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Research Article

Garnet Xenoliths in Andesitic Lavas of Lipari: New Geochemical Data to Provide Additional Information on the Metamorphic Basement Under the Aeolian Arc

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Abstract

The purpose of this paper is to discuss and interpret a comprehensive set of geochemical (major and trace elements) data for xenolithic garnets included in high-K andesites from Lipari Island (Aeolian Archipelago, Italy), with the aim to constraint the parent rocks. Since, among all the mineral phases, garnet has a high affinity for the heavy REE (Dy-Lu) and HFSE (Hf, Zr, Ti), we use it as petrogenetic indicator. The investigated xenoliths are mainly composed of cordierite, garnet and Al-silicates and are considered as fragments of the metamorphic Calabria-Peloritani Orogen inferred to be the basement beneath the Aeolian volcanoes. Xenolithic garnet from Lipari andesites and metamorphic garnets from rocks of Southern Calabria and Peloritani Mountains were sampled and analysed. Major elements were determined through ESEM, whereas trace elements were acquired using LA-ICP-MS. Two types of garnets were recognised on the base of major elements, one homogeneous and one zoned, whit an almandine-dominant composition. The comparison between major and trace elements data of xenolithic and metamorphic garnets allowed defining nature of the basement beneath Lipari Island, which is composed of: a) a metamorphic Unit similar to the kinzigitic ones for the unzoned crystals; b) a metamorphic unit similar to the Aspromonte and not outcropping in Sicily and in Calabria for the zoned garnets.

Introduction

In the Lipari Island (Aeolian Volcanic Arc), Pleistocene lava flows erupted from Monte S. Angelo volcano have been known as Cordierite-Bearing Lavas (CBL) because characterized by presence of metamorphic xenoliths as well as cordierite, which testify the entrapment of the basement rocks [1-3]. CBL are high-K andesites, displaying a range in the geochemical and isotopic compositions that reflect heterogeneity in the magmatic source and/or related magmatic processes [3]. CBL consist of megacrysts of Ca-plagioclase and clinopyroxene, euhedral crystals of cordierite and garnet, microphenocrysts of orthopyroxene and plagioclase, set in a heterogeneous rhyodacitic-rhyolitic groundmass containing abundant metamorphic and gabbroic xenoliths [3]. Besides Lipari, also rocks from the other islands of the Aeolian Arc such as Alicudi, Filicudi, Panarea and Salina contain metamorphic xenoliths which are mainly represented by quartz-rich xenolith displaying evidence of partial melting along grain boundaries and by biotite- gneiss and granulite lithologies [4-6]. The particular structure of the Aeolian Arc, which has been developed on the western margin of the Calabria Peloritani Arc basement, explains the presence of these metamorphic xenoliths in lavas [6]. Specifically, only rocks from Lipari Island show the peculiar cordierite-garnet-Al silicate composition of metamorphic enclaves [2,3,7,8].

In the last decades, several studies [2,3,9-11] have been carried out on these CBL rocks from Lipari in order to define the magmatic processes involved in their genesis. It has been said that garnet-cordierite xenoliths are attributable to metapelitic lithology, but a comparison with rocks of the metamorphic units outcropping in Southern Calabria and Peloritani Mountains to define the nature of the basement beneath the Aeolian Arc, has never been attempted. In this work, we have chosen garnet as petrogenetic indicator, for its propensity to retain and record the growth history in chemical composition, with the aim to define the nature of the basement beneath the Aeolian Arc. To reach this aim, the xenolithic garnet contained in the volcanic rocks of Lipari Island (Aeolian Archipelago, Italy) and the metamorphic garnets from rocks of the Units outcropping in Southern Calabria and Peloritani Mountains (Variscan granulites, Variscan and Alpine Aspromonte Unit, Mela, Mandanici, and Stilo Units) have been collected and analysed. The used approach is based on petrographic investigations of the volcanic rocks and geochemical analyses of the both types of studied garnets, xenolithic and metamorphic. Major and trace element composition of selected crystals has been determined by means of Environmental Scanning Electron Microscopy (ESEM) and Inductively Coupled Plasma Spectrometer with Laser Ablation (LA-ICP-MS), respectively. Our data suggest that the trace element signature is turned out to be a useful tool for tracing back to the source rocks. In this regard, a correct provenance attribution can be obtained by comparing patterns of trace elements of xenolithic and metamorphic garnets, on which can be observe the evident compositional similarities.

Geological Setting

The Aeolian volcanism has developed over a thinned continental crust, along the northern and western margins of the Calabria-Peloritani Arc (CPA, Figure 1A) which represents a fragment of the European Plate affected by a complex structural and metamorphic evolution during both Variscan and Alpine Orogeneses, and migrated away from the Corsica-

Sardinia block to its present position during the Miocene to Quaternary opening of the Tyrrhenian Sea [6]. The structure of the CPA consists of a pile of various tectonic nappes composed of Variscan metamorphic and granitoid rocks, frequently interested by an Alpine metamorphic overprint, and of ophiolitic sequences and Mesozoic to Cenozoic sedimentary rocks, [12]. Besides Lipari, volcanic rocks from other islands, such as Alicudi, Filicudi, Panarea and Salina contain metamorphic xenoliths, which are mainly represented by quartz- rich fragments displaying evidences of partial melting along grain boundaries, and by biotite- gneiss and granulite lithologies [5,13-15]. Only rocks from Lipari Island show the peculiar cordierite- garnet-Al silicate composition of metamorphic enclaves which are already noted by Bergeat [7,8]. Barker (1986) studied the Monte S. Angelo rhyolites constraining the genetic mechanism of lavas through a multidisciplinary study of metamorphic inclusions (Figure 1). The Island of Lipari belongs to the Aeolian archipelago, which is an active volcanic arc located in the southern Tyrrhenian Sea. It consists of several stratovolcanoes, forming seven Islands and several seamounts [16,17]. The volcanic activity took place during Quaternary, from about 1000 ka to present [6,18,19].

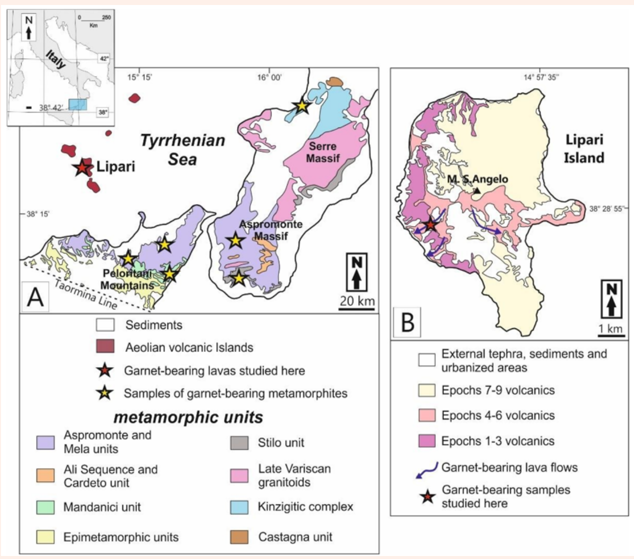

Figure 1: a) Geological sketch map of the southern sector of the CPO (modified after Angi et al., 2010 and Cirrincione et al., 2015). Orange and yellow stars represent the locations of the garnet-bearing samples belonging to the Lipari volcanic complex and to the metamorphic basement which have been studied here; b) Geological sketch map of the Lipari volcanic complex with the location of the garnet-bearing lava samples analyzed in this work (modified after Forni et al. [6]).

Lipari covers an area of about 38 km^2 and is the largest of the Aeolian Islands. Detailed volcanological investigations and geological mapping recognized various cycles of activity [8,10,15,20,21]. Generally, the volcanic products are high-K calc-alkaline and shoshonitic with a bimodal distribution from andesite basalts to andesites to alkaline rhyolites. The oldest rocks outcropping on the island have an age of 223,000 years, the younger ones (Monte Pilato, Forgia Vecchia) date from the sixth century. The geological framework that characterizes Lipari is quite complex. According to Forni et al. [22] it is the result of numerous eruptive episodes that took place in nine Epochs of volcanic activity, separated by dormant periods, volcano-tectonic phases and episodes of terrace formations. The first three Epochs are characterized by the emplacement of calc-alkaline to K-rich calc-alkaline products ranging in composition from basaltic andesites to andesites. Epochs 4-6 show calc-alkaline and K-rich calc-alkaline basaltic andesites to dacites to rhyolites. Epochs 7-9 consists of several periods of volcanic activity whose products display an increase in K with more evolved compositions (rhyolites).

Features of volcanic lavas from Monte S. Angelo

In the Lipari Island, Pleistocene volcanic lava flows from Monte S. Angelo are known as hosting cordierite, garnet and Al-silicate metamorphic crystals of non-volcanic origin. According to Barker [2], these foreign inclusions are fragments of rocks belonging to the Calabria-Peloritani Massif, inferred to be the basement under the Aeolian Arc. These metamorphic fragments - called "xenoliths" - were assimilated by magma during the eruption. They occur mainly in the rhyolitic lavas relative to the final eruptive event of the Monte S. Angelo eruptive centre (Figure 1B). The polygenic volcanic centre of Monte S. Angelo, already active during the Epoch 4, began a new volcanic activity with the emplacement of pyroclastic explosive products (Epoch 5; 6). This explosive activity was followed by the emplacement of widespread volcanic rocks known as "cordierite lavas", whose magmas show evidences of crustal assimilation [2,6,8], [Calanchi et al. 1996, Tranne et al. 2000]. The cordierite lavas from S. Angelo Mount are porphyritic and seriate, with phenocrysts of zoned plagioclase, augite (clinopyroxene) and orthopyroxene set in a groundmass composed of the same phases, plus Fe-Ti oxides and glass. Rare hornblende (amphibole) and biotite (mica) and corroded olivine xenocrysts have been also found. Metamorphic enclaves, representing two different mineralogical suites, are immerged in the lavas. The first suite, gneissic and granulitic, is composed of variable amount of cordierite, garnet, Al-silicate, hercynite, biotite, ilmenite, magnetite and quartz. The second one is gabbroic and consists of orthopyroxene, clinopyroxene, plagioclase and magnetite. All the enclosed mineral phases - occurring as rock fragments and as single xenocrystic phase –frequently show skeletal and rounded appearance, resorption structures and corroded rims or reaction aureoles. Particularly, garnet is present in large crystals, usually rounded and characterized by inclusions of cordierite, biotite, ilmenite and glass.

Environmental scanning electron microscopy

ESEM analyses were performed using instrumentations of the geochemical laboratory of the MIFT Department, at the Messina University. Scanning electron microscope is an ESEM- FEI Inspect-S electron microscope, coupled with Oxford INCA PentaFETx3 EDX spectrometer, a Si(Li) detector equipped by an ultra-thin window ATW2, with a resolution of 137 eV at 5.9 keV (Mn Kα1). The spectral data were acquired in EDX conditions at a working distance of 10 mm, with an acceleration voltage of 20 kV, counting times of 60 s, count for second approximately 3000 (cps) with dead time below 30%. The results were processed by Oxford INCA software Energy. This software uses the XPP matrix correction scheme developed by Pouchou & Pichoir [23,24].

Sampling and Analytical Methods

Samples collection and preparation

Xenoliths from CBL lava have been collected in the Monte S. Angelo area, at Lipari. In addition, garnet-bearing rocks from the various metamorphic Units of the Calabria-Peloritani Orogen have been collected for a comparison. Garnets from both lava and metamorphic rocks have been extracted to facilitate the chemical analysis. The texture of all the significant samples were previously evidenced on the thin sections of rocks, using polarized light microscopy and, after, better defined through electron microscopy observations. The chemical compositions of major and trace elements were determined through Environmental Scanning Electron Microscopy (ESEM) and Inductively Coupled Mass Spectrometer with Laser Ablation (LA-ICP-MS), respectively. Specifically, for the ESEM and the LA-ICP-MS measurements, individual garnet grains were separated through hand picking, using a stereo binocular microscope. The separated crystals were mounted on polished flat using epoxy resin, and cut with a diamond saw up to 30 micrometers thickness. Since glass is a poor conductor, a carbon coating was applied to the polished surface to prevent localized charging and any resulting distortion or reflection of the electron beam.

Laser ablation – inductively coupled mass spectrometry

LA-ICP-MS analyses have been carried out at the Earth Sciences laboratory of the Perugia University. The used analytical device consists of a Thermo Fisher Scientific iCAP Q quadrupole mass spectrometer coupled with a Teledyne/Photon Machine ArF Excimer G2 laser ablation system (Figure 2). Results on the reference material USGS, BCR2G show that, in trace element configuration at 40 microns spot size, precision is better than 6.5% for all elements whereas accuracy is better than 10%. The laser ablation device is a Teledyne/Photon Machine G2 equipped with a Two-Volume ANU (Australian National University) HelEx 2 cell. The laser source is an ATL-I-LS-R solid-state triggered excimer 193 nm laser (Table 1). It is characterized by a maximum energy stabilized output of 12 mJ measured at the laser source. In the energy-stabilized configuration, it shows energy fluctuations of less than 2%, expressed as Relative Standard Deviation (RSD). The pulse duration is < 4 ns resulting in more than 4 GW/cm^2 irradiance on the sample surface. The frequency can be varied from 1 to 300 Hz. The beam delivery system is contained in a fully N2-purged optical path to prevent ozone formation and concomitant energy loss on target. A rotating beam homogenizer, located before the beam shaper, guarantees the homogeneity of the laser beam along its surface. The ablation is performed in Helium (He) atmosphere to enhance the ablation performance, to reduce particles deposition and inter-element fractionation [15,25]. Argon (Ar) and Nitrogen (N) are added after the ablation cell to reduce perturbations on the plasma torch and to enhance sensitivity [14]. Tubing length from the ablation cell to the ICP-MS is reduced at its minimum (about 1 m) to reduce transport-related inter-element fractionation. A squid signal-smoothing device is located before the plasma torch to reduce signal spiking and to increase the stability of the signal (Hu et al., 2008).

Table 1: Representative trace elements data of garnets from Lipari Island lava obtained by LA-ICP-MS analyses.

Sample	Lipari1			Lipari8		
Element	Core	Inter	Rim	Core	Inter	Rim
Si	177159.5	174588.6	183890.6	181086	180431.6	182207.9
Ca	11332.41	10464.47	10702.48	11852.15	10789.63	10560.86
Ca	11857.57	11411.21	11795.77	13273.48	8775.49	11919.99
Sc	181.51	142.58	344.89	218.24	283.22	326.89
V	98.88	64.47	357.57	128.64	157.75	414.5
Mn	59978.89	44133.95	6433.03	12820.78	11104.33	6538.67
Zn	106.51	106.67	97.94	125.79	127.28	107
Ga	13.63	8.34	13.54	13.87	12.7	14.14
Rb	0	0	0.45	0.56	0	0
Sr	0	0.254	0	0.158	0	0
Y	2847	1388.94	314.02	144.01	158.59	365.22
Zr	0	376.38	60.78	84.18	73.24	69.27
Nb	0	0	0	0.088	0	0
Cs	0	0	0.184	0	0	0
Ba	0	0	0	0.45	0	0
La	0	0	0	0.041	0	0
Ce	0	0	0.443	0.262	0.128	0.221
Pr	0	0	0.227	0.137	0.095	0.185
Nd	0.8	0.202	6.2	2.86	3.1	4.01
Sm	6.22	0.84	13.53	8.11	9.92	8.85
Eu	1,048	0.316	0.717	0.642	0.547	0.804
Gd	77.98	12.96	39.58	24.21	28.24	26.87
Tb	27.32	9.95	8.48	4.37	4.94	6.75
Dy	306.02	175.22	60.98	26.66	33.33	58.61
Ho	92.76	61.34	11.88	5.16	6.18	13.84
Er	356.1	219.25	31.42	14.19	15.7	43.35
Tm	58.29	34.8	4.31	1.93	2.05	6.59
Yb	403.13	259.59	27.77	14.36	13.07	43.66
Lu	56.92	40.04	3.89	2.1	2.09	6.47
Hf	4.12	11.72	1.25	1.27	1.18	1.19
Ta	0.253	0.0323	0.015	0.0127	0	0
Pb	0.069	0.044	0	0	0.333	0.062
Th	0.527	0.766	0.0082	0.0171	0	0.0021
U	1.95	3.21	0.043	0.0348	0.019	0.0145

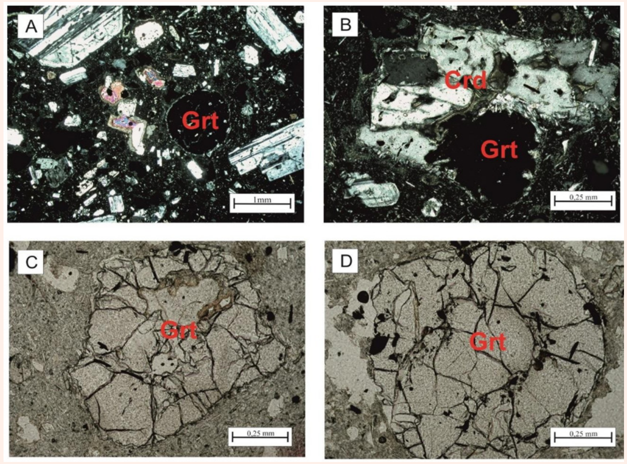

Figure 2: Photomicrographs of metamorphic xenoliths in the Monte S. Angelo Lavas: A general structure with single garnet xenocrysts (+nicols); B) garnet-cordierite enclave (+nicols); C and D) particular of garnet xenocrysts (//nicols).

The bulk composition, in terms of trace elements (REE), Si, Ca, Mn, Rb, Sr, Y, Zr, Nb, Ba, was determined for each garnet crystal, that was mounted on a thin slide, following the method of Petrelli et al. [26]. Precision is expressed as 2σ (expressed as relative standard deviation) and results to be 5% for all the elements, except for Pb (~ 20%), accuracy (expressed as relative deviation from the reference value) are generally better than 10%. External calibration is performed using NIST SRM 610 and 612 glass standards in conjunction with internal standardization using a major element, generally 29Si or 42Ca. Data reduction is performed on the time-resolved signals by carefully selecting homogeneous portion of background and signal intensity.

Results and Discussion

The samples of garnet-bearing lava from Monte S. Angelo have been firstly studied through petrographic investigations. All the collected samples come from different portions of the same lava flow and, in general, show both textural and compositional homogeneity, despite small differences in the relative abundance of the individual mineral phases. In the lava, we have found large xenoliths (foreign rock fragments) representing two distinct mineralogical associations. The first type of xenolith is represented by granulitic gneiss (metamorphic rocks formed at high temperatures and pressures) with various proportions of cordierite, garnet, sillimanite and or andalusite, hercynite, biotite, ilmenite, magnetite, plagioclase (Figures 3a & 3b). The second type contains orthopyroxene, clinopyroxene, plagioclase and magnetite, and probably comes from gabbroic rocks introduced into the magma during the ascent to the surface (Figure 3a). Due to the interaction with magma, all these foreign crystals and/or rocks fragments included in the lavas are frequently partially or strongly resorbed. In the studied samples, garnet is present in sub-rounded to rounded crystals, with a diameter ranging between 0.5 and 3 mm (Figures 3a & 3d), and occurs as individual crystals or aggregate with cordierite and Al-silicate. Detailed SEM-BSE observations evidence the presence of visible external growth zones in some of the garnet crystals (Figure 4a & 4b), indicating multistage growth. SEM-EDX analyses of the major elements evidenced the presence of two types of garnets, one zoned (Figure 4a) and one homogeneous (Figure 4b). The zoned crystals generally show sub- idiomorphic cores bounded by concentric inclusion trails, that define mostly hexagonal shapes of the garnet interiors (Figures 4a & 4b). This features is displayed in the compositional profiles reported in Figures 4c & 4d, on which the almandine (Fe-rich) component ranges from about 64 to 75 %. The zoned crystals (Figures 4a & 4c) show bell-shaped compositional profiles for Mn, which is enriched in the core (20 mol %) and depleted in the rim (5 mol %), and for Mg, 10 mol % in the core and enriched in the rim (25 mol %), suggesting an equilibration temperature lower than 640±30 °C [22]. The homogeneous garnets (Figures 4b & 4d) show flat zoning compositional profiles for all the end-members, with 70 mol % almandine, 20 % pyrope and minor amounts of spessartine (5 mol %) and grossular (5 mol %), suggesting an equilibration temperature above 700 °C [22]. Mineral inclusions, present in both types of garnet, are randomly oriented and consist of quartz (SiO_2), cordierite $(Mg,Fe)_2Al_4Si_5O_{18}$, rutile (TiO_2), sodic-calcic amphibole $[Na_2Ca(Mg,Fe)_5Si_8O_{22}(OH)_2]$ and also titanite ($CaTiSiO_5$). Small crystals of newly-formed minerals - such as clinopyroxene, rutile and cordierite - are present along the rims of several garnets (Table 2).

Table 2: Representative trace elements data (ppm) of garnets from metamorphic units of the Calabria Peloritani Arc obtained by LA-ICP-MS analyses.

Sample	Variscan Aspromonte Unit		Alpine Aspromonte Unit		Stilo Unit		Mela Unit	
Element	Inter	Rim	Core	Rim	Inter	Rim	Core	Rim
Si	177767.19	177767.19	185292.97	178094.41	175476.73	181086.03	196137.56	169820.73
Ca	6904.68	6006.71	7308.99	14229.93	8841.55	7153.69	38574.13	34956.41
Ca	6978.52	5412.77	7280.63	13140.54	9037.81	8205.18	39810.64	36362.35
Sc	91.61	104.11	114.85	89.94	101.29	128.76	154.02	144.18
V	76.6	90.69	53.57	46.35	55.18	41.34	83.19	70.55
Mn	10836.51	10985.09	16756.5	15317.83	29191.78	26072.09	25956.06	21066.2
Zn	28.41	27.12	233.51	194.6	137.21	104.87	171.69	42.14
Ga	9.03	10.86	7.37	7.15	6.87	5.84	10.98	6.25
Rb	0	0	0	7.55	0	0	0.41	0
Sr	0	0	0	16.04	4.12	22.39	2.66	1.3
Y	212.63	203.7	154.02	92	137.58	134.45	320.21	279.71
Zr	1.19	0.93	22.56	2.14	1.85	2.07	114.79	3.98
Nb	0	0	0.92	1.93	0.14	0	0.42	0.19
Cs	0	0	0	0.29	0	0	0.24	0
Ba	0	0	0	31.44	0	0.58	40.35	2.74
La	0	0	0	0	0.25	0.67	21.17	0.1
Ce	0.05	0	0.13	0.09	0.66	2.05	30.92	0.48
Pr	0	0	0	0	0.14	0.26	5.93	0
Nd	0.15	0	0	0.33	0.75	1.23	24.76	0
Sm	0.23	0	0.65	0.98	0.94	1.29	6.49	1.49
Eu	0.18	0.07	0.51	0.82	0.53	1025	2.05	0.93
Gd	5.01	2.53	7.36	4.51	6.77	10.66	16.85	11.57
Tb	2.42	1.63	2.02	1.38	1.98	2.76	4.9	3.99
Dy	30.35	24.72	20.02	13.01	18.88	22.37	44.35	39.03
Ho	8.24	8.37	5.56	3.09	4.94	5.7	10.15	9.29
Er	27.45	31.69	22.13	12.72	16.79	20.95	31.59	30.57
Tm	4.03	5.21	4.46	2.45	2.69	3.82	4.6	4.53
Yb	28.24	38.81	38.78	21.13	18.64	30.82	32.57	30.78
Lu	3.91	5.58	6.09	3.17	2.17	4.4	4.41	4.14
Hf	0.06	0	0.63	0.06	0	0.05	3.52	0.08
Ta	0	0.02	0.26	0.24	0.07	0	0.22	0.12
Pb	0.41	0.06	0.57	1.1	66.82	2.8	5.34	0.31
Th	0.01	0	0.07	0.13	0.13	0.04	8.7	0.01
U	0.01	0.01	0.26	0.11	0.19	0.13	5.73	0.03

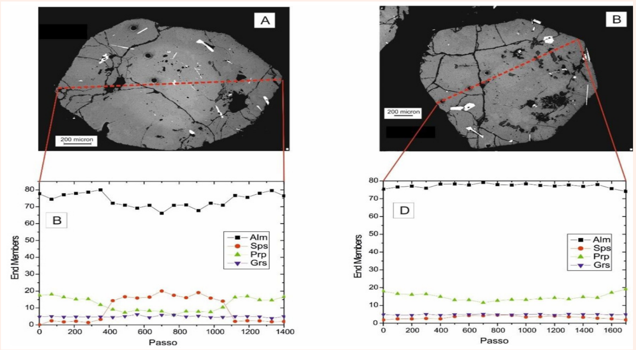

Figure 3: SEM-EDX images of garnets from the metamorphic xenoliths and relative compositional profiles. A) zoned garnet; B) unzoned garnet; C) bell-shaped profiles of the zoned garnet, for Mn enriched core and for Mg enriched in rim; D) flat zoning profiles for all the end-members of a unzoned garnet.

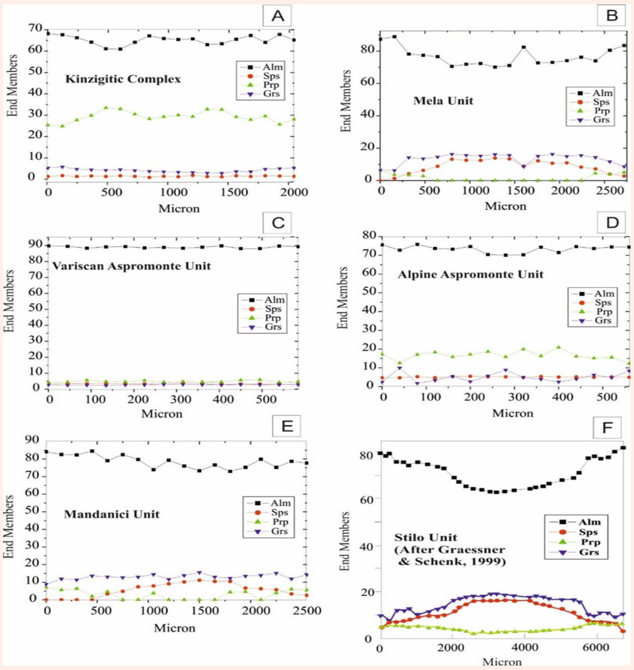

Figure 4: Compositional profiles of garnets analysed for rocks of the Calabria Peloritani Arc from the metamorphic units of: A) Kinzigitic Complex; B) Mela Unit; C) Variscan Aspromonte Unit; D) Alpine Aspromonte Unit; E) Mandanici Unit and D) Stilo Unit after Graessner and Schenk (1999).

For a comparison, we have also been analyzed eight samples of garnet-bearing metamorphic rocks from the "Kinzigitic" Complex (Variscan lower crust), Variscan and Alpine Aspromonte, Mela, Mandanici, and Stilo Units, outcropping in Southern Calabria and in the Peloritani Mountains. The compositional profiles reported in Figure 5 evidence that the homogeneous xenolithic garnets from Monte S. Angelo have the same profiles as the "Kinzigitic" and Aspromonte garnets, whereas the zoned xenolithic ones show profiles very similar to the Alpine Aspromonte, Mela and Stilo garnets, even if the end-members values are closer to those of the Aspromonte. The exam of the trace elements data allowed to better constraining the garnet provenance. REE patterns of all the investigated garnets (data normalized to Chondrite values of Boynton et al. (1989), are reported in Figure 6. These patterns reveals that all the garnets are HREE (Tb, Dy, Ho, Er, Tm, Yb, Lu, Y) -enriched and LREE (La, Ce, Pr, Nd, Sm, Eu, Gd) -depleted, with a moderate negative Eu anomaly (Figure 6). The core and the intermediate parts of the zoned xenolithic garnets from Monte S. Angelo show the large HREE enrichment, while the rim is the most HREE enriched part of the homogeneous xenolithic garnets. The comparison with the garnets belonging to the metamorphic rocks evidenced that the unzoned xenolithic crystals contained in the lava show the same REE distribution pattern as the "Kinzigitic" garnets. Also, the zoned xenolithic ones are similar to the "Kinzigitic" garnets, but, except for rims, inasmuch the xenolithic garnets are more enriched in HREE. The unzoned xenolithic garnet shows the same Zr, Hf and Th contents as all the metamorphic analysed garnets. On the contrary, the zoned one is more enriched in all the above elements, both in the core and in the intermediate portion of the crystals, the rim showing the same abundance as the unzoned crystals. This result has been confirmed also by the similar content of the High Field Strength Elements (HFSE), such as Hf, Zr, Sm, Ti, Tb, Y, Tm and Yb. Comparing the chondrite normalized patterns of these elements to those of the garnets from the metamorphic Units (Granulitic Complex, Mela, Aspromonte and Stilo), we can better constrain an origin from the granulitic ones and exclude the other units. As regards the other xenolithic mineral phases recognized in the lavas, cordierite and prismatic sillimanite are common in the "Kinzigitic" rocks, whereas andalusite is found in the Aspromonte, Mela and Stilo Units. Therefore, it can be deduced that the basement beneath the Aeolian Arc should be made up of the "Kinzigitic" Unit, which is extensively exposed in the Serre Massif (Southern Calabria), and probably also of the Aspromonte Unit (Southern Calabria and Peloritani Mountains) or by a medium-grade Unit similar to the Aspromonte ones and not exposed in the Calabrian Arc [27-30].

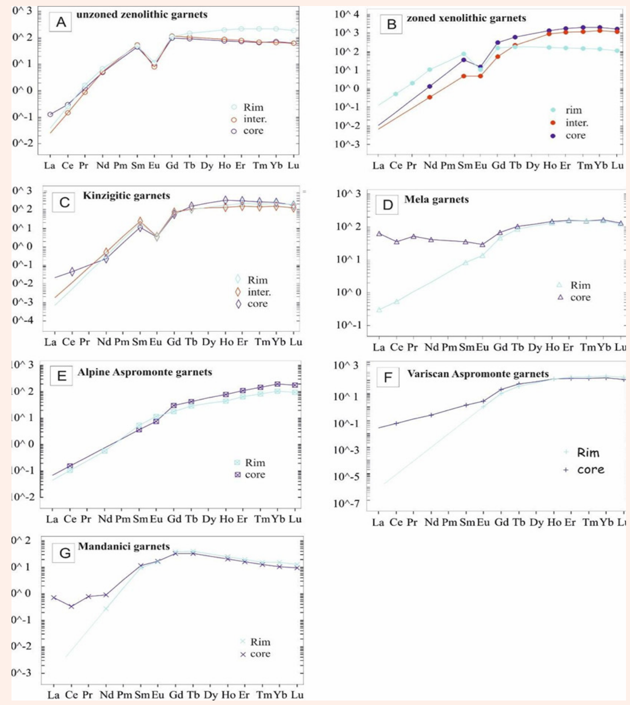

Figure 5: REE pattern distribution of garnets from the Calabrian Peloritani Arc metamorphic units, normalized to Chondrite values of Boynton et al. (1989).

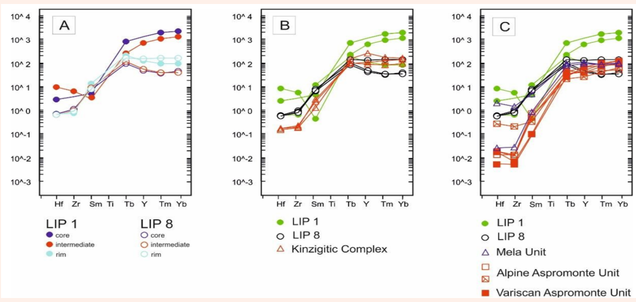

Figure 6: Spider diagrams reporting abundances of High Field Strength Elements (HFSE) contained in the analyzed garnets normalized to values of the Primordial Mantle of McDonough et al. (1992).

Conclusion

The trace elements contained in xenolithic garnets from the Monte S. Angelo lavas, and the comparison with metamorphic garnets from the Alpine nappe pile outcropping in Southern Calabria and in the Peloritani Mountain, allowed deducing information on the type of crystalline basement beneath the Lipari Island. Trace element data of the xenolithic garnets from the Monte S. Angelo high-K andesites suggests a source region composed by at least two types of metamorphic basements. The first is of "Kinzigitic" type, the second one is more similar to the Aspromonte Unit. The REE distribution determined for both types of garnets from the Lipari high-K andesites, reveals similar abundances. As a whole, these garnets are both HREE-enriched and LREE depleted with a moderate negative Eu anomaly. A provenance from Mela, Mandanici, Cardeto or Stilo rocks can be excluded. As regards the other xenolithic mineral phases recognized in the lavas, cordierite and sillimanite are common in the "Kinzigitic" rocks, whereas andalusite is found in the Aspromonte, Mela and Stilo Units. Consequently, we can conclude that the basement beneath the Aeolian Arc is very similar to the "Kinzigitic" Unit, which is extensively exposed in the Serre Massif (Southern Calabria), as well as to the Aspromonte Unit (Southern Calabria and Peloritani Mountains) or by a medium-grade nappe similar to the Aspromonte Unit and not exposed in the Calabrian Arc.

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