle Carbonate Complex, while are absent in the upper Marly Dolomitic Complex. On these field evidences the dykes are therefore considered of Middle Triassic age (Macciotta *et al.,* 1986). The metabasites have been interpreted as original transitional basalts probably produced in a continental rift setting (Bonardi *et al.*, 1982; Macciotta *et al.,* 1986), related to strike-slip tectonics according to Zuppetta *et al.* (1984).

The metabasite dykes are meters thick, show a variable grey-green colour and appear massive to strongly foliated. Samples with a weakly developed metamorphic foliation show relics of an original porphyritic texture where phenocrysts of albite and pseudomorphs of epidote + actinolite after primary mafic minerals occur. A relic sieve texture sometimes occurs in plagioclase phenocrysts. The microcrystalline groundmass consists of albite + quartz + chlorite + epidote + calcite ± actinolite. The most common mineralogical assemblages are: albite + chlorite + actinolite + quartz + oxides and albite + chlorite + calcite + quartz + oxides.

On the basis of field and microstructural study, it is possible to identify two main deformational events. The first produced the main schistosity (S1) defined by the alignment of chlorite and amphibole, while the second event developed a crenulation cleavage on the previous surface locally producing a S2 foliation.

Actinolite occurs either as pseudomorphs, together with epidote, chlorite and quartz on former magmatic mafic phenocrysts, and as more or less aligned needles in the groundmass. Pyroxene relics may be found in the core of some actinolite crystals. Chlorite is present in association with actinolite in the pseudomorphs or aligned along S1; it is often present also as patches within grains of calcite forming millimetre-sized amygdales. Pale pleochroic epidote s.s. and clinozoisite occur in the groundmass. Quartz occurs in small crystals in the groundmass to form polycrystalline aggregates, and also in the calcite + chlorite amygdales. Fe-Ti-oxide minerals are present in the matrix as well as in the epidote + actinolite association.

## Analytical methods

Whole rock chemistry was determined by using XRF Philips PW1480 at the Dipartimento di Scienze della Terra, University of Calabria. Trace element concentrations were determined by using an ICP-MS system by solution nebulisation. The powder was dissolved by microwave digestion using Mars5 microwave apparatus (CEM technologies). In particular about 100 mg of powder were dissolved using a mixture of hydrofluoric acid (2 ml HF), nitric acid (8 ml $HNO_3$) and perchloric acid (2 ml $HClO_4$), all reagents are by Merck "suprapur" quality, into teflon (TFM) digestion vessels.

Before complete evaporation of acids 2ml of perchloric acid were to ensure complete removal of hydrofluoric acid. In order to obtain the solutions they were left to cool down gently and diluted to 100 ml with millipore water. For each sample we prepared two diluted solutions (1/4 and 1/5) and we used as internal standard indium, germanium and rhenium. The external calibration curves were prepared using Merck and Perkin Elmer standard solutions. Three external calibration curves were prepared: the first was prepared with Merck "ICP multielement standard solution VI" to analyse Ba, Co, Cr, Li, Ni, Rb, Sr, U, V, Zn; the second was prepared using Perkin Elmer "multi-element Calibration Standard 2 solution" to analyse REE (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu) and Sc,Y and Th; the third was prepared using Perkin Elmer mono-element solutions to analyse Zr, Nb, Hf and Ta.

Standard reference materials (QLO1 Quartz Latite and AGV2 Andesite) were prepared in the same way and were used as unknown sample; concentrations of the elements are compared with certified values to evaluate accuracy and precision of analytical data.

## Geochemistry

Eleven representative samples from the three studied dykes have been analysed to determine their composition in terms of major, trace and REE elements. The metabasites have $SiO_2$ contents

TABLE 1
*Major element compositions of the metabasite dykes (anhydrous value, wt.%).*

| Sample | AF1 | AF2 | AF3 | AF4 | CA1 | CA2 | CA3 | CF1 | CF2 | CF3 | CF4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 52.68 | 52.41 | 52.00 | 53.15 | 51.62 | 53.07 | 52.50 | 49.60 | 50.21 | 48.82 | 49.08 |
| $TiO_2$ | 1.51 | 1.42 | 1.06 | 1.89 | 1.74 | 1.56 | 1.81 | 1.70 | 1.90 | 1.52 | 1.68 |
| $Al_2O_3$ | 15.03 | 14.77 | 15.90 | 12.57 | 13.88 | 14.64 | 13.51 | 12.88 | 12.20 | 13.86 | 13.50 |
| $Fe_2O_{3(tot)}$ | 12.70 | 12.15 | 14.16 | 14.11 | 11.57 | 9.15 | 12.63 | 10.01 | 14.74 | 12.83 | 13.70 |
| MnO | 0.09 | 0.14 | 0.10 | 0.19 | 0.14 | 0.16 | 0.09 | 0.09 | 0.11 | 0.08 | 0.10 |
| MgO | 9.89 | 11.69 | 9.43 | 9.07 | 1.04 | 12.07 | 10.05 | 16.08 | 15.34 | 17.15 | 16.03 |
| CaO | 4.28 | 3.96 | 4.06 | 4.91 | 7.12 | 6.05 | 6.79 | 4.82 | 5.12 | 4.01 | 4.71 |
| $Na_2O$ | 3.03 | 2.92 | 2.50 | 3.12 | 2.56 | 3.07 | 2.85 | 0.67 | 0.21 | 1.40 | 0.92 |
| $K_2O$ | 0.57 | 0.37 | 0.61 | 0.78 | 0.0 | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 |
| $P_2O_5$ | 0.22 | 0.26 | 0.18 | 0.21 | 0.32 | 0.22 | 0.12 | 0.15 | 0.17 | 0.32 | 0.28 |
| LOI | 5.45 | 6.02 | 6.11 | 8.84 | 5.12 | 6.31 | 5.02 | 4.81 | 4.93 | 4.35 | 4.66 |

ranging from 48.8 to 53.1 wt.%, on an anhydrous basis (TABLE 1). Scattered CaO, $Na_2O$, $K_2O$, Sr, Ba and Rb contents of the analysed rocks are most likely the result of high degrees of post-magmatic modification, as also indicated by the high variable values of LOI (4.14-8.84 wt.%). Many incompatible elements and transition metals (e.g. Th, Ta, Hf, Zr, Nb, Ti, REE, Ni, Cr, V) (TABLE 2) are relatively immobile during alteration or low-grade metamorphism and are here used to describe the original magmatic features of the metabasites.

The samples plot in the alkali basalt field in the $Zr/TiO_2$ vs. Nb/Y diagram (Winchester and Floyd, 1977; not shown). In the Ti/Y vs. Nb/Y diagram (Fig. 2) the CA and CF samples plot in the within-plate basalt field and the AF samples in the transitional MORB. On the other hand, all the metabasites from the San Donato Unit studied by Macciotta *et al.* (1986) plot vexclusively in the within-plate field, along the transitional-alkaline basalts.

The studied samples are characterised by $TiO_2$ contents in the range of 1.06-1.90 wt.% and high Ti/V ratios ranging from 48 to 94 (Fig. 3). Ti/V ratios greater than 50 are considered exclusively representative for alkaline within-plate basalts (Shervais, 1982; Saccani and Photiades, 2005), whereas Ti/V ratios in the 20-50 range are the

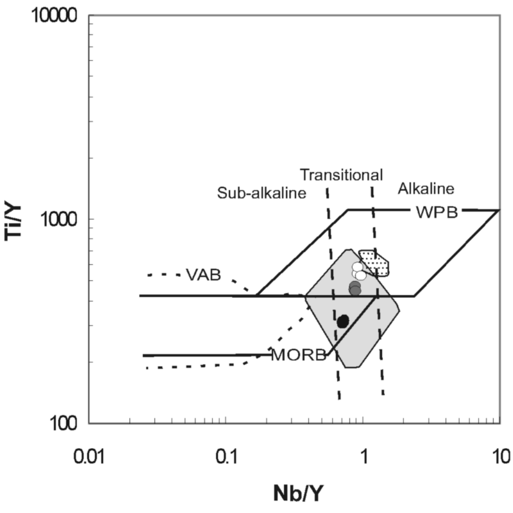


Fig. 2 - Ti/Y vs Nb/Y diagram (Pearce, 1982) for the Triassic metabasites from the San Donato Unit of Northern Calabria. Black circles: AF samples; grey circles: CF samples; white circles: CA samples. WPB, within plate basalts; MORB, mid-ocean ridge basalts; VAB, volcanic arc basalts. Dotted area represents composition of metabasite dykes from the Mt. Pollino area studied by Macciotta *et al.* (1986). Shaded area represents compositions of Triassic within-plate basalts from Mirdita-Subpelagonian mélange units (data from Saccani and Photiades, 2005).

Table 2
*Trace element compositions of the metabasite dykes (ppm).*

| Sample | AF1 | AF2 | AF3 | AF4 | CA1 | CA2 | CA3 | CF1 | CF2 | CF3 | CF4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| V | 128.47 | 129.20 | 116.08 | 169.25 | 129.11 | 99.85 | 143.63 | 159.30 | 158.40 | 144.63 | 209.31 |
| Cr | 315.89 | 318.50 | 274.02 | 393.35 | 264.27 | 198.09 | 280.28 | 363.63 | 361.75 | 317.60 | 449.50 |
| Co | 51.62 | 52.48 | 46.29 | 58.98 | 45.43 | 36.02 | 45.97 | 58.85 | 59.28 | 51.44 | 65.07 |
| Ni | 227.59 | 228.84 | 194.84 | 250.73 | 189.07 | 140.34 | 180.58 | 279.34 | 276.63 | 241.26 | 305.38 |
| Cu | 73.40 | 73.69 | 62.48 | 74.70 | 58.10 | 42.49 | 50.88 | 58.87 | 58.56 | 50.06 | 59.48 |
| Zn | 101.49 | 93.36 | 88.87 | 132.12 | 101.70 | 77.20 | 113.04 | 122.56 | 113.99 | 108.18 | 158.28 |
| Sr | 181.43 | 184.65 | 191.09 | 211.11 | 759.66 | 722.37 | 817.00 | 245.74 | 249.37 | 256.98 | 286.49 |
| Ba | 58.29 | 57.90 | 59.14 | 52.93 | 19.56 | 16.75 | 14.99 | 5.58 | 5.54 | 6.88 | 6.13 |
| Pb | 2.03 | 2.06 | 2.70 | 2.06 | 4.87 | 5.40 | 4.28 | 4.48 | 4.42 | 9.66 | 7.70 |
| Y | 26.16 | 26.83 | 27.38 | 27.21 | 20.48 | 18.39 | 18.48 | 21.66 | 21.57 | 21.78 | 22.00 |
| La | 16.87 | 17.02 | 17.94 | 17.71 | 13.96 | 12.36 | 12.51 | 13.33 | 13.16 | 13.69 | 13.86 |
| Ce | 27.41 | 27.56 | 29.42 | 29.18 | 29.07 | 26.32 | 26.52 | 28.71 | 28.62 | 30.44 | 30.67 |
| Pr | 4.48 | 4.58 | 4.96 | 4.93 | 4.02 | 3.75 | 3.77 | 3.89 | 3.85 | 4.21 | 4.20 |
| Nd | 21.38 | 21.60 | 23.87 | 23.62 | 18.28 | 17.52 | 17.96 | 18.00 | 18.05 | 19.48 | 19.66 |
| Sm | 5.39 | 5.53 | 6.08 | 6.02 | 4.81 | 4.44 | 4.56 | 4.71 | 4.72 | 5.15 | 5.15 |
| Eu | 2.00 | 2.03 | 2.24 | 2.21 | 1.71 | 1.63 | 1.65 | 1.72 | 1.68 | 1.83 | 1.86 |
| Gd | 6.77 | 6.88 | 7.33 | 7.24 | 5.83 | 5.29 | 5.40 | 5.91 | 5.84 | 6.12 | 6.17 |
| Tb | 0.90 | 0.92 | 1.01 | 1.01 | 0.81 | 0.77 | 0.76 | 0.85 | 0.83 | 0.91 | 0.91 |
| Dy | 4.91 | 4.92 | 5.43 | 5.35 | 4.40 | 4.13 | 4.14 | 4.66 | 4.61 | 4.98 | 4.97 |
| Ho | 0.79 | 0.80 | 0.80 | 0.78 | 0.71 | 0.59 | 0.60 | 0.78 | 0.75 | 0.72 | 0.72 |
| Er | 2.05 | 2.06 | 2.01 | 2.02 | 1.84 | 1.57 | 1.56 | 2.06 | 2.01 | 1.91 | 1.93 |
| Tm | 0.25 | 0.24 | 0.25 | 0.24 | 0.23 | 0.19 | 0.20 | 0.26 | 0.25 | 0.24 | 0.25 |
| Yb | 1.48 | 1.47 | 1.47 | 1.46 | 1.42 | 1.17 | 1.20 | 1.61 | 1.61 | 1.47 | 1.48 |
| Lu | 0.21 | 0.21 | 0.22 | 0.21 | 0.20 | 0.17 | 0.17 | 0.23 | 0.23 | 0.20 | 0.21 |
| Th | 1.55 | 1.52 | 1.53 | 1.58 | 1.60 | 1.36 | 1.34 | 1.80 | 1.72 | 1.71 | 1.74 |
| Zr | 118.18 | 116.39 | 123.70 | 121.23 | 119.03 | 100.54 | 96.61 | 138.38 | 136.23 | 109.79 | 106.49 |
| Nb | 19.99 | 19.75 | 19.44 | 19.29 | 19.52 | 16.85 | 16.77 | 19.49 | 19.10 | 19.08 | 19.03 |
| Cs | 0.89 | 0.88 | 0.88 | 0.87 | 0.03 | 0.03 | 0.03 | 0.07 | 0.07 | 0.07 | 0.07 |
| Hf | 3.18 | 3.19 | 3.19 | 3.13 | 3.09 | 2.57 | 2.55 | 3.82 | 3.81 | 2.92 | 2.84 |
| Ta | 1.56 | 1.48 | 1.25 | 1.22 | 1.06 | 1.00 | 0.99 | 1.22 | 1.24 | 1.22 | 1.18 |

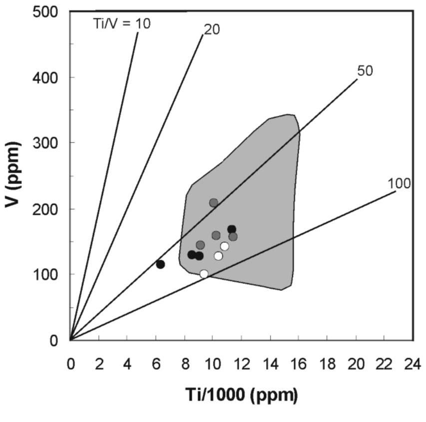


Fig. 3 - V vs. Ti/1000 diagram (Shervais, 1982) for the studied rocks. Ti/V<20, convergent plate margin basalts; 20<Ti/V<50, MORBs and continental flood basalts; Ti/V>50, alkaline within-plate basalts. Contoured area: within-plate basalts from Mirdita-Subpelagonian melange Units (data from Saccani and Photiades, 2005). Symbols as in Fig. 2.

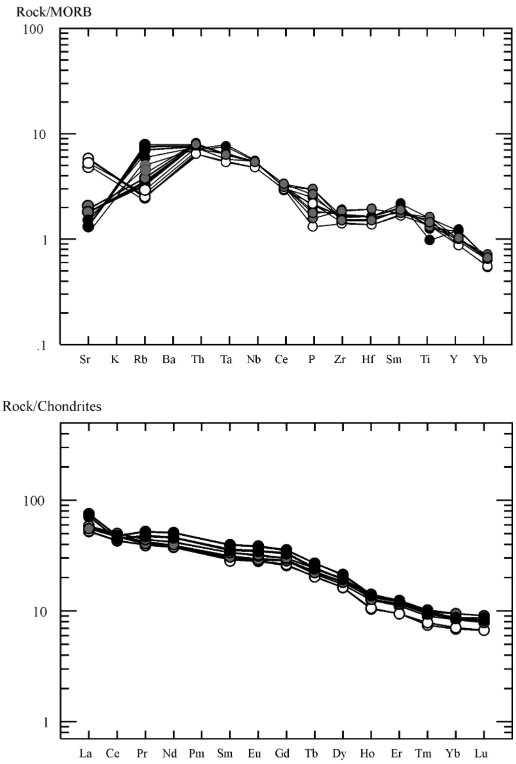


Fig. 4 - MORB-normalised spiderdiagrams and Chondrite-normalised REE patterns of the studied samples (Pearce, 1983; Sun and McDonough, 1989). Symbols as in Fig. 3.

typical values of MORBs (Shervais, 1982).

Mg# values are high in the CF samples (Mg# = 67.1-72.4), associated with highest Cr and Ni content (317-449 and 241-305, respectively). The other two dykes show lower Mg# values (CA = 60.9-72.1; AF = 55.7-65.2),, Cr (CA = 198-280 ppm; AF = 274-393 ppm) and Ni (CA = 140-189; AF = 195-251 ppm).

The MORB normalised spider diagrams, reporting the elements apparently less affected by mobility (Fig. 4), show identical patterns for the three dykes, perfectly fitting with that of E-type MORBs, and paralleling, at lower values, the OIB patterns of within plate alkali basalts.

Chondrite-normalized REE patterns are vary similar for the three dykes and are characterized by LREE enrichment compared to HREE, as indicated by the (La/Yb)N ratios, in the range 5.9-8.7, with the lowest and highest values for the CF and AF samples, respectively.

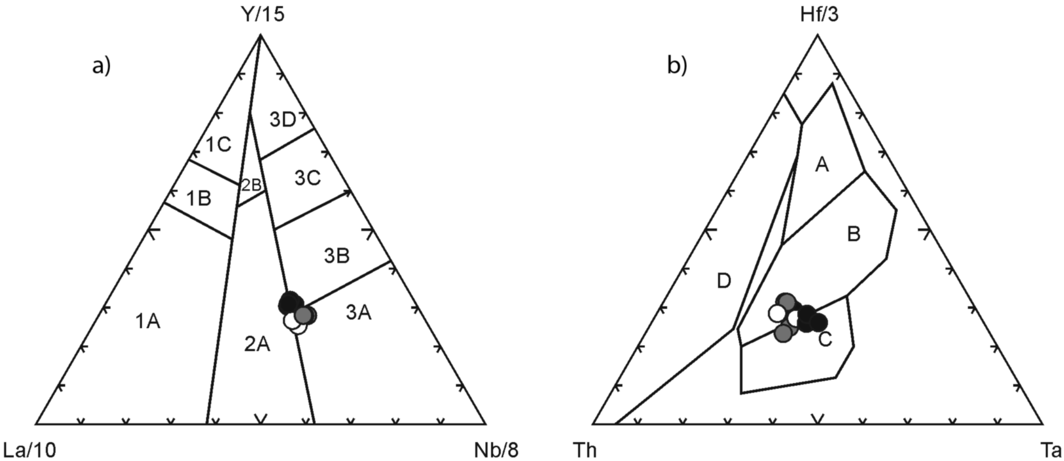


Fig. 5 - Tectonic discrimination diagrams for the studied metabasite dykes; a) La/10-Y/15-Nb/8 (Cabanis and Lecolle, 1989) 1A = calc-alkali basalts, 1C = volcanic-arc tholeiites, 1B = overlap area between 1A and 1C, 2A = continental basalts, 2B = back-arc basin basalts, 3A = alkali basalts from intercontinental rift, 3B = enriched-MORB, 3C = weakly enriched-MORB, 3D = N-type MORB; b) Hf-Th-Ta (Wood, 1980), A = N-type MORB, B = E-type MORB, C = alkaline within-plate basalts, D = volcanic-arc basalts. Symbols as in Fig. 2.

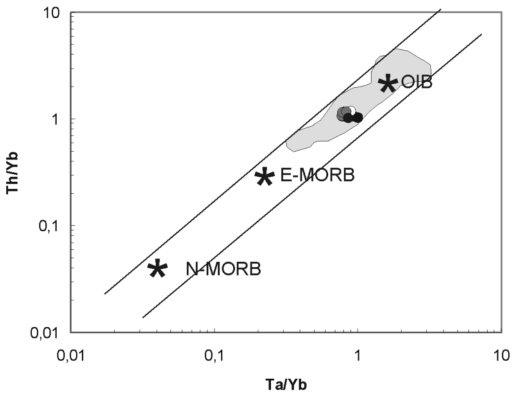


Fig. 6 - Th/Yb vs Ta/Yb diagrams for the metabasites, compared to Triassic transitional-alkali basalt (E-MORB to within-plate basalts) from the Hellenide Orogenic Belt (shaded area; reference data from Pomonis *et al.,* 2005; Saccani and Photiades, 2005). The diagonal band of constant Th/Ta ratio represents the MORB-OIB array). Compositions of N-MORB, E-MORB and OIB are from Sun and McDonough (1989). Symbols as in Fig. 2.

## Tectonomagmatic and petrogenetic implications

The tectonic setting of the San Donato metavolcanic rocks was tested using different tectonic discrimination diagrams, where the studied samples mostly straddle the boundary between the within plate basalts and E-MORBs (Fig. 5). In the Th/Yb vs. Ta/Yb diagram (Fig. 6) the studied samples plot within the MORB-OIB array, in the field representative for within-plate basalts generated by partial melting of an enriched mantle source and without evidence of significant continental crust contamination.

San Donato metabasites plot in the same field of Triassic volcanic rocks from the Hellenide Orogenic Belt such as the alkali basalts of Evia, Pindos, Avdella mélange and Koziakas (Pomonis *et al.,* 2005; Saccani and Photiades, 2005). Triassic within-plate basalts with geochemical features analogue to that of San Donato metabasites are also known from many other SE European regions (e.g., Samos, Mirdita-Subpelagonian zone, Cyprus, Romania, Turkey, Mallorca Island; Pe-Piper, 1998; Güngör and Erdogan, 2002; Saccani *et al.*, 2004; Saccani and Photiades, 2005; Lapierre *et al.,* 2007; Lustrino and Duggen, unpublished data).

All the above Triassic alkali metabasites have been considered linked to the Early Alpine-Tethys evolution and two main geodynamic settings are suggested to explain their OIB-type geochemical features, namely, seamount activity on ocean floor and continental rift-related magmatism.

The studied rocks display clear field relationships that rule out their emplacement in an oceanic environment, since some of the dykes are intruded within the basal mixed terrigenous-carbonatic sequence of the San Donato Unit. The most probable emplacement area of the San Donato Unit at the time of the Triassic magmatic activity is compatible with a thinned continental margin. The early geodynamic evolution of the Alpine Tethys is well constrained in the Albanide-Hellenide Subpelagonian zone where the main stages are represented by Early Triassic continental break-up along the northern Gondwana margin (Pe-Piper and Piper, 2002) and subsequent opening of the Pindos ocean between the Adria and Pelagonian margins since the Middle Triassic (Saccani *et al.,* 2003). The metabasites from the San Donato Unit offer the opportunity to reconstruct the early evolution of the Alpine Tethys for its, still mostly undocumented, westernmost domain.

The studied metabasalts display incompatible element and REE features very similar to those of E-MORB and OIB from various ancient and modern settings, suggesting an important participation of enriched mantle sources, not modified by subduction-related processes, in the magma generation processes.

In the Y/Nb vs. Zr/Nb diagram (Fig. 7), the data for the studied metabasites are plotted together with East Mediterranean Triassic E-MORBs and within-plate basalts and with modern oceanic basalts. The studied rocks plot

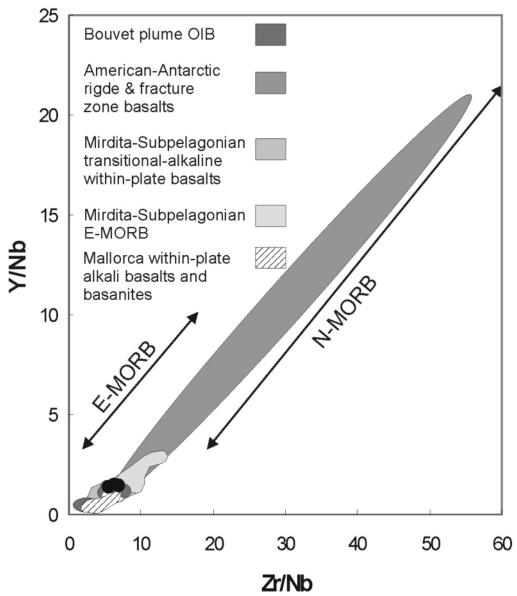


Fig. 7 - Y/Nb vs. Zr/Nb diagram with composition of metabasite dykes compared with east-Mediterranean Triassic E-MORB and within-plate basalts and with modern basalts influenced by upwelling mantle plume. Reference fields after Saccani and Photiades (2005) and Lustrino and Duggen (unpublished data). Symbols as in Fig. 2.

within the mixing field between OIBs and N-MORBs, very close to the pure OIB component, confirming the limited, if any, interaction with subduction-related components during their genesis. The studied metabasalts plot very close to the transitional-alkaline Subpelagonian within-plate basalts to E-MORB (Albanide-Hellenide Orogenic Belt) whose origin has been linked to interaction, at variable proportions, between uprising primitive asthenosphere and a OIB-type mantle source during middle-Triassic ocean basin formation between the Adria and Pelagonia micro-plates (Saccani and Photiades, 2005). They also show a close similarity with coeval Iberian rocks such as the Mallorca Island within-plate alkali basalts and basanites (Lustrino and Duggen, unpublished data).

According to many authors (e.g., Pe-Piper, 1998; Saccani and Photiades, 2005) these enriched transitional-alkaline basalts may have been emplaced either in oceanic islands or in a passive continental margin setting. Pe-Piper (1998) suggested that an OIB-type asthenospheric mantle source was involved in the generation of the Triassic rift-related alkali basalts of Greece. In this case a mantle plume was hypothesized, centred on the Antalya area (S Turkey) where huge volumes of alkali basalts were produced, and influencing MORB compositions even after the opening of the oceanic basins. According to Robertson (2002), small-scale plume effects, rather than large ones, are probably involved in some areas affected by rifting and it is possible that different relatively small plumes, with a spacing of hundreds of km, were involved in Triassic rifting in the Eastern Mediterranean. The geochemical features of San Donato metabasites are consistent with low degree partial melting of an enriched mantle source in a extensional setting. Based on regional reconstructions and petrological features, the Middle Triassic San Donato metabasites may document the early phases of continental break-up leading to the opening of the Alpine Tethys. This interpretation is in agreement with those of many authors (Cavazza and Wezel, 2003; Garfunkel, 2004; Passeri *et al*., 2005, and references therein; Ciarapica, 2007) believing that remnants of such a westernmost Tethyan branch, referred from time to time, as Mesozoic Ionian Basin, Ionian Tethys, East Mediterranean Basin, Sicanian-Lagonegro Basin and so on are at present, represented by the Ionian Sea and East Mediterranean.

In particular, a location during the Middle Triassic of the San Donato Unit on a thinned continental crust separating the European continental margin from the western margin of Adria, as suggested by Beccaluva *et al.* (2005) appears very likely (Fig. 8).

The observed mineralogical associations suggest that studied rocks experienced a multistage metamorphic evolution related to the

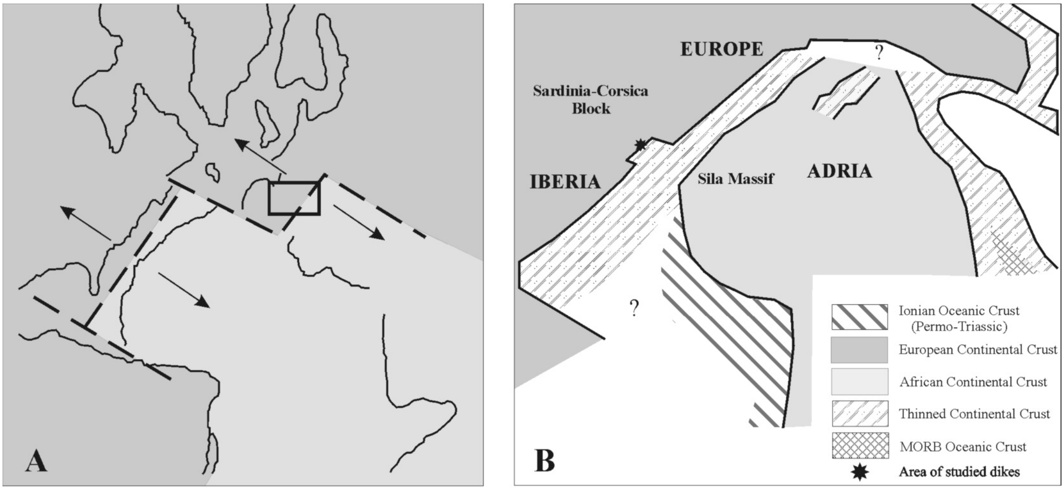


Fig. 8 - Hypothetic Triassic rift system in the central Mediterranean area (from Beccaluva *et al.,* 2005, modified).

Alpine orogenic cycle. The stage I is documented by the synkinematic actinolite + chlorite + clinozoisite assemblage suggesting greenschist facies thermobaric conditions. The calcite + chlorite + quartz association, found both in the amygdales and in the groundmass, is representative for the stage II and may be referred to the "Transitional Facies" of Cho and Liou (1987). The occurrence of the latter paragenesis suggests an increase of $X_{CO_2}$ in the fluid phase.

## CONCLUSIONS

Metabasite dykes and sills extensively intrude the Triassic carbonate sequence of the San Donato Unit (Mt. Pollino area, northern Calabria). Field constraints suggest the emplacement age may be ascribed to Middle-Upper Trias, corresponding to the age of the initial stages of continental rifting that affected the western Mediterranean area.

The dykes are meters wide, and appear massive to strongly foliated with relics of an original porphyritic texture. Metamorphic assemblages developed in two different stages: the first stage developed under greenschist facies conditions; the second stage produced the "Cal+Chl+Qtz" association ("Transitional Facies" of Cho and Liou, 1987), that overprinted the previous paragenesis, indicating $X_{CO_2}$ increase in the fluid phase. The presence of such metamorphic assemblages in these rocks is consistent with the hypothesis of the involvement of the European carbonate platforms in the subduction process under the western margin of the Adria plate.

Magmatic protoliths, of basaltic composition, reveal geochemical affinity with anorogenic magmatism. The trace element geochemistry is compatible with the hypothesis of derivation by partial melting of an enriched mantle source, without evidence of significant continental crust contamination. Tectonic discrimination diagrams suggest composition transitional between intracontinental rifting basalts and E-MORB.

Geochemical features indicate that these products can considered the precursor of the continental stretching and rifting process that led, during the Jurassic, to the opening of several oceanic basins bordering the Adria plate (Fig. 8).

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