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# Granitoid stones from Calabria (Southern Italy): petrographic, geochemical and petrophysical characterization of ancient quarries of Roman Age

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## Abstract

This paper reports the results of a petrographic, geochemical and petrophysical study of granitoid rocks from a Roman quarry close to the town of Parghelia (Calabria, southern Italy). Here, remnants of abandoned pillars and well preserved cuts testify that these materials were employed as building stones. The lithotypes cropping out in the Parghelia area consist of Late Variscan (~ 300 Ma) two-mica granitoids, occurring into two varieties: a dominant medium-coarse grained porphyritic granodiorite and a subordinate heterogranular granite. The granitoids from the quarry, for which we propose the term “Granito di Parghelia”, exhibit a restricted compositional range and distinctive petrographic characteristics, such as the occurrence of K-feldspar megacrysts and white mica, that result useful for archaeometric purposes. Moreover, ultrasonic investigation showed that Granito di Parghelia is characterised by average velocity values of compressional waves ~ 4.0 km/s, widely ranging even at mesoscopic scale; this heterogenous mechanical behaviour is due to microfractures and megacrysts distribution in the rocks. The above textural and physical features may provide helpful constraints in studies concerning the provenance and diffusion of granitoid rocks employed in monuments of archaeological importance in southern Italy and may shed new light about the granite trade in the Mediterranean during the Roman age.

*Key words:* Porphyritic granitoid; building material; Roman quarry; Calabria; Southern Italy.

## Introduction

Granite was a lithotype particularly appreciated by ancient Romans as building material. The Romans used to quarry the granitoid rocks all over the Mediterranean area and employed them in the most important centres of the Empire. As far as Italy is concerned, the main extraction sites at that time (Galetti et al., 1992) were the islands of Giglio (“Granito dell’isola del Giglio”), Elba (“Vecchio Granitello”) and Sardinia (“Granito sardo”). According to Galetti et al. (1992), the two former granitoid stones were only used in Rome and in other localities of central Italy, while the latter was diffused in the whole Italian territory. In southern Italy, despite Orsi (1926) speculated about the existence of a Roman extraction site at Nicotera (southern Calabria), no real evidence was obtained until Solano (1985) finally found the quarry and reported the first data about it. On the basis of pottery and coin findings, he also dated the extraction site to the first century A.D.; later Antonelli et al. (2010) proposed that the quarry was possibly abandoned in A.D. 369 after an earthquake destroyed the town of Nicotera, as also mentioned by Orosius in *Historiarum adversus paganos*. Nevertheless, it is worth noting that other extraction sites were repeatedly opened in the area and that the "Granito di Nicotera" has been exploited until very recent times. Cirrincione et al. (2003; 2004a, b) and Antonelli et al. (2010) studied and comprehensively characterised the "Granito di Nicotera" from a petrographic and geochemical viewpoint.

The occurrence of another ancient extraction site, located about 15 kilometers north of Nicotera, close to Parghelia town, was later reported by Cirrincione et al. (2003) and Solano (2003). These Authors provided preliminary information about the site, where remnants of abandoned pillars and well preserved cuts still occur. Unfortunately, no information about the employment and circulation of the granitoid stones from the Parghelia extraction site are currently available. Nevertheless, it is worth noting that in 2011 the Italian Ministry of Cultural Heritage and Activities declared the Roman quarry of Parghelia as an important archaeological site of Italy, because of the excellent conservation state, which permits direct observation of Roman exploitaion methodologies. At the same time, the archaeological site provides new information about stone materials used in antiquity and Roman granite trade in the Mediterranean area. The aim of the present work is a petrographic, geochemical and petrophysical characterization of the granitoid rocks exploited in the Roman quarry of Parghelia, which were employed and traded during the Roman period together with the most popular "Granito di Nicotera". The obtained results are useful as a reference in studies concerning the provenance and diffusion of granitoids employed in monuments of archaeological importance.

## Geological and petrographic background

The Capo Vaticano Promontory (CVP; southern Calabria), where the Roman extraction sites of Parghelia and Nicotera are situated, is a structural high located along the Tyrrhenian coast of the Calabria-Peloritani Orogen (CPO), an arcuate belt located in the central Mediterranean area (Figure 1). The CPO is mainly made up of pre-Mesozoic crystalline basement rocks including very low- to high-grade metamorphic rocks of Variscan and pre-Variscan age (e.g.; Schenk, 1990; Atzori et al., 1994; Graessner et al., 2000; Cirrincione et al., 2005; Appel et al., 2011; Williams et al., 2012) and large volumes of late Variscan plutonic rocks (~ 300 Ma; e.g., Del Moro et al., 1982; Rottura et al., 1990; Fornelli et al., 1994; Graessner et al., 2000; Fiannacca et al., 2005; 2008), which form quartz-diorite to granite batholiths in the Serre Massif-Capo Vaticano Promontory (southern Calabria) and in the Sila Massif (northern Calabria), as well as isolated and small leucotonalite to leucogranite plutons scattered along the whole orogen. The pre-Mesozoic basement rocks were locally overprinted at different extents during the Alpine metamorphic cycle, which also affected part of ocean and continent-derived Mesozoic units (Piluso et al., 2000; Pezzino et al., 2008; Cirrincione et al., 2009; 2012).

The CVP is bordered by several normal fault segments, mainly striking NE-SW and WNW-

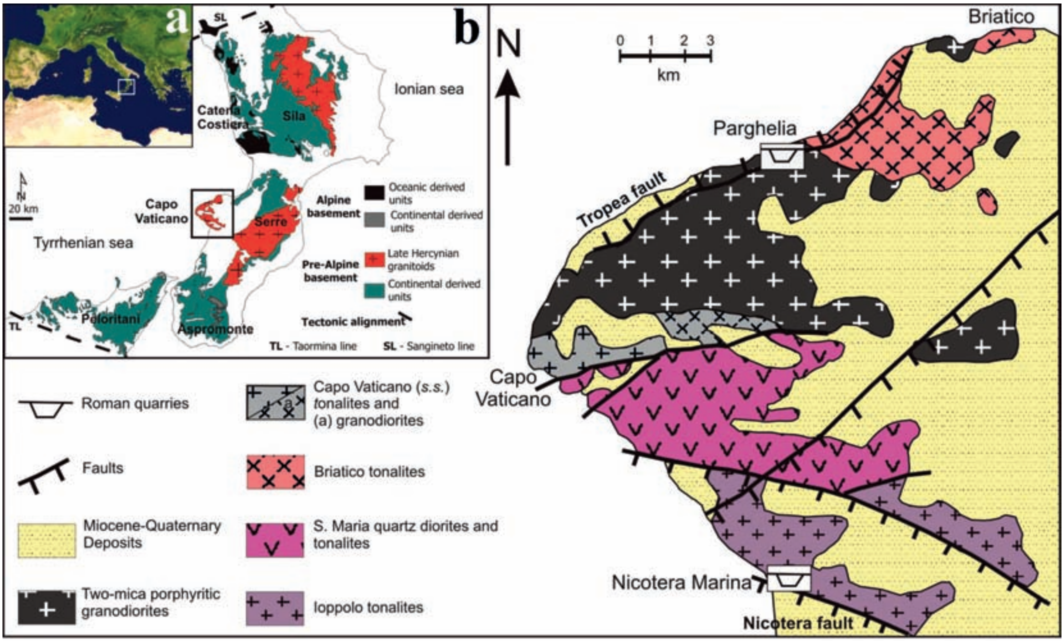


Figure 1. Geological sketch map of the Capo Vaticano Promontory (after Rottura et al., 1991; Antonelli et al., 2010, modified) with location of the Roman quarries. Inserts show: a) Location of the Calabria-Peloritani Orogen in the central Mediterranean area; b) Geological sketch map of the Calabria-Peloritani Orogen with distribution of basement units and late Variscan granitoids (after Angì et al., 2010, modified).

ESE, occurring also in the Tyrrhenian offshore and showing recent activity (Ghisetti, 1979; 1981; Monaco and Tortorici, 2000), as suggested by the 1905 seismic event that affected offshore of the CVP. In particular, the Tropea and Vibo faults, which are NW dipping, control the morphology of the northern part of the promontory since the coastline is characterised by steep morphology and by a trend parallel to these structures. Tortorici et al. (2003) identified six orders of marine terraces with their paleoshorelines and a top surface, relating them to the last main Quaternary highstands of the global eustatic curve. Moreover, according to the same Authors, the uplift rates in the Briatico and Tropea sectors are averagely 1mm/year.

The Capo Vaticano granitoids (Rottura et al., 1991) extend over an area of about 270 km$^2$, although they are largely covered by discontinuous remnants of Miocene and Pliocene carbonate and terrigenous deposits (Burton, 1971). The granitoids comprise dominant weakly peraluminous tonalites, accounting for about 65% of the exposed magmatic rocks, and strongly peraluminous porphyritic granodiorites with minor granites (~ 35%). A few quartz-diorites, as well as aplite-pegmatite dykes, locally occur. Tonalites are strongly foliated in the northern and southern part of the promontory (Briatico, S. Maria and Ioppolo tonalites) and weakly foliated in the central part (Capo Vaticano tonalites s.s.) where they are intruded by the granodiorites. The CVP tonalites are medium- to coarse-grained rocks composed of zoned plagioclase, quartz, biotite (~ 20 vol. %), small amounts of hornblende (< 5% vol.) and scarce interstitial K-feldspar.

Apatite, allanite (often rimmed by epidote), ilmenite, zircon and titanite are the main accessory phases. Quartz-diorite and tonalite microgranular enclaves, with both hornblende and biotite as mafic phases, are typically enclosed within the tonalites. Tonalites have $SiO_2$ contents in the range of 58-67% and show a calcalkaline affinity and a dominant weakly peraluminous composition, with A/CNK values mostly in the range of 1.0-1.1.

The CVP granodiorites are medium to coarse grained rocks, commonly porphyritic for the occurrence of euhedral K-feldspar megacrysts often defining a magmatic foliation. The rocks consist of quartz, euhedral plagioclase, perthitic and commonly poikilitic microcline, biotite and muscovite, with minor fibrolitic sillimanite and rare poikilitic garnet. Apatite, zircon, ilmenite and monazite occur as accessory phases. They lack mafic microgranular enclaves but typically contain centimetre-sized roughly polygonal mineral aggregates, consisting of muscovite and green-brown biotite with minor plagioclase and apatite, which probably formed at expenses of former cordierite. Granodiorites are acidic ($SiO_2$ = 68-73%) and mainly strongly peraluminous, with subordinate weakly peraluminous samples (A/CNK = 1.07-1.32).

According to Rottura et al. (1991) the tonalites from Capo Vaticano were generated by interaction of mantle-derived magmas with a large proportion of crustal material geochemically and isotopically akin to the CPV granodiorites. The granodiorites, in turn, have been considered mostly not related to the associated tonalites through processes of simple fractionation or assimilation-fractional crystallization. Their petrographic and geochemical features are better explained as the result of mixing processes between crustal acidic melts and components derived from tonalites by fractional crystallization or assimilation-fractional crystallization.

## The Roman granite quarries of the Capo Vaticano Promontory

The quarry of Parghelia sits on the CVP granodiorites (Figure 1) that, in the study area, occur into two varieties: a dominant medium-coarse grained porphyritic type and a subordinate heterogranular one (Figure 2a,b); in particular, the exploited granitoids belong to the porphyritic type. Surveys of the quarry, together with findings, suggest that it was likely active during the Roman period. It is noteworthy that, despite the granitoids of the area have been the subjects

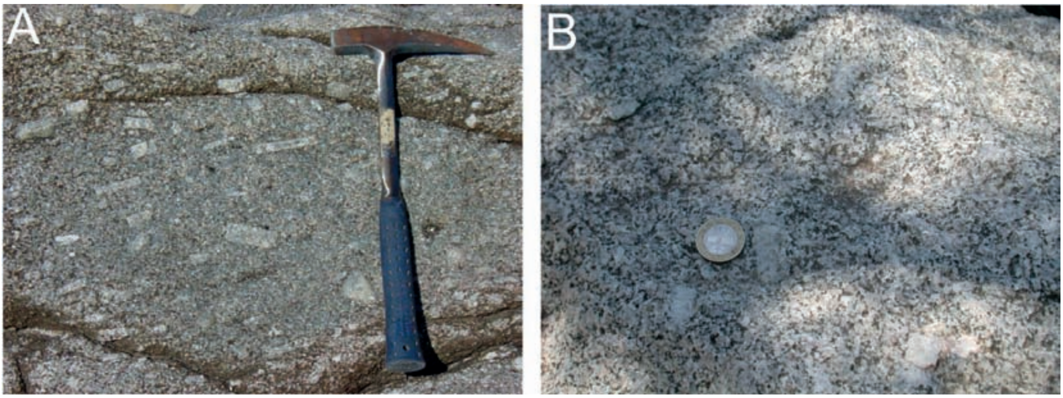


Figure 2. Details of the two varieties of granitoids which crop out at the quarry and its surroundings: a) “Porphyritic granitoid” (quarry front); b) Heterogranular granitoid variety (road cut near to the quarry site).

of petrological studies (Rottura et al., 1991 and references therein), only recently they have been dealt with as stones of archaeometric interest (e.g., Cirrincione et al., 2004a,b).

The quarry is located along the coastline close to Parghelia town, in the surroundings of Vibo Valentia city and, in particular, between a reef known as "La Pizzuta" and the harbour of Tropea town (Figure 3a,b); it extends from about 15 to 45 m above the sea level, running along the flanks of the cliff for about 60 meters in length. Along the abandoned quarry, which is partially covered by debris material, there are still several cuts and some paralellepipedal blocks as ruins (Figure 4a) whose size is around 2.80x0.50x0.50 m; some wegde holes are also present in the living rock (Figure 4b). Rounded unfinished pillars have been recently placed on the terrace of a touristic residence which has been built at the top of the cliff (Figure 4c,d); their lenght varies from 3.5 to 4.0 m and their diameter is about 0.7 m. The occurrence of remnants of abandoned pillars as well as unfinished slabs and columns supports evidence about the employment of such materials for both ornamental and structural purposes. Finally, several pieces of slabs from this site have been reported underwater as well (Cuteri et al., 2011).

It is noteworthy that, even though the Roman quarry of Parghelia is distant only a few kilometers from the quarry of Nicotera, the granitoids exploited at Parghelia are different from "Granito di Nicotera" in terms of mineralogical, petrographic and geochemical features. Indeed, the "Granito di Nicotera" is mostly a weakly peraluminous tonalite, while the typical rock type at the Parghelia site is a strongly peraluminous porphyritic granodiorite (Figure 1). At the scale of the outcrop, mesoscopic features easily allow identification of the two granitoid types. The lithotypes from the quarry of Nicotera consist of tonalite and

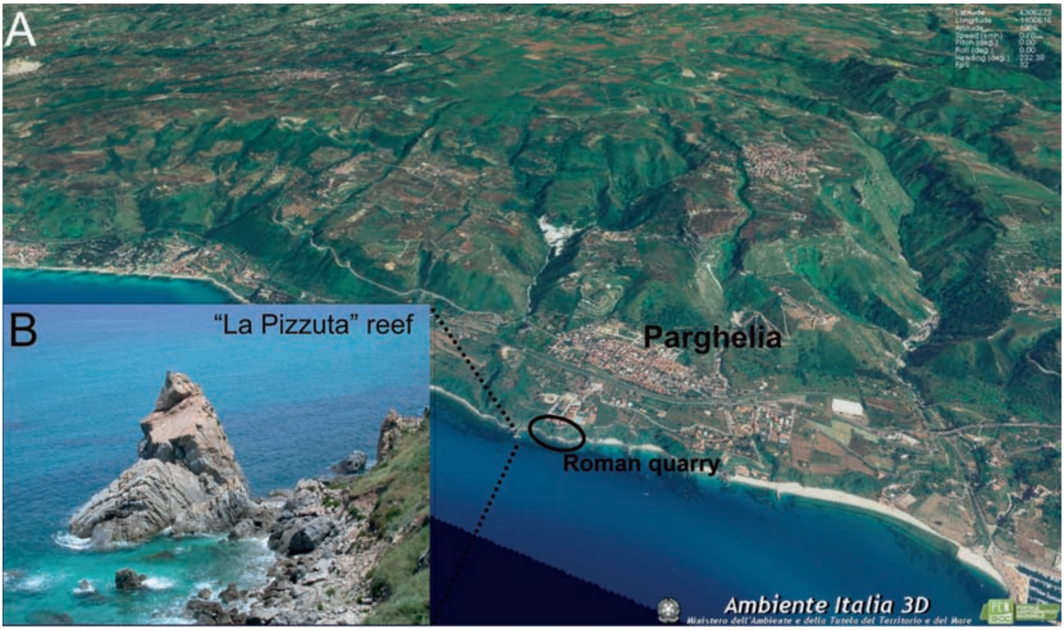


Figure 3. a) Location of the Roman extraction site at the cliff called "La Pizzuta", on the coastline near Parghelia; b) View of "La Pizzuta" reef (from which the cliff is named).

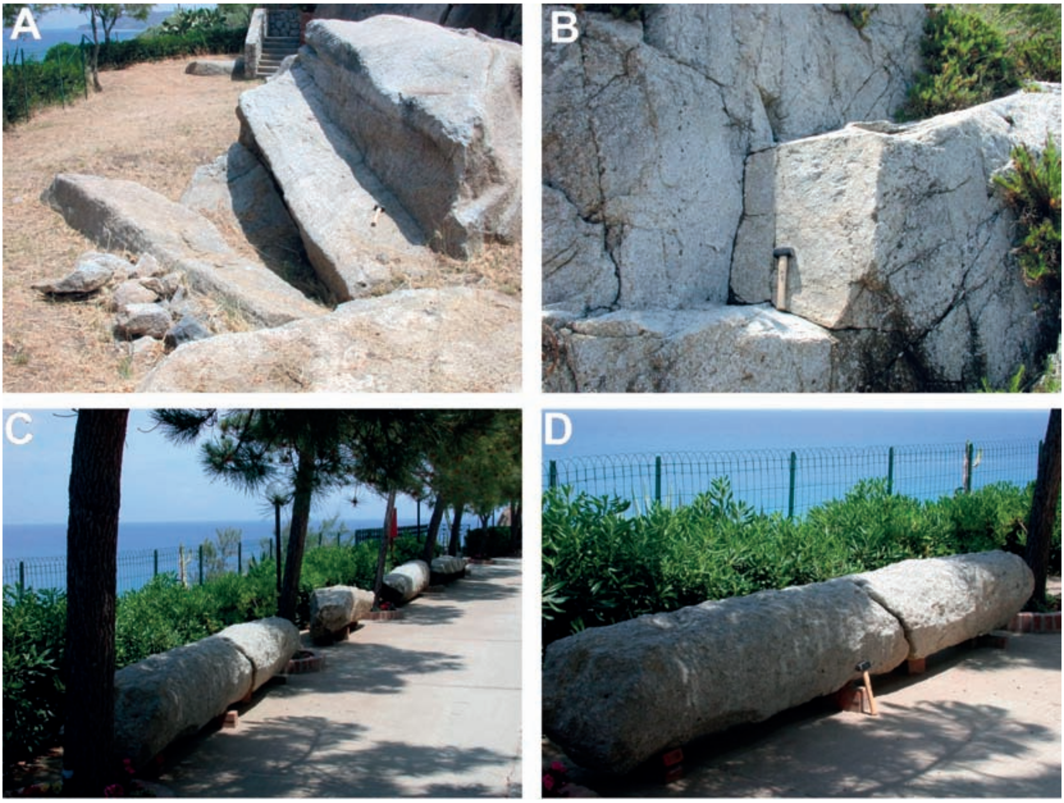


Figure 4. a, b) Parallelepipedal blocks and cuts of "Porphyritic granitoid" as remnants abandoned at the quarry; c, d) Rounded unfinished pillars placed on the terrace of a touristic residence at the top "La Pizzuta" cliff.

minor granodiorite (Cirrincione et al., 2004b; Antonelli et al., 2010), which are medium grained (~ 4.0 mm), with evident black spots of biotite representing the main mafic phase, and only minor amounts (1-3% vol.) of green hornblende. Plagioclase (oligoclase) is idiomorphic and sometimes zoned, while the rare K-feldspar (microcline) is often altered to clay minerals. Important, the texture of the Granito di Nicotera is hypidiomorphic and homogranular.

## Methods

In order to obtain a comprehensive characterisation of Parghelia granitoids, sample collection was carried out, within the extraction locality, according to two different criteria: on the one hand, we collected porphyritic granitoid samples detached from cuts and from pillars and slabs that were abandoned in the quarry ("KA" group); on the other hand, we also sampled heterogranular rock specimens in the area immediately above the quarry, close to the town of Parghelia ("PA" group), where marks of former exploitation are evident at a lesser extent.

Petrographic and petrophysical properties together with geochemical features were determined at Department of Biological, Geological and Environmental Sciences, University of Catania.

In consideration of the large abundance and uneven distribution of K-feldspar megacrysts in the studied granitoid rocks, representative modal classification was carried out with a point counter, by integrating the results from eight thin sections obtained from a grid on a representative sampled area (average: 2000 points for each section; Figure 5a,b). Petrographic features were also integrated with microscope observations on thin sections obtained by all of the rock specimens. In addition, in order to investigate the relationship between textural features and physical properties, we carried out ultrasonic wave velocity tests on representative granitoid samples from Parghelia (both KA and PA groups) as well as from Nicotera extraction sites. To this aim, ultrasonic wave velocity (Vp) test was carried out at standard laboratory conditions on specimens collected at the quarries, according to the ASTM designation (D2845-00). The device used for measurements of transit time (μs) is the PUNDIT 6 (CNS Farnell), with two different sets of transducers, operating at 54 and 200 kHz, respectively and an accuracy of ± 0.3 μs. XRF chemical investigation on major and selected trace elements of the KA and PA samples was carried out on rock powder pellets with a Philips PW 2404 spectrometer equipped with a Rh anticathode; for calibration we used numerous international geostandards. L.O.I. (weight loss on ignition) was determined by gravimetric method after leaving rock powders overnight into a furnace operating at 950 °C. Results are set out in Table 1.

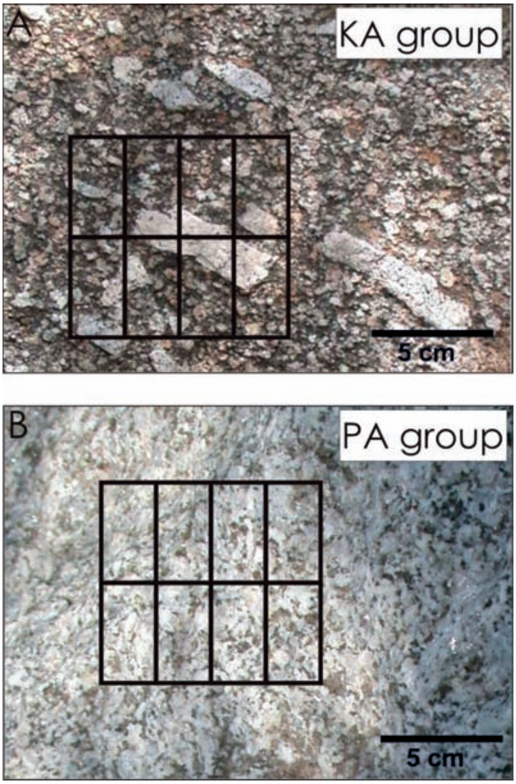


Figure 5. Integrating modal analyses from eight thin sections for a representative sampled area of each granitoid variety (KA and PA group, respectively).

## Petrography and physical properties

The KA porphyritic granitoids contain K-feldspar megacrysts, commonly defining a magmatic foliation (Figure 2a), up to 10 cm in lenght and set in a medium- to coarse-grained matrix (Figure 6a) mainly composed of quartz, plagioclase, K-feldspar, biotite and white mica; the two micas mostly occur as large crystals with common intergrowths (Figure 6b-d). In the PA-group, K-feldspar megacrysts are rarer and reach only 3-4 cm in length (Figure 2b); matrix-forming minerals (Figure 6e) are the same as in the KA group apart from the occurrence of fibrolitic sillimanite (Figure 6f), found in fine fibrous masses mainly enclosed within white mica, feldspars and along their contact; white mica is sometimes present as fine-grained aggregates (Figure 6g). Rare garnet may occur in both KA and PA groups (Figure 6h); zircon, apatite, opaques and monazite are the typical accessory phases. The Colour Index (CI) ranges from 15 to 21 and from 8 to 13 in the KA and PA granitoids, respectively.

Table 1. Major and selected trace element abundances of studied granitoid rocks.

| wt% | KA1 | KA2 | KA3 | KA4 | KA5 | KA6 | KA7 | PA1 | PA2 | PA3 | PA4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 69.31 | 68.40 | 68.28 | 68.79 | 66.92 | 69.95 | 70.14 | 72.45 | 72.39 | 72.62 | 72.25 |
| $TiO_2$ | 0.46 | 0.40 | 0.41 | 0.44 | 0.66 | 0.45 | 0.44 | 0.26 | 0.20 | 0.23 | 0.22 |
| $Al_2O_3$ | 15.97 | 16.69 | 16.05 | 16.37 | 16.02 | 15.89 | 15.50 | 15.52 | 15.78 | 15.38 | 15.63 |
| $Fe_2O_3$tot | 3.05 | 2.71 | 2.79 | 3.08 | 4.42 | 3.01 | 3.04 | 1.95 | 1.59 | 1.72 | 1.79 |
| MgO | 0.96 | 0.90 | 0.90 | 1.04 | 1.49 | 1.07 | 0.92 | 0.51 | 0.39 | 0.43 | 0.43 |
| MnO | 0.04 | 0.03 | 0.03 | 0.03 | 0.05 | 0.04 | 0.04 | 0.04 | 0.04 | 0.03 | 0.06 |
| CaO | 2.79 | 2.60 | 2.53 | 2.86 | 3.00 | 2.74 | 2.68 | 1.57 | 1.37 | 1.49 | 1.50 |
| $Na_2O$ | 3.30 | 3.04 | 3.08 | 3.29 | 3.01 | 3.21 | 3.41 | 3.49 | 3.35 | 3.45 | 3.39 |
| $K_2O$ | 3.37 | 4.70 | 3.91 | 3.63 | 3.17 | 3.29 | 2.83 | 3.75 | 4.46 | 3.90 | 3.96 |
| $P_2O_5$ | 0.09 | 0.11 | 0.10 | 0.10 | 0.21 | 0.07 | 0.06 | 0.11 | 0.12 | 0.11 | 0.11 |
| L.O.I. | 0.67 | 0.42 | 1.92 | 0.37 | 1.05 | 0.29 | 0.93 | 0.35 | 0.32 | 0.65 | 0.68 |
| ppm | | | | | | | | | | | |
| Pb | 34 | 9 | 41 | 36 | 30 | 31 | 27 | 31 | 30 | 20 | 21 |
| Ni | b.d. | b.d. | b.d. | b.d. | b.d. | b.d. | b.d. | b.d. | b.d. | 29 | 30 |
| Rb | 80 | 85 | 85 | 78 | 88 | 76 | 72 | 83 | 90 | 91 | 91 |
| Nb | 10.4 | 9.2 | 9.4 | 10.3 | 12.7 | 9.5 | 9.6 | 8.1 | 6.5 | 4.3 | 3.4 |
| Zr | 206 | 215 | 201 | 212 | 194 | 214 | 214 | 122 | 100 | 112 | 111 |
| Y | 25 | 20 | 24 | 23 | 29 | 25 | 28 | 23 | 19 | 19 | 25 |
| Sr | 336 | 349 | 337 | 329 | 300 | 329 | 311 | 193 | 193 | 234 | 234 |
| V | 18.0 | 13.9 | 16.0 | 15.2 | 26.3 | 16.6 | 16.7 | 6.7 | 5.3 | 5.1 | 6.1 |
| Ba | 1,360 | 2,260 | 1,770 | 1,490 | 1,150 | 1,290 | 1,100 | 728 | 956 | 772 | 731 |
| La | 58 | 60 | 58 | 61 | 55 | 61 | 61 | 34 | 28 | 18 | 24 |
| Ce | 116 | 119 | 116 | 121 | 110 | 121 | 122 | 68 | 55 | 33 | 33 |
| Th | 17.2 | 17.2 | 17.4 | 18.7 | 17.4 | 18.4 | 18.6 | b.d. | b.d. | 8.6 | 8.5 |

b.d = below detection limits.

Table 1. Continued...

| wt% | PA5 | PA6 | PA7 | PA8 | PA9 | PA10 | PA11 | PA12 | PA13 | PA14 | PA15 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 71.35 | 71.88 | 72.51 | 72.94 | 72.81 | 72.22 | 72.93 | 73.24 | 73.16 | 71.53 | 72.29 |
| $TiO_2$ | 0.25 | 0.38 | 0.24 | 0.20 | 0.23 | 0.22 | 0.24 | 0.22 | 0.19 | 0.20 | 0.23 |
| $Al_2O_3$ | 16.02 | 14.74 | 15.48 | 15.32 | 15.25 | 14.78 | 15.27 | 15.16 | 15.52 | 16.10 | 15.53 |
| $Fe_2O_3$tot | 1.96 | 2.54 | 1.72 | 1.59 | 1.73 | 1.69 | 1.78 | 1.61 | 1.45 | 1.57 | 1.69 |
| MgO | 0.51 | 0.81 | 0.47 | 0.39 | 0.44 | 0.43 | 0.47 | 0.44 | 0.36 | 0.34 | 0.43 |
| MnO | 0.04 | 0.04 | 0.03 | 0.03 | 0.04 | 0.04 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| CaO | 1.46 | 2.13 | 1.54 | 1.31 | 1.31 | 1.36 | 1.36 | 1.17 | 1.26 | 1.34 | 1.48 |
| $Na_2O$ | 3.34 | 2.93 | 3.32 | 3.31 | 3.17 | 3.31 | 3.31 | 2.95 | 3.29 | 3.49 | 3.62 |
| $K_2O$ | 4.15 | 3.74 | 3.89 | 4.12 | 4.29 | 3.87 | 4.06 | 4.62 | 4.42 | 4.72 | 3.82 |
| $P_2O_5$ | 0.12 | 0.09 | 0.10 | 0.11 | 0.12 | 0.13 | 0.12 | 0.14 | 0.13 | 0.14 | 0.11 |
| L.O.I. | 0.78 | 0.73 | 0.70 | 0.69 | 0.63 | 1.96 | 0.44 | 0.44 | 0.19 | 0.53 | 0.76 |
| ppm | | | | | | | | | | | |
| Pb | 21 | 19 | 20 | 21 | 34 | 20 | 20 | 23 | 22 | 24 | 27 |
| Ni | 26 | 31 | 28 | 27 | b.d. | 25 | 29 | 29 | 25 | 30 | b.d. |
| Rb | 99 | 80 | 91 | 97 | 92 | 90 | 95 | 105 | 103 | 104 | 80 |
| Nb | 5.2 | 7.2 | 4.0 | 3.8 | 7.3 | 3.9 | 4.1 | 3.5 | 2.9 | 3.4 | 7.1 |
| Zr | 108 | 158 | 113 | 96 | 98 | 103 | 102 | 92 | 93 | 96 | 106 |
| Y | 19 | 18 | 17 | 16 | 15 | 19 | 19 | 18 | 18 | 19 | 16 |
| Sr | 232 | 331 | 240 | 222 | 180 | 225 | 229 | 213 | 224 | 248 | 195 |
| V | 6.4 | 12.7 | 6.3 | 5.2 | 5.2 | 6.9 | 6.0 | 6.0 | 3.7 | 5.4 | 5.8 |
| Ba | 720 | 1,115 | 847 | 631 | 688 | 592 | 681 | 661 | 677 | 1,031 | 761 |
| La | 24 | 39 | 22 | 15 | 25 | 25 | 31 | 21 | 26 | 30 | 33 |
| Ce | 40 | 64 | 26 | 26 | 49 | 45 | 43 | 39 | 35 | 45 | 65 |
| Th | 8.4 | 9.0 | 7.7 | 7.1 | b.d. | 7.9 | 8.7 | 7.5 | 6.3 | 7.0 | b.d. |

b.d = below detection limits.

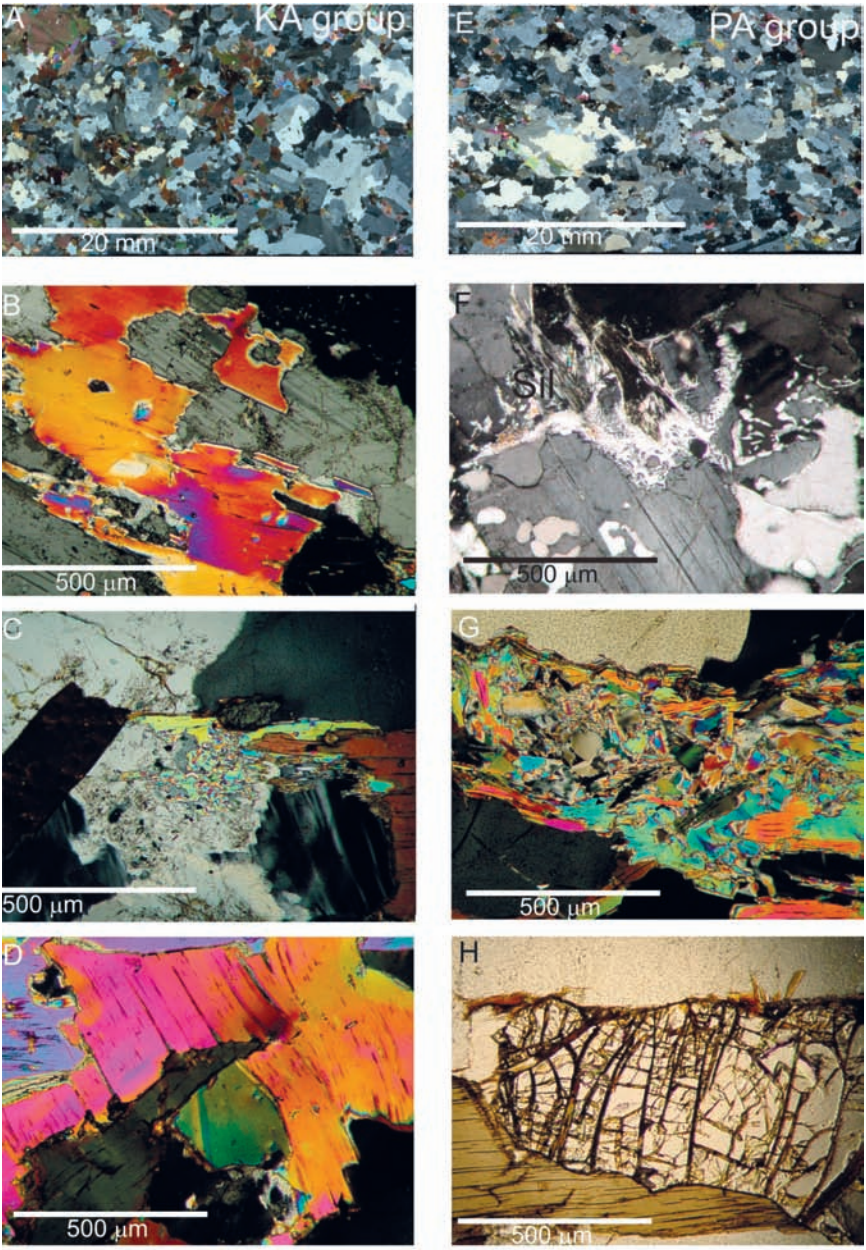


Figure 6. Selected photomicrographs. a-d) KA group (porphyritic granitoid). a) Detail of the matrix; b) Resorbed muscovite grain in contact with plagioclase and K-feldspar; c) Micas intergrowths; d) Large white mica grains. e-h) PA group (heterogranular variety). e) Details of the matrix; f) Fine fibrous masses of fibrolitic sillimanite as replacement of muscovite along contact among plagioclase, K-feldspar and quartz; g) Fine grained mica aggregates; h) Garnet and biotite. All pictures taken at crossed polarizers except for picture h (lower polarizer).

According to the modal abundances, the KA granitoid rocks classify as granite with minor granodiorite, whereas the PA group falls into the granodiorite field (Figure 7).

The two varieties, i.e. porphyritic (KA group) and heterogranular (PA group), are characterised by different behaviour in terms of elastic properties. Indeed, the porphyritic variety, which is characterised by visible microfracturing mostly developed around and/or inside feldspar megacrysts, shows on the whole relatively low ultrasonic wave velocity values (average ~ 4.0 km/s). In particular, the matrix is characterised by average velocity of about 4.6 km/s, whereas values drop down to ~ 3.3 km/s close to microfractures and increase up to 4.8 km/s in the megacrysts (Figure 8). This causes a physical behaviour, in agreement with textural features, to be

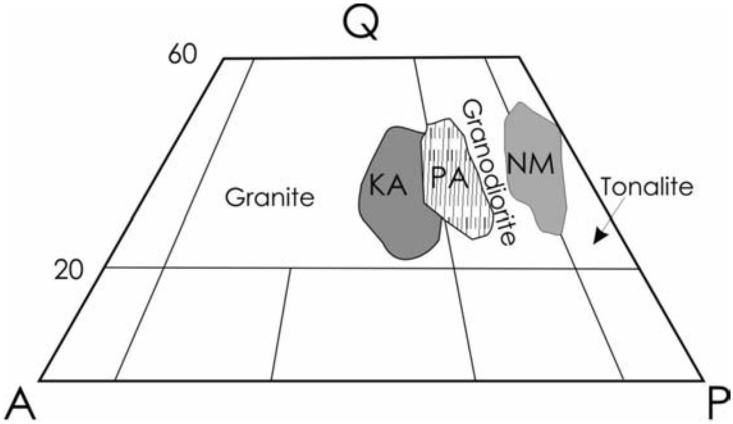


Figure 7. Petrographic classification based on the QAPF diagram (Streckeisen, 1973) of granitoids from the Roman quarry at “La Pizzuta” (KA group) and the area immediately above the quarry (PA group). For comparison, field of granitoids from the quarry of Nicotera (NM) is also reported (after Cirrincione et al., 2004b; Antonelli et al., 2010).

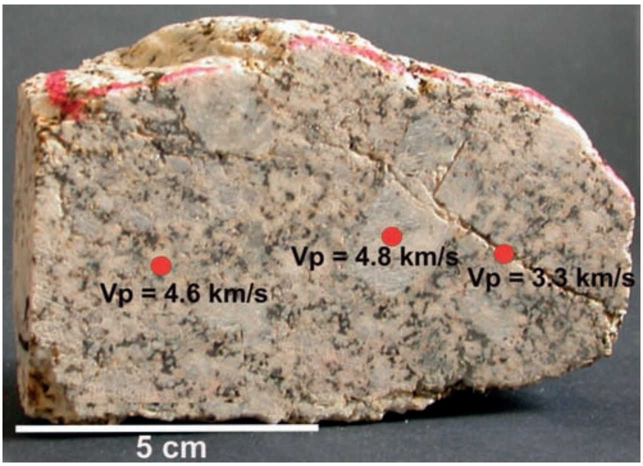


Figure 8. Ultrasonic velocity distribution within an hand-scale granitoid specimen.

heterogeneous even within the same lithotype and an overall poor elastic quality. Indeed, the Rock Quality Index (QI; Tourenq et al., 1971), which is the ratio between measured and theoretical compressional velocity according to the formula QI= $Vp_{measured/}\sum Vp_i M_i$ *100 (where $Vp_i$ and $M_i$ are the compressional velocity of each constituting mineral phase and its modal percentage, respectively) ranges from 50% (at the microfractures) to ~ 80% (average matrix). Compared to the porphyritic group, the heterogranular one shows higher velocity and QI values (average ~ 4.9 km/s and 83%, respectively). Interestingly, these latter specimens behave homogeneously by taking into account the velocity distribution. Finally, for a comparison we also determined the average ultrasonic wave velocity (whose distribution is homogeneous) for the "Granito di Nicotera" (average value = 4.7 km/s; QI ~ 80%).

## Geochemistry

The Parghelia granitoid rocks show a strongly peraluminous composition (A/CNK > 1.1) and a calcalkaline affinity (Figure 9), in agreement with Rottura et al. (1991). Two different compositional groups have been identified, even if, in apparent contrast with the results of petrographic investigations, samples collected from columns and from the extraction site (KA samples) classify all as granodiorites in the R1-R2 diagram (Figure 10), while samples from the top of the quarry (PA samples) plot in the granite field, close to the boundary with the granodiorites. Because of the marked grain size heterogeneity within both KA and PA sub-types, we rely on classification based on geochemical features that takes into account a much larger rock volume. Compositions of other porphyritic granitoids from the CPO as well as those of the "Granito di Nicotera" (Table 2; Antonelli et al., 2010) have also been plotted for comparison in the same R1-R2 diagram. It is possible to observe that the granitoids from the two Roman quarries of Nicotera and Parghelia, other than showing specific structural and modal features are clearly distinguishable also on geochemical grounds. The same can be said after comparing the KA samples with other CPO granitoid rocks sharing similar field and thin section characteristics such as the porphyritic granitoids from Parghelia and other CVP localities (Rottura et al., 1991), as well as the K-feldspar megacryst-bearing granitoids from the adjacent Serre Massif (Del Moro et al., 1994).

The KA samples are all acidic, with a $SiO_2$ content in the range 67.6-70.8 wt%. Their relatively restricted composition is observable in many major and trace element vs. $SiO_2$ diagrams (e.g., MgO, $FeO_{tot}$, $TiO_2$, CaO, Sr, La vs. $SiO_2$), where the KA porphyritic granodiorites plot within well defined fields, distinguishable from the PA samples as well as from the less evolved tonalites from Nicotera and from the other porphyritic granitoids from southern CPO (Figure 11). In the Harker diagrams element variations are mostly not regular, but studied samples plot along trends of general negative correlation for MgO, $FeO_{tot}$, $TiO_2$, $Al_2O_3$, CaO, Sr, Ba and positive correlation for $Na_2O$, $K_2O$ and Rb. In some diagrams (especially in the $K_2O$, Rb, Sr, Ba, La vs. $SiO_2$ diagrams) the porphyritic granitoids appear to define different trends from those defined by the Nicotera tonalites that, as already suggested in other studies (e.g., Rottura et al., 1991), would indicate the lack of simple genetic links between the granodiorite and tonalite rocks. Besides, within the porphyritic types it is possible to notice that the KA samples show typical "internal" positive correlation for $TiO_2$ and La and negative correlation for Rb, Sr and Ba, that differ from the behaviour showed by the porphyritic granitoids from other localities. It is also to be noticed that, among the investigated groups, the KA samples show averagely the highest Zr, Y, LREE, Sr, Ba,

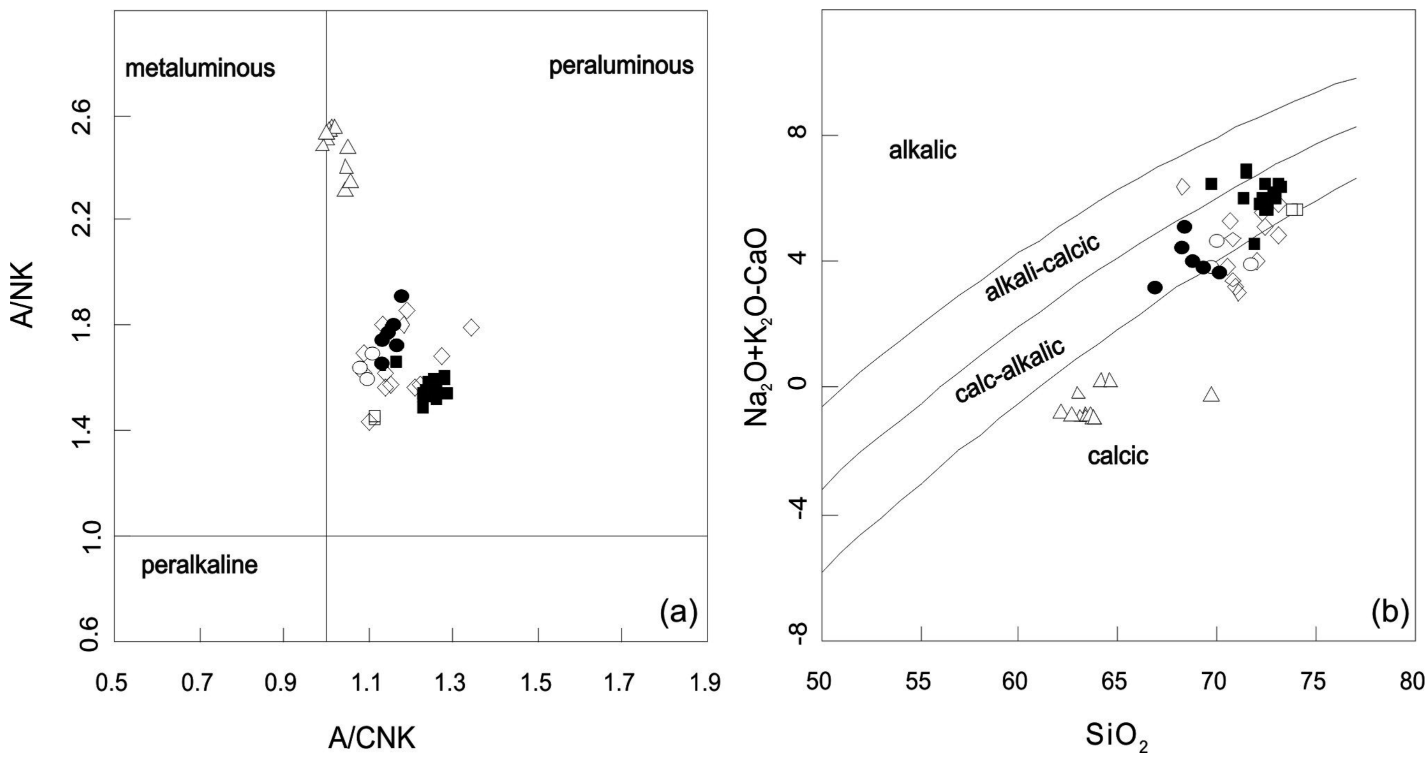


Figure 9. a) $Al_2O_3/(CaO+Na_2O+K_2O)$ vs. $Al_2O_3/(Na_2O+K_2O)$ molar diagram (after Shand, 1943); and b) $SiO_2$ vs. $Na_2O+K_2O-CaO$ diagram (after Frost et al., 2001) for KA (black circles) and PA (black squares) granitoid samples from the Parghelia extraction site. In the diagram are also plotted for comparison the compositions of other granitoid rocks from central Calabria. Rhombs = porphyritic granodiorites from Capo Vaticano Promontory (Rottura et al., 1991); white circle = porhyritic granodiorites from Serre Massif (Del Moro et al., 1994); white squares = porhyritic granites from Serre Massif (Del Moro et al., 1994); triangles = tonalites from Nicotera extraction site (Cirrincione et al., 2004b).

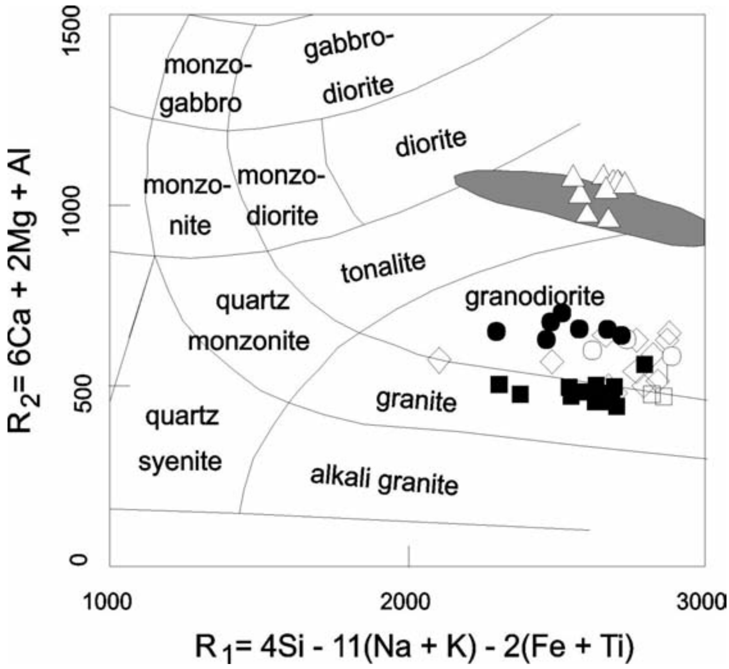


Figure 10. Geochemical classification of studied rocks in the multicationic R1R2 diagram of De La Roche et al. (1980). Shaded area: tonalites from Nicotera extraction site (Antonelli et al., 2010). Symbols as in Figure 9.

Th and Ce contents (e.g., Figure 12a) and the lowest Ni and $P_2O_5$ contents. Finally, by taking into account the proposed existence of two different CVP granodiorite types characterized by different degrees of enrichment in Rb and internal positive correlation of Rb vs. Ba (Rotttura et al., 1991), the KA granodiorites result to belong to the "low-Rb" granodiorite group (Figure 12b).

## Final comments

This study focuses on the characterisation of a Roman quarry close to the town of Parghelia, for which no literature data are available. Our results show that, on the whole, the petrographic and geochemical characteristics of the granitoids from this ancient quarry are peculiar and therefore they are distinguishable from similar granitoids of Calabria as well as from other granitoid stones traded in antiquity in the Mediterranean area. For this stone material we propose the name "Granito di Parghelia", which corresponds to a two-mica porphyritic granodiorite, exhibiting a restricted compositional range and specific petrographic characteristics, such as the occurrence of K-feldspar megacrysts and abundant white mica, which make it peculiar in terms of archaeometric purposes. These features may indeed provide important constraints in studies concerning the granitoid stones trade during the Roman age as well as the provenance of granitoids employed in monuments of archaeological importance in southern Italy (e.g. Galetti et al., 1992; De Vecchi et al., 2000; Punturo et al., 2003; Antonelli et al., 2010).

Table 2. Major and selected trace element abundances of "Granito di Nicotera" from Cirrincione et al. (2004b).

| wt% | NM1 | NM2 | NM3 | NM4 | NM5 | NM6 | NM7 | NM8 | NM9 | NM10 | NM11 | NM12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 64.09 | 64.63 | 69.68 | 63.00 | 63.41 | 62.13 | 63.13 | 63.41 | 63.72 | 63.64 | 62.69 | 63.82 |
| $TiO_2$ | 0.65 | 0.63 | 0.46 | 0.85 | 0.68 | 0.76 | 0.69 | 0.69 | 0.67 | 0.70 | 0.67 | 0.66 |
| $Al_2O_3$ | 16.21 | 16.12 | 15.56 | 16.71 | 16.00 | 16.15 | 16.43 | 16.18 | 16.10 | 16.13 | 16.03 | 16.02 |
| $Fe_2O_3$tot | 5.27 | 5.03 | 2.81 | 5.30 | 5.56 | 6.14 | 5.52 | 5.50 | 5.45 | 5.54 | 5.47 | 5.36 |
| MgO | 2.79 | 2.73 | 1.54 | 3.02 | 3.43 | 3.45 | 3.42 | 3.31 | 3.29 | 3.40 | 3.24 | 3.24 |
| MnO | 0.08 | 0.07 | 0.05 | 0.10 | 0.10 | 0.11 | 0.10 | 0.09 | 0.10 | 0.10 | 0.10 | 0.10 |
| CaO | 4.81 | 4.74 | 4.68 | 5.15 | 5.39 | 5.50 | 5.50 | 5.44 | 5.43 | 5.40 | 5.29 | 5.42 |
| $Na_2O$ | 2.80 | 2.77 | 3.06 | 2.52 | 2.65 | 2.55 | 2.71 | 2.69 | 2.70 | 2.62 | 2.68 | 2.68 |
| $K_2O$ | 2.23 | 2.14 | 1.34 | 2.41 | 1.87 | 2.14 | 1.84 | 1.81 | 1.78 | 1.90 | 1.74 | 1.78 |
| $P_2O_5$ | 0.20 | 0.19 | 0.10 | 0.19 | 0.19 | 0.18 | 0.17 | 0.17 | 0.17 | 0.18 | 0.18 | 0.17 |
| L.O.I. | 0.87 | 0.92 | 0.72 | 0.76 | 0.74 | 0.90 | 0.49 | 0.72 | 0.59 | 0.39 | 1.93 | 0.77 |
| ppm | | | | | | | | | | | | |
| Pb | 4.2 | 4.3 | 4.2 | 9.6 | - | - | - | - | - | - | - | - |
| Ni | 36 | 38 | 34 | 35 | - | - | - | - | - | - | - | - |
| Rb | 79 | 78 | 43 | 78 | - | - | - | - | - | - | - | - |
| Nb | 6.0 | 4.9 | 2.3 | 7.0 | - | - | - | - | - | - | - | - |
| Zr | 106 | 106 | 115 | 152 | - | - | - | - | - | - | - | - |
| Y | 9.2 | 8.6 | 8.1 | 8.5 | - | - | - | - | - | - | - | - |
| Sr | 281 | 282 | 308 | 299 | - | - | - | - | - | - | - | - |
| V | 89 | 80 | 50 | 93 | - | - | - | - | - | - | - | - |
| Ba | 667 | 638 | 385 | 838 | - | - | - | - | - | - | - | - |
| La | 16.1 | 8.3 | 15.3 | 7.9 | - | - | - | - | - | - | - | - |
| Ce | b.d. | 11.4 | 9.7 | 3.3 | - | - | - | - | - | - | - | - |

b.d. = below detection limits; - = not available.

Currently, the only finds which are likely to be related to the "Granito di Parghelia" come from the archaeological site of Sibari (northern Calabria), and in particular from "Parco del Cavallo", where some small fragments of pillars, made of porphyritic granite, have been collected. Petrographic investigation carried out on one fragment from the Sibari site matched several features of the Parghelia quarry, whereas the size of samples collected from the archaeological site was not large enough to allow truly representative geochemical data to be obtained. At the moment, no other similar findings are reported; however, it is worth noting that similar porphyritic granitoids have been recognised in some monuments located in the city of Syracuse (Sicily). Finally, the apparent limited diffusion of the "Granito di Parghelia" in the monuments during the Roman

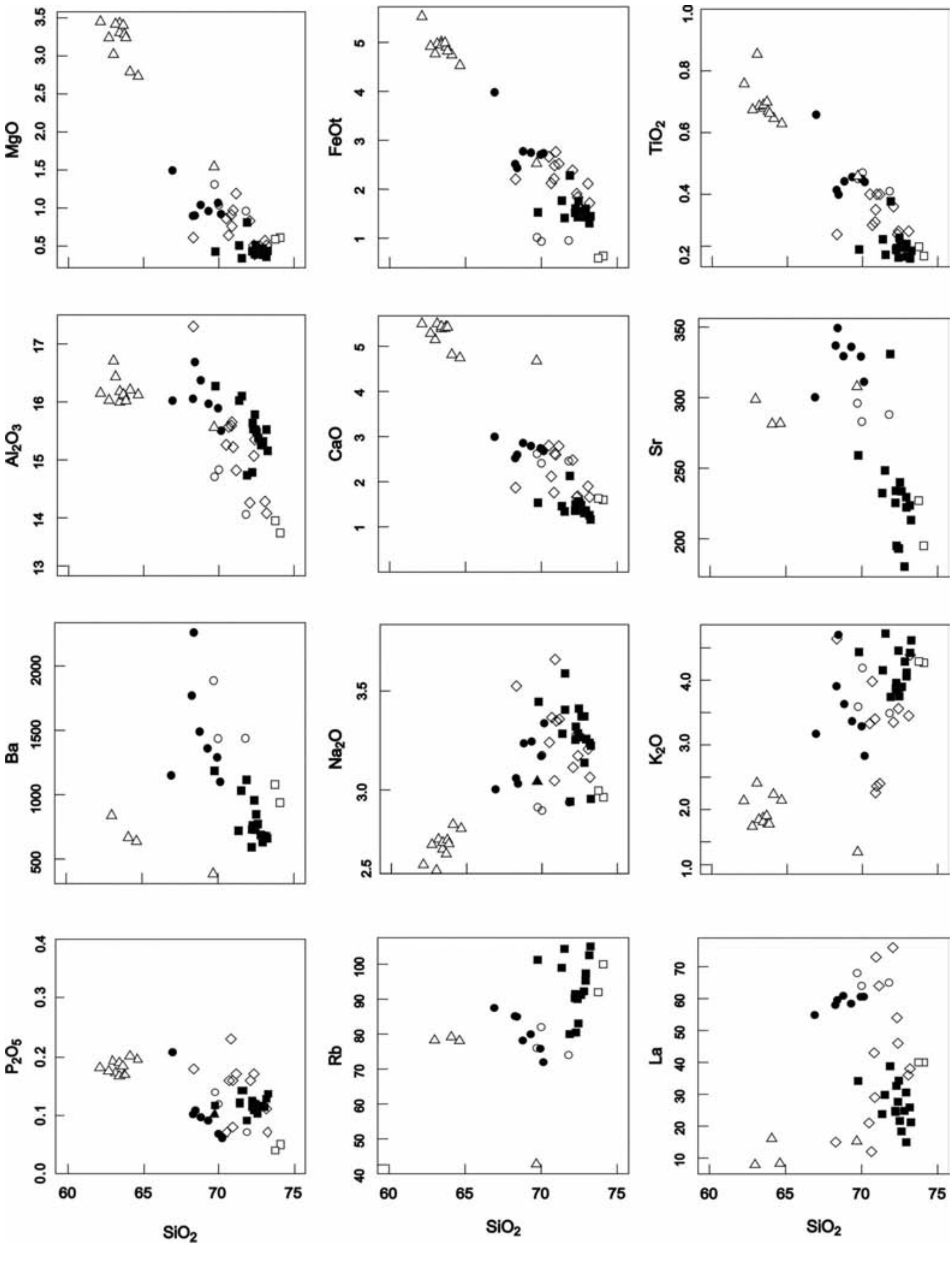


Figure 11. Harker diagrams for selected major (wt%) and trace (ppm) elements of studied granitoid rocks. Symbols as in Figure 9.

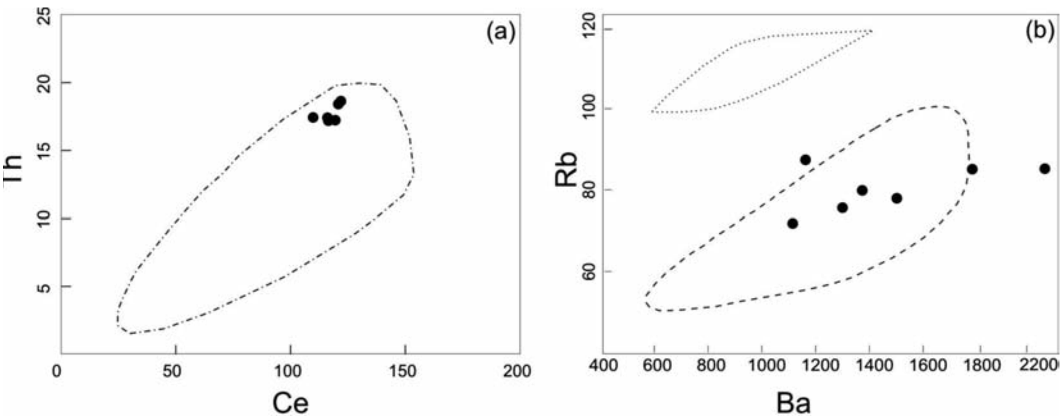


Figure 12. a) Ce vs. Th and b) Ba vs. Rb variation diagrams for the porphyritic granodiorites of the Roman quarry of Parghelia. Dotted-hatched field in a) represents the variation range of the CVP porphyritic granodiorites (after Rottura et al., 1991); dotted and hatched fields in b) represent "high" and "low" Rb porphyritic granodiorites from CVP (after Rottura et al., 1991), respectively.

age would suggest a restricted employment if compared to the "Granito di Nicotera", maybe as a consequence of the relatively poor quality of the Parghelia granitoid stone in terms of mechanical properties, as revealed by ultrasound tests. Indeed, results pointed out that the "Granito di Parghelia" is overall characterised by relatively low velocity values (Vp average ~ 4.0 km/s), with the lowest at the microfractures (~ 3 km/s) and the highest (~ 4.8 km/s) in the megacrysts. As a consequence, these granitoids result to be extremely heterogeneous in terms of mechanical properties, as also testified by the Rock Quality Index ranging from 50 to 80%. Such feature could explain the scarce distribution of stone materials extracted from the quarry, where intact blocks were difficult to be cut, as attested by the occurrence of fractured slabs and pillars left abandoned at the extraction site. This could also clear up the reason because, after the quarry was dismissed (probably after the A.D. 469 earthquake), it was not reactivated anymore, differently from the "Granito di Nicotera" extraction site, which has been instead exploited until very recent times.

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