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Geochemistry and tectonic setting of triassic magmatism from the Lercara Basin (Sicily, Italy)

Di Bella Marcella [a,b], Italiano Francesco [a], Romano Davide [a],
Alessandro Tripodo [b], Sabatino Giuseppe [b,*]

[a] Istituto Nazionale di Geofisica e Vulcanologia, Via Ugo La Malfa, Palermo, Italy
[b] Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, Università di Messina, Italy

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* Corresponding author:
gsabatino@unime.it

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ABSTRACT

Petrological and geochemical data of Triassic magmatic rocks from Lercara Basin (Central Sicily), provide new information about the intraplate volcanism related to the Pangea break up. The magmatic rocks crop out as subvolcanic bodies and are packed in several Lower Triassic clayey lithologies correlated to the sedimentation inside the Imerese and Sicano domains. The samples are splitted in two groups: the first includes transitional to alkaline basalts, with sub-ophitic texture; the second includes more altered rocks, with porphyritic texture, showing alkali basaltic to phonolitic compositions. Major and trace element data of single groups show small variations indicating fractional crystallization processes. Abundances and ratios of incompatible trace elements indicate that rocks were formed in an intraplate continental environment from different mantle sources with E-MORB to OIB-type compositions. Low partial melting degrees at the transition between spinel and garnet lherzolite fields can be hypothesized for parental magmas of the Lercara Basin. We propose that magma batches moved toward the surface along lithospheric fractures originated by flexure and uplift of the Mesozoic Pangea supercontinent.

Keywords: Lercara Basin; intraplate continental volcanism; dikes; SEM-EDS; XRF; spinel-garnet-lherzolite source.

INTRODUCTION

Sicily represents a significant study area from the volcanological point of view, due to the occurrence of several episodes of magmatic activity from Late Precambrian to present (Lucido et al., 1978; Tanguy, 1978; Bianchini et al., 1998; Trua et al., 1998; Beccaluva et al., 1998; Civetta et al., 1998; Armienti et al., 2004; Cirrincione et al., 2005; Fiannacca et al., 2008, 2013; Di Bella et al., 2010). Triassic magmatism related to continental rifting is documented in western-central Sicily, but only a few information are available about the geodynamic significance in the Mesozoic Mediterranean geodynamic framework (Bellia et al., 1981; Grasso and Scribano, 1985; Grasso et al., 1995; Guarnieri et al., 2000; Cirrincione et al., 2014, 2016). Cirrincione et al. (2014) and Cirrincione et al. (2016) recently provided further information on the old magmatism providing petrological, geochemical and isotopic data for subalkaline basalts, basaltic andesites and Na-alkaline basalts outcropping in western Sicily (Lercara Basin) that constrained mantle sources and magma evolution mechanisms. Both studies suggest that the magmatism occurred during the Mesozoic fragmentation of the Pangea supercontinent before the opening of the Central Atlantic Ocean.

Magmatism in this region was triggered by the geodynamic evolution of the primordial Tethys ocean. In particular from Permian to Early Giurassic, the Sicilian area was involved in the rifting phase of the Neothetyan margins. During this time, an oceanic seaway existed between the present western Sicily and the Permian

Tethys, along the Gondwanian margin since the late Early Permian (Catalano et al., 1988a, 1988b, 1998c, 1991; Kozur, 1993; Di Stefano and Gullo, 1997a). In this context, deep-water sequences were deposited together with carbonate blocks and breccia (Catalano et al., 1991) forming the oldest known deposit of the Sicilian Appenninic-Magrhebian chain, named as "Lercara Formation", in which the studied magmatic rocks outcrop as subvolcanic bodies (dikes/sills).

The paper accounts for new petrological and geochemical data that improve the already existing data-set (Cirrincione et al., 2014, 2016) for the Mesozoic volcanic rocks outcropping in Western Sicily. The volcanic rocks sampled in the Lercara Basin are investigated by a multidisciplinary approach, involving petrographic, mineralogical and chemical analysis aimed of constraining origin and tectonic setting and to gain an insight into the Triassic magmatism in Sicily. Our new data set is also compared with the available literature data relative to coeval volcanic rocks from the same area.

TECTONIC HISTORY AND GEOLOGICAL SETTING OF THE AREA

During the Late Paleozoic, the Variscan Orogeny led to the formation of the Pangea supercontinent through the collision between Gondwana and Laurussia (Stampfli and Borel, 2002). The Paleotethys roll-back associated to the northward subduction underneath Laurasia, drove the opening of Neothethys Ocean to the East of the today Spain. The break-up rifting phase occurred during Permian when a series of rifts set up in northern margin of Gondwana (Stampfli et al., 2013). A rift branch developed in the Sicily paleo-area (Lercara Basin) and probably became oceanized during Triassic. The remains of this paleo-area are today located in central Sicily, which is part of the Appenninic-Maghrebian Thrust-fold Belt, a segment of the Alpine collisional belt. This segment is described as a result of both post-collisional convergence between Africa and Europe and roll-back of the subduction hinge of the Ionian lithosphere (Grasso et al., 1991; Cirrincione et al., 2015).

In the geological context of the Appenninic-Maghrebian Chain (Figure 1A), into the Permian-Triassic sequence of the Lercara Unit, the examined sub-volcanic bodies crop out (Lentini and Carbone, 2014; Catalano et al., 2010a).

According to Lentini and Carbone (2014), the Lercara Unit is composed of four different sequences: i) Lercara Complex; ii) Mufara Formation; iii) Meso-Cenozoic cover and iiii) Numidian Flysch.

The Lercara Complex, also called "Lercara Formation", is formed by polychromous pelitic argillites, turbiditic sandstones and red clays, intercalations of silicoclastic and carbonate turbiditic sandstones. Calcareous breccias and megabreccias are interbedded. From the late 19th century, the age of the Lercara Formation has been a matter of extreme controversy among geologists, due to geological complexity of the Western Sicily, affected by the Late Alpine Orogeny. The Lercara Formation was referred to the Permo-Carboniferous (Baldacci, 1886; Fabiani and Ruiz, 1933; Castany, 1956), to the Permian (Gemmellaro, 1887; Fabiani and Trevisan, 1937; Broquet et al., 1966; Mascle, 1967; Broquet, 1968; Catalano et al., 1988a, 1988b, 1988c, 1991; Flugel et al., 1991; Gullo, 1993; Kozur et al., 1996a; Di Stefano and Gullo, 1997a, 1997b), and to the Triassic (Montanari, 1968; Catalano and D'Argenio, 1978; Catalano and Montanari, 1979; Cirilli et al., 1988, 1990; Carrillat, 2001). The most recent age determinations are provided by Carcione (2007) by sedimentological and biostratigraphic determinations that assigned the Lercara Formation to the Anisian/Ladinian to Carnian age. The Lercara Formation represents a deep water sequence rich in Pelagic fauna where a lot of carbonate blocks from adjacent seamounts or reefs rolled in (Catalano et al., 1991; Catalano et al., 1988c; Flügel et al., 1991). The paleoenvironment setting of these sediments can be referred to a slope and turbiditic basin.

The Mufara Formation represents the Triassic portion of Lercara Unit and is composed of grey argillites, cherty limestones, with yellow, grey and red marls of Middle Triassic age. These deposits are followed by alternating yellow marls and marly limestones of Carnian age. The most recent study by Buratti and Carrillat (2002), later confirmed by Carrillat and Martini (2009), dated the Mufara Formation to the Upper Triassic (Late Longobardian/Early Cordevalian to Late Tuvalian, Carnian).

Finally the Meso-Cenozoic cover is formed by a carbonatic Jurassic-Oligocene succession which shows a lot of affinities with the coeval successions belonging to Imerese and Trapanese Domains.

The Upper Oligocene-Lower Miocene sequence (brown clays and quartz-arenites) of the Numidian Flysch represents the top of the Lercara Unit. The relationship between Numidian Flysch and the lower body of the Lercara Unit is unclear since the original stratigraphic contact had been strongly mobilized during Alpine Orogeny.

Outcrop description

The two investigated subvolcanic bodies from the Lercara Basin, are respectively located to the North of Roccapalumba-Alia Railway Station (Latitude 37°45'57''N, Longitude 13°40'19''E) and near Cozzo Cuccagna locality, along SP22, about 4 km West to Alia (Latitude 37°48'04''N, Longitude 13°40'20''E) (Figure 1B). They outcrop as tabular sheets (sill) intruded between older layers of sedimentary rocks, or

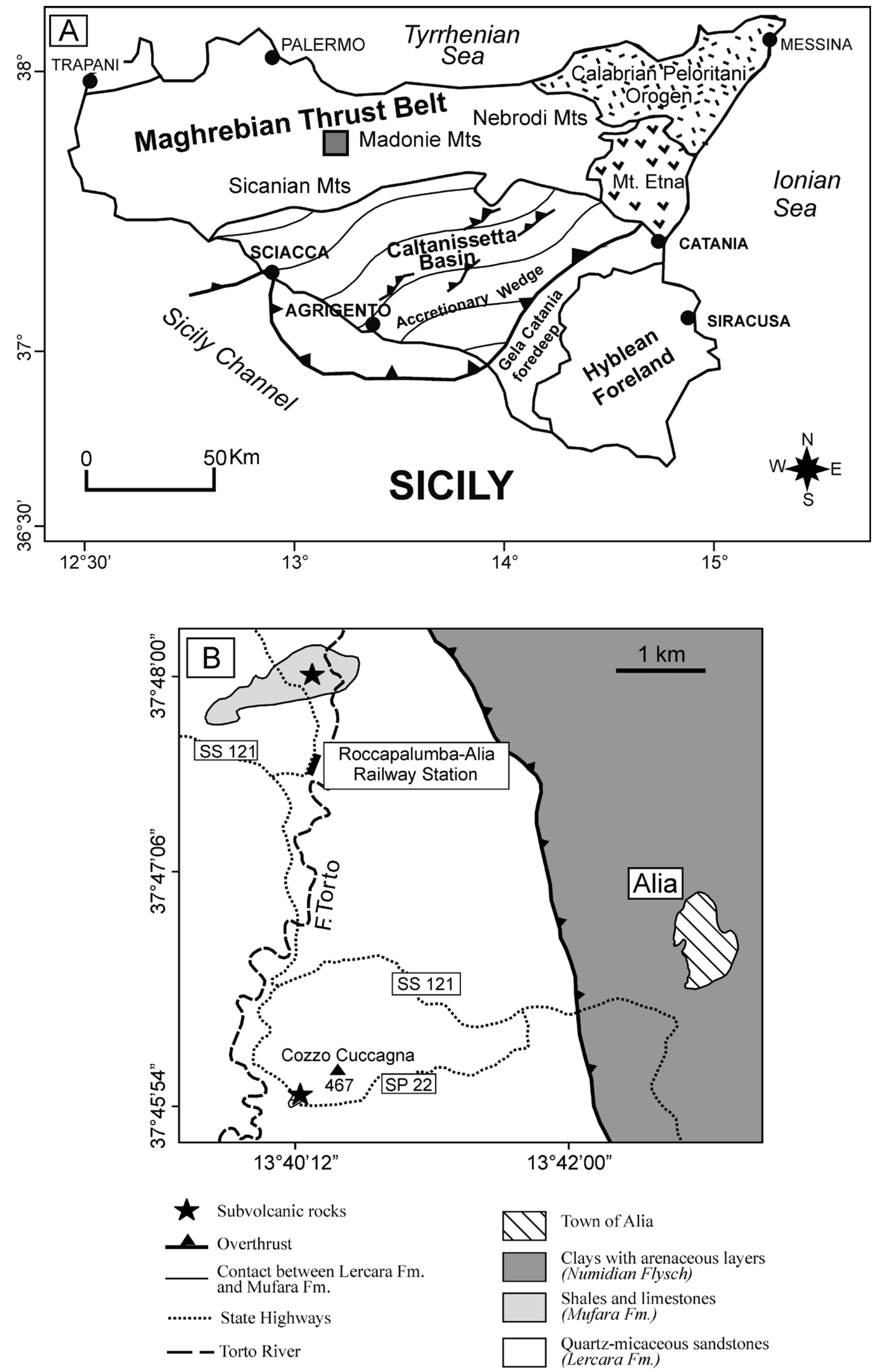

Figure 1. A) Sketch map of Sicily and B) geological map with location of the studied outcrops (black stars).

as discordant intrusive sheets (dikes), cutting the older rocks. In particular, the three meters-tick rocks nearby the railway Station represent the brittle and external portion of a volcanic intrusion (Figure 2A and B). The other outcrops are an altered magmatic intrusion, but in this case is formed by an external powdery matrix containing an internal preserved bulbous portion (Figure 2C and D).

The volcanic bodies are interbedded within the Middle Triassic sequence of the Lercara Unit and the relationship between sub-volcanics and the surrounding Middle Triassic deposits is clearly expressed through the unmodified original contacts. On the contrary, the relationships between the Lercara Complex and the Mufara Formation is not clear, consequently it is difficult to understand whether they

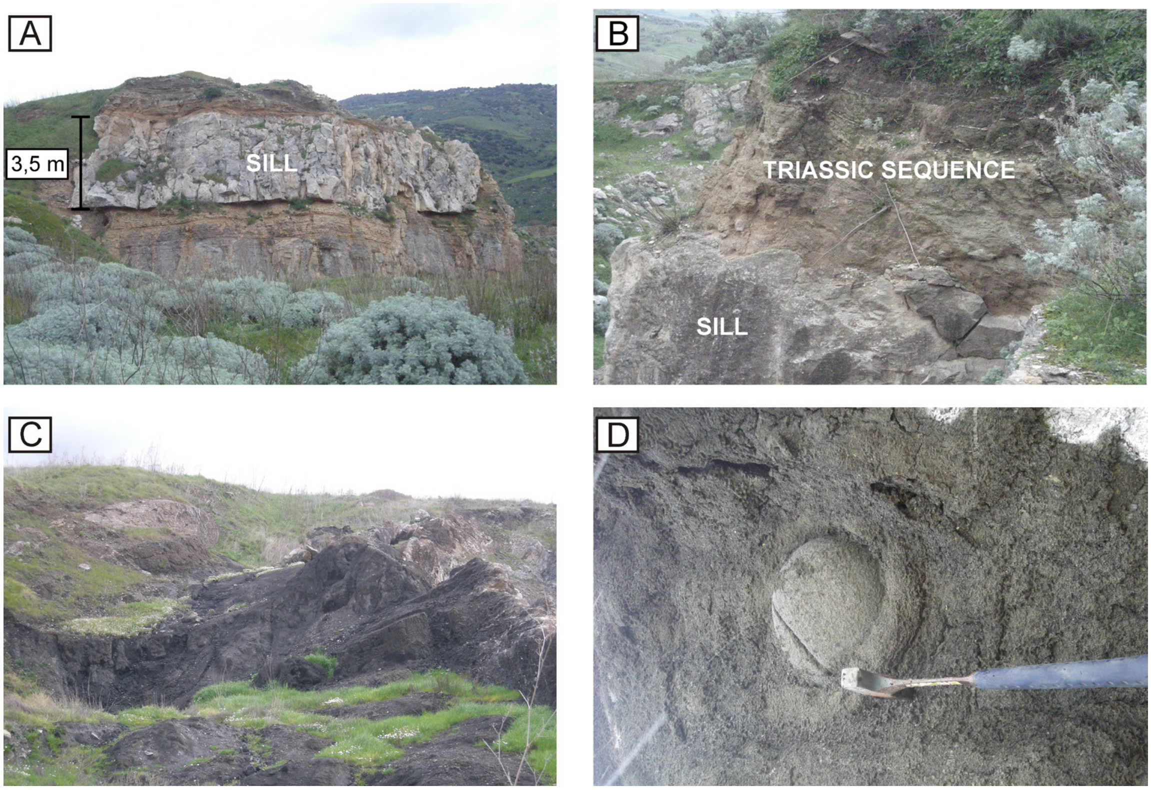

Figure 2. Outcrops of the studied volcanic sites. Roccapalumba-Alia: A) The volcanic body (sill) intruding the Middle Triassic sequence of the Lercara Unit; B) Contact between the volcanic body and the Middle Triassic sequence. Cozzo Cuccagna: C) Intense surface erosion of the altered volcanic rocks; D) Concentric features related to spheroidal weathering caused by groundwater circulation through joints and fractures.

were tectonically emplaced within melanges or represent reworked material (olistolith) due to sliding phenomena, as already suggested by Lentini and Carbone (2014).

SAMPLES AND ANALYTICAL METHODS

Fourteen samples of Triassic magmatic rocks have been collected, eight coming from the Cozzo Cuccagna locality (CC1÷CC8) and six from the Roccapalumba-Alia railway station (RA1÷RA6). All samples have been have been carefully cleaned because of their secondary alteration and of the presence of secondary carbonate and treated with diluted acid (HCl 5%) before analyses. The analytical measurements were performed using the instruments of the CERISI Geochemical Laboratory of the Messina University, using procedures later described in detail.

The mineral composition of selected mineral phases has been determined at the Earth Sciences SEM Laboratory of the Messina University. Analyses have been carried out by an ESEM-FEI Inspect-S electron microscope coupled with Oxford INCA PentaFETx3 EDX spectrometer, an Si(Li) detector equipped by a ultra thin window ATW2, by using a resolution of 137 eV at 5.9 keV (Mn Kα1). The spectral data were acquired in ESEM (Environmental Scanning Electron Microscope) condition at working distance of 10 mm with an acceleration voltage of 20 kV, counting times of 60 s, approximately 3000 cps with dead time below 30%. The results were processed by INCA software Energy. This software uses the XPP matrix correction scheme developed by Pouchou and Pichoir (1984, 1985).

Major (SiO_2, TiO_2, Al_2O_3, FeO_{tot}, MnO, CaO, K_2O, P_2O_5) and some trace elements (Nb, Zr, Y, Sr, Rb, Ba, Co, Cr, V, Ce, La, Ni) have been determined on rock powder pellets. by XRF spectrometry using the WDXRF method with Bruker model S8 Tiger setup (Bruker 2015 a,b). The excitation source is a tube of Rh at 4 kW. The concentrations of the major and minor elements have been calculated using the software package GEO-QUANT M, an accurate method for measuring 11 elements using more than 20 certified material for calibration lines (Bruker 2015 a,b). For the calculation of the trace elements, however, the software GEO-QUANT T, a simple solution for the determination of these elements in geological materials, was used (Bruker 2015 a,b). The latter is a pre-calibrated and standardized method by the manufacturer, installed in the instrument present in the laboratory. This method was validated using two standard samples GBW07103 and GBW07406. Performing the quality control, the analysis must meet the narrow analytical range provided by the standards certificates.

PETROGRAPHY AND MINERAL CHEMISTRY

Petrographic investigation highlight that the rocks sampled from the two outcrops in the Lercara Basin show different structure (Figure 3 A,B). The Roccapalumba-Alia rocks are rather altered, though the original porphyritic texture has been preserved. They show olivine and/or pyroxene phenocrysts pseudomorphically replaced by calcite set in a groundmass composed of plagioclase microliths and opaque grains plus a cryptocrystalline dark component (Figure 3A). Secondary phases include clay minerals and iron oxy-hydroxides both frequently replacing primary minerals (phenocrysts and microlites). Carbonates have been also observed, as filling of vesicles and fractures. The Cozzo-Cuccagna group is composed of medium to coarse grained crystalline rocks, with mainly granular sometimes subordinately ophitic texture (Figure 3B). They are composed of variable amount of plagioclase, clino- and orthopyroxene and olivine, with subordinate biotite and brown amphibole (brown hornblende), accessory and opaque minerals. Secondary phases as chlorite, green pargasitic-type amphibole, minerals of serpentine and zeolite groups, have been also found. Plagioclase is present as euhedral to subheudral tabular crystals and anehdral grains that can be concentrically zoned with polysynthetic twinning. Plagioclase is labradoritic to andesinic in composition, often sericitized and fracturated (Figure 4A). Pyroxene represents the predominant mafic phase. The clinopyroxene grains display a pink to light-

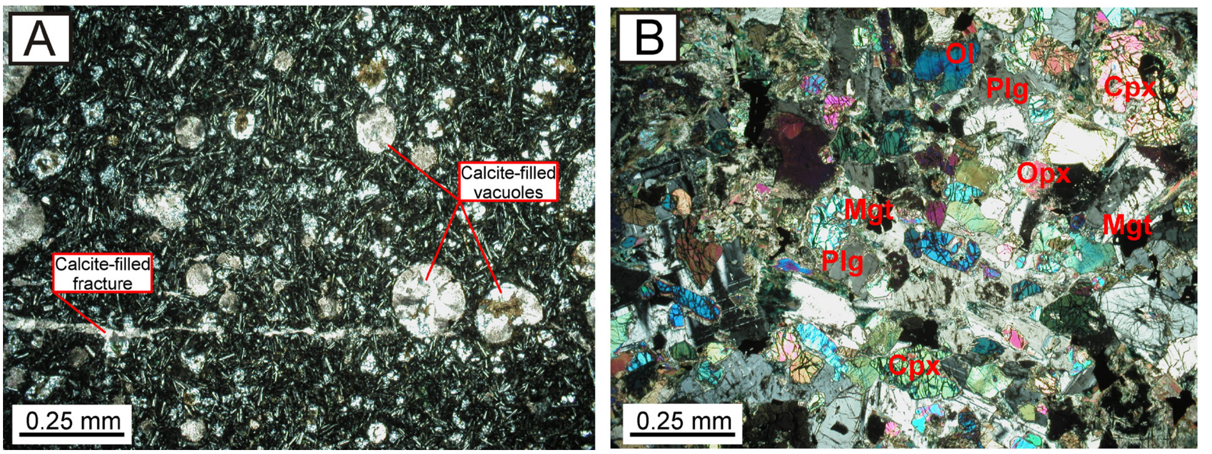

Figure 3. Representative crossed nicols microphotographs of the studied rocks: A) Roccapalumba-Alia rocks; B) Cozzo Cuccagna rocks. Ol: Olivine; Cpx: Clinopyroxene; Opx: Orthopyroxene; Plg: Plagioclase; Mgt: Magnetite.

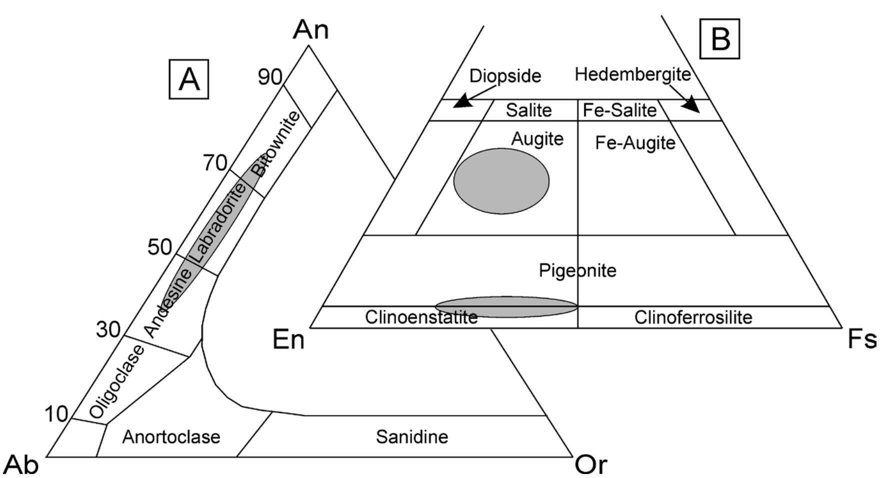

Figure 4. Classification diagrams of pyroxenes (Morimoto et al., 1988; Figure 4A) and feldspars (Deer et al., 1963; Figure 4B) of Cozzo Cuccagna samples.

Table 1. XRF chemical analyses of major (wt%) elements of the studied samples.

SAMPLE Wt %	CC1	CC2	CC3	CC4	CC5	CC6	CC7	CC8	RA1	RA2	RA3	RA4	RA5	RA6
SiO_2	48.69	48.29	48.69	47.11	47.75	48.33	46.82	48.79	52.01	54.29	61.48	61.85	49.98	51.79
TiO_2	1.24	1.75	1.25	1.28	1.19	1.13	1.28	1.30	2.39	2.76	2.38	2.50	3.15	3.16
Al_2O_3	11.03	10.93	9.20	9.25	9.20	8.54	10.27	9.67	12.90	14.12	15.55	15.83	13.95	13.86
Fe_2O_3	11.90	11.80	12.40	13.69	13.73	13.67	13.72	13.71	3.82	4.91	4.30	4.19	8.07	7.75
MgO	14.27	14.15	17.92	18.35	18.03	18.14	16.48	16.15	2.15	2.63	2.34	2.49	6.51	5.73
MnO	0.14	0.12	0.14	0.14	0.14	0.14	0.14	0.14	0.08	0.08	0.05	0.05	0.08	0.08
CaO	6.87	6.81	6.14	6.17	5.84	5.88	7.17	6.37	12.32	9.37	4.93	4.98	8.41	7.96
Na_2O	1.79	1.77	1.39	1.43	1.49	1.22	1.44	1.41	2.26	2.60	3.47	4.06	2.34	2.33
K_2O	0.34	0.34	0.42	0.41	0.38	0.44	0.41	0.37	6.22	5.06	4.00	2.79	2.85	3.24
P_2O_5	0.11	0.11	0.08	0.07	0.08	0.07	0.00	0.00	0.47	0.39	0.18	0.15	0.96	0.90
L.O.I.	3.70	4.01	2.33	2.07	2.15	2.41	2.16	2.05	5.52	3.86	1.31	1.11	3.76	3.23
Total	100.08	100.08	99.96	99.97	99.98	99.97	99.89	99.96	100.14	100.07	99.99	100.00	100.06	100.03

Table 2. XRF chemical analyses of trace (ppm) elements of the studied samples.

SAMPLE (ppm)	CC1	CC2	CC3	CC4	CC5	CC6	CC7	CC8	RA1	RA2	RA3	RA4	RA5	RA6
Sc	17	20	16	15	17	12	14	12	11	17	9	14	21	23
V	105	146	103	107	103	97	105	107	170	204	150	161	216	215
Cr	315	392	313	334	374	405	333	420	178	191	181	188	219	222
Co	72	73	71	80	84	85	79	81	31	38	63	50	40	44
Ni	663	466	665	748	761	779	771	795	128	147	278	210	150	167
Cu	114	92	113	127	158	208	275	296	67	78	74	72	56	61
Zn	99	108	98	109	108	105	105	109	93	115	136	149	114	135
Ga	14	19	15	16	15	15	15	16	22	25	23	23	24	24
As	1	5	3	7	1	2	1	0	5	7	18	10	5	5
Rb	9	9	9	10	11	10	9	10	29	30	20	16	25	31
Sr	155	253	156	175	176	175	155	153	267	327	233	260	589	638
Y	9	15	9	10	10	9	12	10	15	17	12	11	21	22
Zr	63	105	64	73	65	66	71	73	126	150	112	112	282	302
Nb	9	14	8	9	9	9	9	9	21	25	14	15	48	51
Mo	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Sn	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sb	0	0	0	0	0	0	0	0	0	0	1	2	0	0
Cs	13	19	13	14	13	12	14	14	28	30	23	24	33	33
Ba	50	81	50	51	64	57	43	42	94	110	272	470	299	289
La	12	12	12	12	12	12	12	12	12	12	12	12	44	40
Ce	10	18	1	11	7	5	2	2	30	39	12	7	81	88
Pb	6	9	7	6	6	8	7	7	6	3	5	5	3	4
Th	4	4	3	3	3	3	3	3	4	5	4	4	8	9
U	6	7	6	6	6	6	6	6	7	7	6	7	10	10

green pleochroism, typical of elevated TiO_2 contents. The orthopyroxene occurs as subheudral colorless grains. According to IMA characterization all the analysed clinopyroxene are augitic whereas the orthopyroxene are enstatite-rich (En≈74%) (Figure 4B). In general they are characterized by compositional zonation of crystals, with rimward enrichment in FeO and TiO_2 and depletion in MgO, SiO_2 and Al_2O_3. Olivine occur as anehdral and subheudral interstitial grains indicating a late crystallization during the fractional crystallization process. Generally their composition ranges from Fo_{75} to Fo_{70} with a slight rimward enrichment in fayalite. Petrographic analyses show the presence of irregular fractures filled with secondary minerals (serpentine, chlorite, iddingsite). The analyzed opaque minerals are ilmenites with minor magnetite and Cu, Fe and Ni sulfides. Small apatite and zircon crystals have been also found. The rocks are reasonably fresh, although sericitization of plagioclase and the slight serpentization of olivine grains is noticeable in some samples.

WHOLE ROCK GEOCHEMISTRY

The major and trace element XRF data carried out for the studied samples are reported in Tables 1 and 2. Many of them show L.O.I. values exceeding 2% (up to 5.52%). For this reason, during geochemical data discussion, we paid attention to elements like Zr, Y, Nb, and Ti, considered geochemically immobile during deuteric processes.

The Nb/Y vs SiO_2 diagram of Whinchester and Floyd (1977) (Figure 5A) shows that the Cozzo Cuccagna samples fall in the alkali basalt field, whereas the Roccapalumba-Alia rocks fall in the field of alkali basalts (RA5, RA6), trachy-andesites (RA1, RA2) and phonolite (RA3, RA4). It is difficult to define the affinity (K or Na) of those rocks, since alkaline elements Na and K might be heavily modified during alteration. Therefore, the immobile element ratios Nb/Y vs Ti/Y (Figure 5B) have been used in order to define the chemical character of the studied volcanic suites. On Figure 5B diagram, the rocks from Cozzo Cuccagna plot in the field of transitional basalts, whereas most of the Roccapalumba-Alia rocks are alkaline basalts (Figure 5B) and all fall in the intraplate field. The samples analysed by Cirrincione et al. (2014) define two groups plotting in the fields of MORB and within plate basalts.

The two groups of samples, however, frequently plot along single evolutionary trends on the binary variation diagrams (Figure 6), suggesting a common origin. In particular, the Cozzo-Cuccagna gabbroic rocks are mafic and characterized by the high MgO (up to 18.35%) and Fe_2O_3 (up to 13.73%). Variation diagrams of major elements vs MgO (Figure 6) define overall negative trends for all oxides except Fe_2O_3 showing some scattering with the Roccapalumba-Alia samples. These trends are compatible with an evolution of the entire magma suite from Cozzo Cuccagna as parent magma. As regards the trace element compositions (Figure 7), the compatible elements Cr, Ni and Co are positively correlated with MgO, with the highest values observed for gabbroic rocks. LILE (Rb, Ba and Sr), HFSE (Zr, Nb, Y) and REE (Ce) in Roccapalumba-Alia group, show an increase of values against MgO for the mafic compositions and invert their trends in the most silicic rocks. These trends are compatible with an evolution by fractional crystallization, with separation of mafic minerals in the basaltic range, joined by feldspars and accessory phases in the intermediate-late stage of evolution.

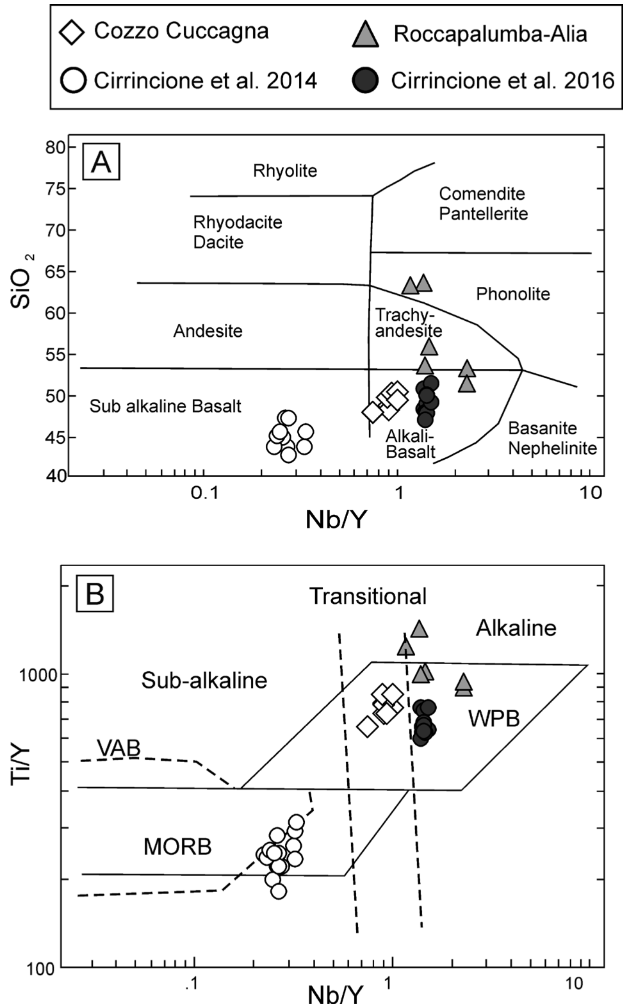

Figure 5. Classification of the studied magmatic rocks: in A) Nb/Y vs SiO2 plot of Whinchester and Floyd (1977); B) Nb/Y vs Ti/Y plot of Pearce (1982) - WPB Within-plate basalts, MORB Mid ocean Ridge Basalts, VAB Volcanic Arc Basalts. For comparison data from Cirrincione et al., 2014, 2016 are also plotted.

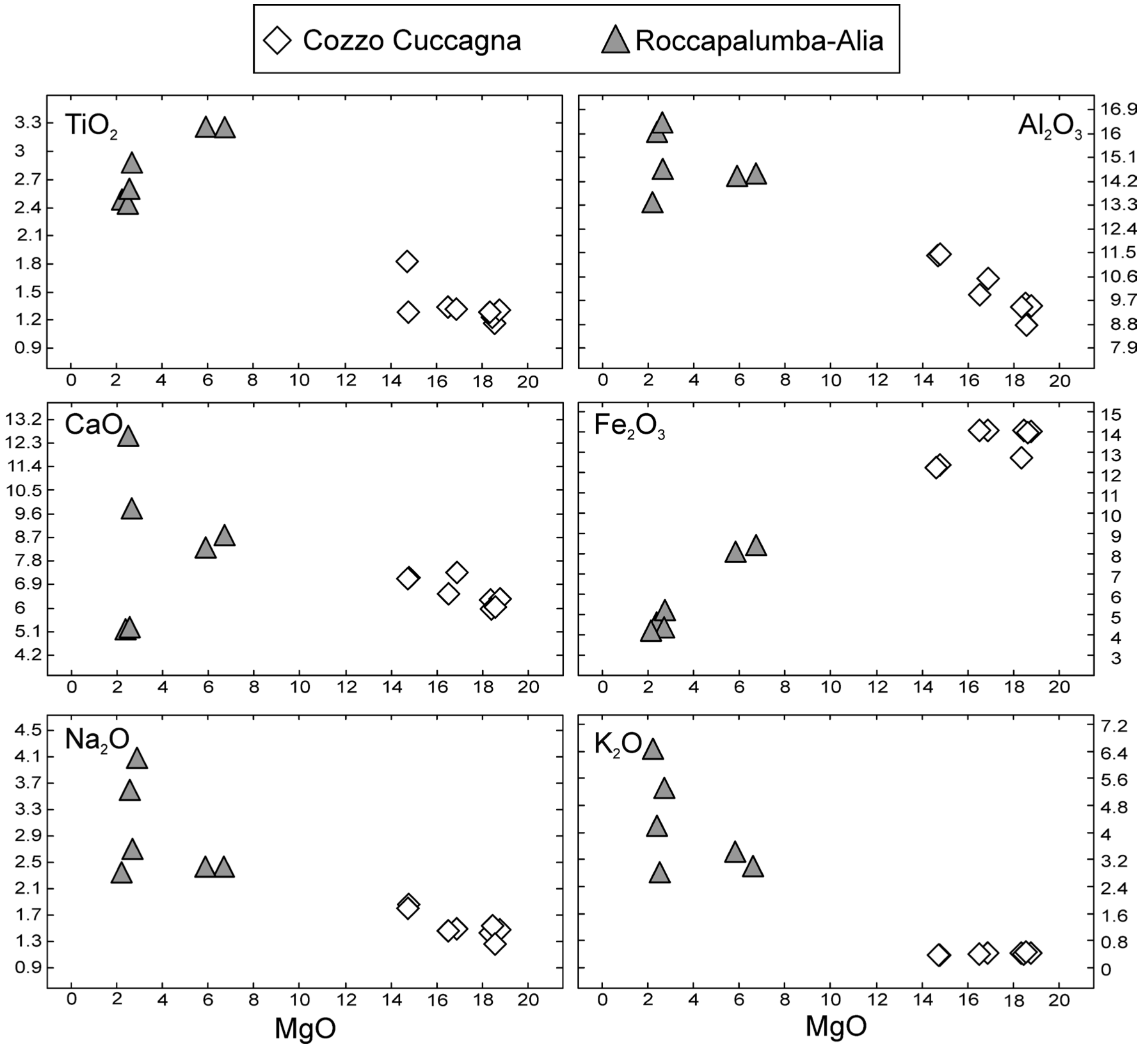

Figure 6. Variation diagrams of major element vs. MgO (wt%).

The poorly variable values of incompatible element ratios (e.g. Nb/Y, Zr/Nb) support this conclusion. Mantle-normalized incompatible element patterns of mafic samples is shown in Figure 8 (McDonough et al., 1992). Although many trace elements are lacking, the Cozzo Cuccagna rocks show smooth pattern which resemble E-MORB with a Ce negative spike.

DISCUSSION AND CONCLUSIONS

The analytical results gained on the collected samples denote the transitional-alkaline origin of the rocks, ranging in composition from basalts to phonolite. Major and trace element variations suggest that all the rocks represent a single magmatic suite formed by fractional crystallization starting from mafic parents represented by the Cozzo Cuccagna magmas. The variability of trace element abundances and ratios are typical of anorogenic alkaline magmatic sequences usually emplaced in other Late Triassic continental environments (Traversa et al., 2003; Monjoie et al., 2005; Lago et al., 2012; Barca et al., 2010; Bortolotti et al., 2008; La Pierre et al., 2007; Maury et al., 2008). In particular, the Cozzo-Cuccagna alkali basalts show incompatible trace element patterns similar to the enriched MORB compositions (Figure 8). The negative cerium anomalies are consistent with variable amounts of a sedimentary component injection by former subduction in the mantle source (Neal and Taylor, 1989). Cirrincione et al. (2014, 2016) suggested an OIB-like geochemical signature for the Na-alkaline basalts and an E-MORB-like composition has been envisaged for the sub-volcanic tholeiitic basaltic–andesitic intrusions cropping out in the Lercara area (Western Sicily). The combined data-set from this study and from Cirrincione et al. (2014, 2016) demonstrate that during Late Triassic, in the intra-continental rift environment of Lercara Basin various stage of volcanism emplaced variable magma

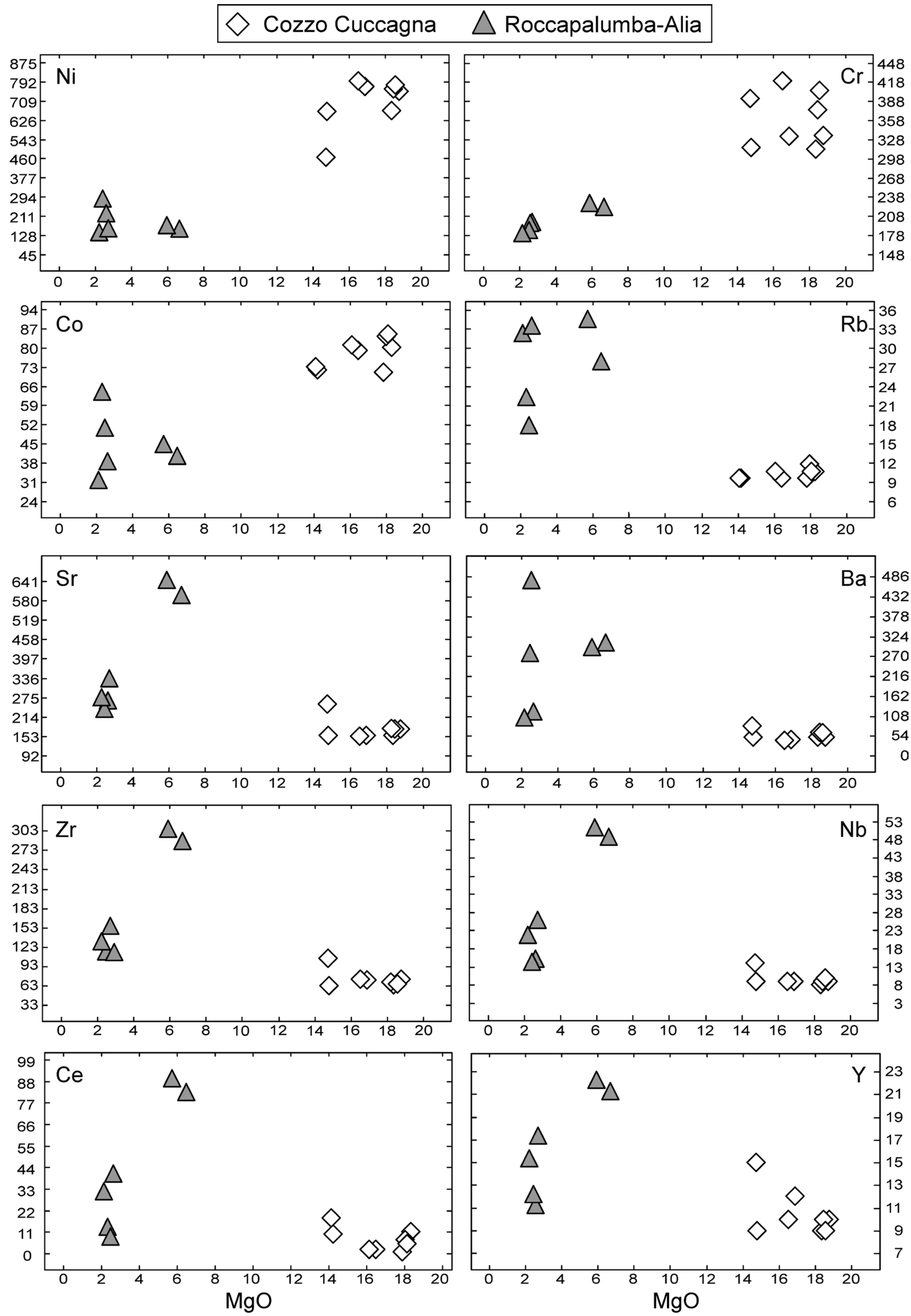

Figure 7. Variation diagrams of some trace element (ppm) vs. MgO (wt%).

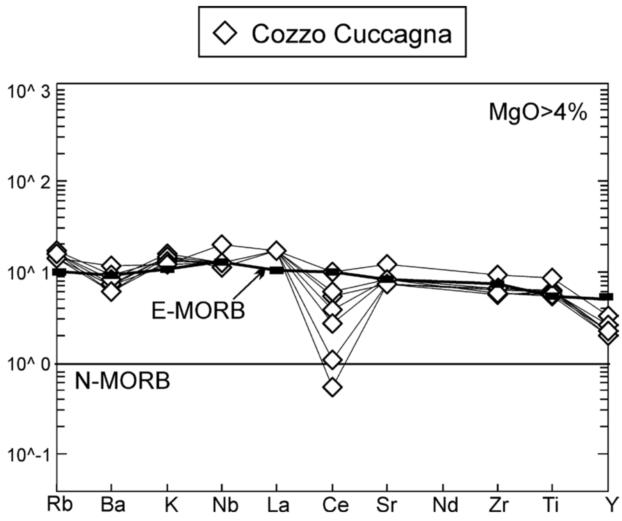

Figure 8. Patterns of incompatible elements normalized to primordial mantle composition of McDonough et al. (1992) for rocks (MgO > 4 wt%) from the Lercara Basin. E-MORB pattern after Sun and McDonough (1989).

types from alkaline (Na and K) to tholeiitic composition which is not an unusual association during continental rifting processes.

Figure 9 compares our data set with literature data (Cirrincione et al., 2014, 2016) of other magmatic rocks outcropping over the whole Lercara Basin in order to provide a complete picture of the rift-related continental magmatism evolution.

The intraplate character of the studied magmatic rocks is evidenced on the Ti vs. V diagram by Shervais (1982; Figure 9A). This diagram is used to distinguish MORB from island-arc volcanic rocks. The fractionation of V and Ti during partial melting and fractional crystallization is a function of the oxygen fugacity. The fields of E-MORB and N-MORB have been reported on the diagram where the Ti/V ratio increases from island-arc to MORB to OIB basalts. The Ti/V ratio for the alkaline volcanic rocks of the Lercara Formation ranges between 50 and 100, similar to that of within plate basalts, with the alkaline group falling on the separation line between OIB and alkaline

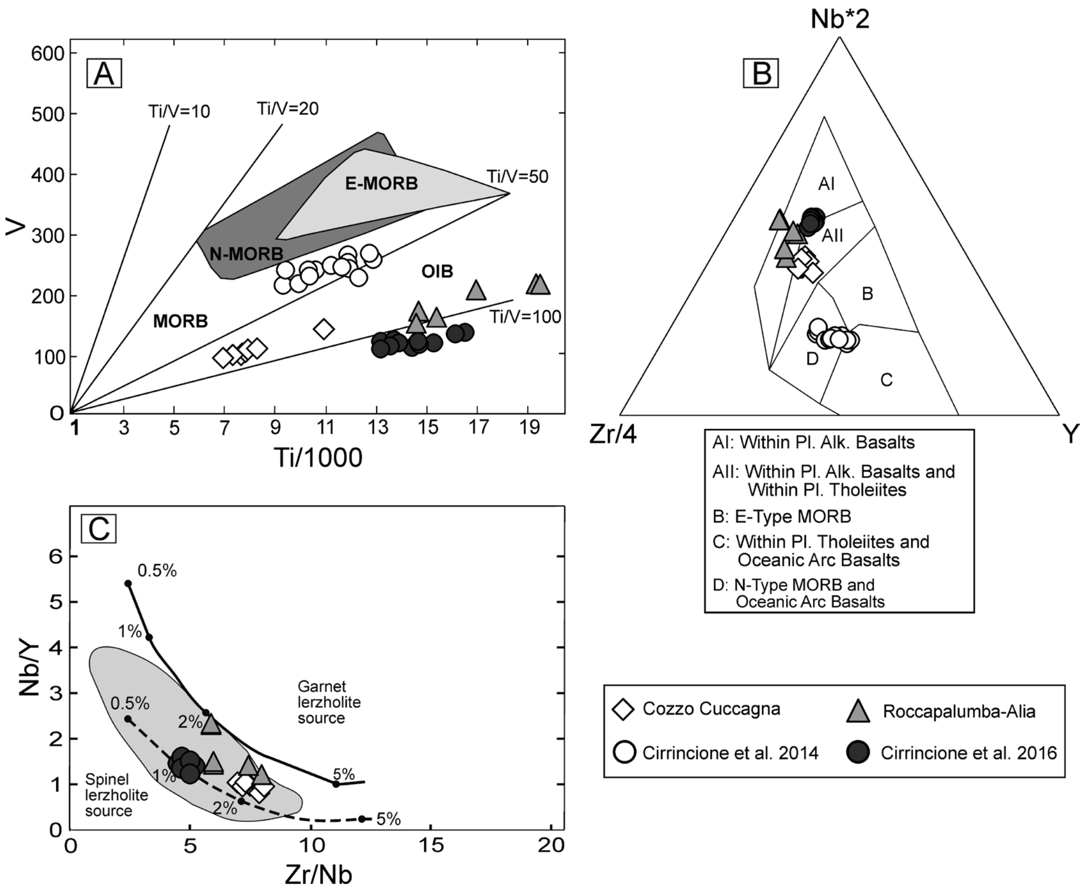

Figure 9. Discrimination diagrams: A) V vs. Ti plot from Shervais (1982) - the fields are: N and E MORB Normal and enriched Mid Ocean Ridge Basalts; OIB Ocean Island Basalts; B) Zr-Nb-Y diagram by Meschede (1986); C) Variation of Zr/Nb versus Nb/Y after Wilson and Downes (2001). Model melting curves for 0.5-5 % partial melting of spinel- and garnet-peridotite facies mantle from Harangi (2001).

basalts fields. The tholeiites analysed by Cirrincione et al. (2014) occupy also the MORB area and are very close to the N-MORB field showing lower values of Ti/V ratio. The Nb-Zr-Y diagram of Figure 9B (Maschede, 1986) reveals a better discrimination for the geotectonic setting in which the involved magma originated separating the alkaline rocks that fall in the OIB field from the tholeiites analysed by Cirrincione et al. (2014) falling in the field of MORB.

To test possible magma sources and the degrees of partial melting, models of Nb/Y vs Zr/Nb variations (Harangi, 2001) have been calculated (Figure 9C). The models show that all the studied rocks originated in a transition zone between garnet- and spinel-peridotite facies mantle, by low degree of partial melting (from ~1 to ~2%). Those mantle facies were probably located close to the base of the continental lithosphere, as hypothesizes for some modern analogues (Bogaard and Wörner, 2003).

Trace element abundances and ratios indicated that magmatic events, could be related to the post-Variscan global re-organization of plates that evolved during Late Triassic times preceding the neo-Tethyan rifting. The presence of alkaline and tholeiitic magmatic rocks in the Lercara Basin, well represents the Triassic extensional geodynamic context, taking place throughout the Pangea break-up (Cirrincione et. al., 2014, 2016). The volcanism results as delocalized magmatic pulses risen during Late Triassic along lithospheric fractures of the African paleomargin, during the stage of continental dismembering of the Pangea Supercontinent.

We suggest that the information on the nature of the upper mantle cannot provide insights on the geodynamic significance of magmatism occurred hundreds of millions years ago. The geodynamic settings changed and the mantle might be expected as more depleted after repeated events of melt extraction or, alternatively more enriched, after possible metasomatizing processes.

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REFERENCES

Armienti P., Tonarini S., D’Orazio M. and Innocenti F., 2004. Genesis and evolution of Mt. Etna alkaline lavas: Petrological and Sr-Nd-B isotope constraints. Periodico di Mineralogia 73, 29-52.

Baldacci L., 1886. Descrizione geologica dell’isola di Sicilia. Memorie della Carta Geologica d’Italia.

Barca D., Cirrincione R., De Vuono E., Fiannacca P., Ietto F., Lo Giudice A., 2010. The Triassic rift system in the northern Calabrian-Peloritani Orogen: evidence from basaltic dyke magmatism in the San Donato Unit. Period. Mineral. 79, 61-72.

Beccaluva L., Siena F., Coltorti M., Di Grande A., Lo Giudice A., Macciotta G., Tassinari R. and Vaccaro C., 1998. Nephelinitic to tholeiitic magma generation in a trastensional tectonic setting: an integrated model for the Iblean volcanism (Sicily). Journal of Petrology 39, 1547-1576.

Bellia S., Lucido G., Nuccio P.M., Valenza M., 1981. Magmatismo in area trapanese in relazione all’evoluzione geodinamica della Tetide. Rend. Soc. It. Min. Petr. 38, 163-174.

Bianchini G., Clocchiatti R., Coltorti M., Joron J.L., Vaccaro C., 1998. Petrogenesis of mafic lavas from the northernmost sector of the Iblean district (Sicily). European Journal of Mineralogy 10, 301-315.

Bogaard P.J.F. and Wörner G., 2003. Petrogenesis of basanitic to tholeiitic volcanic rocks from the Miocene Vogelsberg, Central Germany. Journal of Petrology 44, 569-602.

Bortolotti V., Chiari M., Marcucci M., Photiades A., Principi G., Saccani E., 2008. New Geochemical and age data on the ophiolites from the Othrys area (Greece): implication for the Triassic evolution of the Vardar ocean. Ofioliti, 33, 135-151.

Broquet P., Caire A. and Mascle G.H., 1966. Structure et evolution de la Sicile occidentale. Bulletin de la Société Géologique de France 8, 994-1013.

Broquet P., 1968. Etude geologique de la region des Madonies (Sicile). These Fac. Sc. Lille, 797 pp.

Bruker, 2015a. Product Overview: Advanced Analytical Solutions.

Bruker, 2015b. XRF Lab Report - S8 TIGER plus GEO-QUANT M, 6 pp.

Buratti N. and Carillat A., 2002. Palynostratigraphy of the Mufara Formatio (Middle-Upper Triassic, Sicily). Rivista Italiana di Paleontologia e Stratigrafia 108, 101-117.

Caflisch L., 1966. La Geologia di Monti di Palermo. Rivista Italiana di Paleontologia e Stratigrafia 12 , 1-797 pp.

Carcione L., 2007. Sedimentology, Biostratigraphy and Mineralogy of the Lercara Formation (Triassic, Sicily) and its Palaeogeographic Implications. Thèse Université de Genève, Terre et Environnement 68, 247 pp.

Carrilat A. and Martini I.R., 2009. Palaeoenvironmental reconstruction of the Mufara Formation (Upper Triassic, Sicily): high resolution sedimentology, biostratigraphy and sea-level changes. Palaeogeography, Palaeoclimatology, Palaeoecology 283, 60-76.

Carrillat A., 2001. Palaeoenvironmental reconstruction of the Mufara Formation (Upper Triassic, Sicily): biostratigraphy, organic facies, sedimentological and geochemical approach. Doctoral Thesis, Département de Géologie et Paléontologie, Terre et Environment, University of Geneva, 145 pp.

Castany G., 1956. Essai de synthese geologique du territoire Tunisie-Sicile. Annales des Mines et de la Géologie 16, 96 pp.

Catalano R. and D’Argenio B., 1978. An essay of palinspastic restoration across western Sicily. Geologica Romana 17, 145-

159.
Catalano R. and Montanari L., 1979. Geologia dei Monti di Trabia-Termini Imerese e dei Monti Sicani orientali (Fogli Bagheria e Termini Imerese, Sicilia centro settentrionale). Rendiconto dell'Accademia di Scienze Fisiche e Matematiche della Società Nazionale di Scienze, Lettere e Arti in Napoli, 46 pp.
Catalano R., Di Stefano P., Gullo M., Kozur H., 1988a. The stratigraphic and paleogeographic significance of the rich occurrence of Pseudofunishius (Conodonta) in pelagic late Ladinian-early Carnian sediments of western Sicily. In: Atti del 74th Congresso della Società Geologica Italiana, A, pp. 114-118, Sorrento.
Catalano R., Di Stefano P. and Kozur H., 1988b. First evidence for lower Permian Albaillellacea (Radiolarian) in the Tethyan Eurasia. In: Atti del 74th Congresso della Società Geologica Italiana, Sorrento, A, 119-123.
Catalano R., Di Stefano P., Kozur H., 1988c. New results in the Permian and Triassic stratigraphy of western Sicily with special reference to the section at Torrente San Calogero SW of Pietra di Salomone (Sosio Valley). In: Atti del 74th Congresso della Società Geologica Italiana, Sorrento, A, 126-132.
Catalano R., Di Stefano P., Kozur H., 1991. Permian circumpacific deep-water faunas from the western Tethys (Sicily, Italy) – New evidences for the position of the Permian Tethys. Palaeogeography, Palaeoclimatology, Palaeoecology 87, 75-108.
Catalano R., Avellone G., Basilone L., Gasparo Morticelli M., Lo Cicero G., 2010. Note illustrative del F. 608 "Caccamo" della Carta Geologica d'Italia alla scala 1:50.000. Con contributi di: C. Gugliotta, C. Di Maggio, A. Contino, C. Albanese, G. Lena, A. Sulli, E. Di Stefano and S. Bonomo. 221 pp., 73 ff., ISPRA.
Cirilli S., Montanari L. and Panzanelli Fratoni R., 1988. Palinomorfi nella Formazione Lercara: nuovi elementi di datazione. In: Atti del 74° Congresso della Società Geologica Italiana Sorrento, Abstract B, 140-142.
Cirilli S., Montanari L., Panzanelli Fratoni R., 1990. Palynomorphs from the Lercara Formation (Sicily): New biostrtigraphic data. Bollettino della Società Geologica Italiana 109, 123-133.
Cirrincione R., Fiannacca P., Lo Giudice A., Pezzino A., 2005. Evidence of early Palaeozoic continental rifting from mafic metavolcanics of southern Peloritani Mountains (North-Eastern Sicily, Italy). Ofioliti, 30, 15-25.
Cirrincione R., Fiannacca P., Lustrino M., Romano V., Tranchina A., 2014. Late Triassic tholeiitic magmatism in Western Sicily: A possible extension of the Central Atlantic Magmatic Province (CAMP) in the Central Mediterranean area. Lithos 188, 60-71.
Cirrincione R., Fiannacca P., Lustrino M., Romano V., Tranchina A.,Villa I.M., 2016. Enriched asthenosphere melting beneath the nascent North African margin: trace element and Nd isotope evidence in middle-late Triassic alkali basalts from central Sicily (Italy). International Journal of Earth Sciences 105, 595-609.
Civetta L., D'Antonio M., Orsi G., Tilton G.R., 1998. The geochemistry of volcanic rocks from Pantelleria Island, Sicily Channel: petrogenesis and characteristics of the mantle source region. Journal of Petrology 39, 1453-1491.
Di Bella M., Russo S., Pino P., Baldanza A., Sabatino G., 2010. Evidence of Early Oligocene submarine volcanism in the Caltanissetta Basin (Central-Southern Sicily). Periodico di Mineralogia 79, 1-20.
Di Stefano P. and Gullo M., 1997a. Permian deposits of Sicily: a review. Geodiversitas 19, 193-202.
Di Stefano P. and Gullo M., 1997b. Late Paleozoic-Early Mesozoic stratigraphy and paleogeography of Sicily. In: Catalano R. (Ed.), Time scales and basin dynamics: Sicily, the adjacent Mediterranean and and other natural laboratories. Field Workshop in western Sicily, 8th Workshop of the ILP Task Force "Origins of Sedimentary Basins", R.
Fabiani R. and Trevisan L., 1937. Di alcune novita geologiche nel territorio del foglio di Termini Imerese (Palermo). Bollettino della Societa di Scienze Naturali ed Economiche 19, 1-6.
Fabiani R. and Ruiz C., 1933. Sui giacimenti permiani del Sosio (Palermo) e sugli strofomenidi in essi trovati. Memorie della Società Geologica Italiana 1, 1-22.
Fiannacca P., Williams I.S., Cirrincion R., Pezzino A., 2008. Crustal contributions to Late-Hercynian peraluminous magmatism in the Southern Calabria-Peloritani Orogen, Southern Italy: petrogenetic inferences and the Gondwana connection. Journal of Petrology 49, 1497-1514.
Fiannacca P., Williams I.S., Cirrincione R., Pezzino A., 2013. The augen gneisses of the Peloritani Mountains (NE Sicily): Granitoid magma production during rapid evolution of the northern Gondwana margin at the end of the Precambrian. Gondwana Res., 23, 782-796.
Flugel E., Di Stefano P. and Senowbari-Daryan B., 1991. Microfacies and depositional structure of allochtonous carbonate base-of-slope deposits: the Late Permian Pietra di Salomone megablock, Sosio Valley (Western Sicily). Facies 25, 147-186.
Gemmellaro G.G., 1887. La fauna dei calcari con Fusulina della Valle del fiume Sosio nella provincia di Palermo. Fasc. 1, Cephalopoda; Ammonoidea. Giornale di Scienze Naturali ed Economiche 79, 1-106.
Grasso M. and Scribano V., 1985. Geological and petrological notes on a Triassic sill on the southern slope of the Mount Altesina (central Sicily); a contribution to the knowledge of the Triassic magmatism in Sicily. Bollettino della Società Geologica Italiana 104, 229-238.
Grasso M., Butler R.W.H., La Manna F., 1991. Thin skinned deformation and structural evolution in the NE segment of the Gela Nappe, SE Sicily. Studi Geol. Camerti, Vol. Spec., 9-17.

Grasso M., Miuccio G., Maniscalco R., Garofalo P., La Manna F. Stamilla R., 1995. Plio-Pleistocene structural evolution of the western margin of the Hyblean Plateau and the Maghrebian foredeep, SE Sicily. Implications for the deformational history of the Gela Nappe. Annales Tectonicae 9, 7-21.

Gullo G., 1993. Studi stratigrafici sul Permiano ed il Trias pelagico della Sicilia occidentale. Tesi di Dottorato, 1-203, Palermo.

Harangi S., 2001. Neogene magmatism in the Alpine-Pannonian Transition Zone- a model for melt generation in a complex geodynamic setting. Acta Vulcanologica 13, 25-39.

Kozur H.W., 1993. Gulloides n. gen. - A new Conodont Genus and Remarks to the Pelagic Permian and Triassic of Western Sicily. Jahrbuch der Geologischen Bundesanstalt 136, 77-87.

Kozur H.W., Krainer K., Mostler H., 1996a. Ichnology and sedimentology of the Early Permian deepwater deposits from the Lercara-Roccapalumba area (Western Sicily, Italy). Facies 34, 123-150.

Lago M., De la Horra R., Ubide T., Galé C., Galán-Abellán B., Barrenechea J.F., López-Gómez J., Benito M.I., Arche A., Alonso-Azcárate J., Luque F.J., Timmerman M.J., 2012. First report of a Middle-Upper Permian magmatism in the SE Iberian Ranges: characterization and comparison with coeval magmatism in the western Tethys. Journal of Iberian Geology 38, 331-348.

Lapierre H., Bosch D., Narros A., Mascle G.H., Tardy M., Demant A., 2007. The Mamonia Complex (SW Cyprus) revisited: remnant of Late Triassic intra-oceanic volcanism along the Tethyan southwestern passive margin. Geological Magazine, 144, 1-19.

Lentini F. and Carbone S., 2014. Geologia della Sicilia-ISPRA, Memorie Descrittive della Carta Geologica d'Italia 95, 7-414.

Lucido G., Nuccio P.M., Valenza M., Giunta G., 1978. Magmatism in the Sicano Basin (Sicily) related to Meso Cenozoic tectonics of the north-African paleomargin. Mineralogica et Petrographica Acta 22, 55-69.

Mascle G.H., 1967. Remarques stratigraphiques et structurales sur la region de Palazzo-Adriano, Monts Sicani (Sicile). Bulletin de la Société Géologique de France 11, 104-110.

Maury R.C., Lapierre H., Bosch D., Marcoux J., Krystyn L., Cotten J., Bussy .F, Brunet P., Senebier F., 2008. The alkaline intraplate volcanism of the Antalya nappes (Turkey): a late Triassic remnant of the Neotethys. Bulletin de la Société Géologique de France 179, 397-410.

McDonough W.F., Stosch H.G., Ware N.G., 1992. Distribution of titanium and the rare earth elements between peridotitic minerals. Contributions to Mineralogy and Petrology 110, 321-328.

Meschede M., 1986. A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb-Zr-Y diagram. Chemical Geology 56, 207-218.

Monjoie P., Bussy F., Lapierre H., Pfeifer H.R., 2005. Modeling of in situ crystallization processes in the Permian mafic layered intrusion of Mont Collon (Dent Blanche nappe, western Alps). Lithos 83, 317-346.

Montanari L., 1968. Materiale per la geologia dell'Alto Lercarese (Sicilia). Bollettino della Società Geologica Italiana 87, 133-142.

Neal C.R. and Taylor L.A., 1989. A negative Ce anomaly in a peridotite xenolith: evidence for crustal recycling into the mantle or mantle metasomatism. Geochimica et Cosmochimica Acta, 53, 1035-1040.

Pouchou J.L. and Pichoir L., 1984. Possibilités d'analyse en profondeur à la microsonde électronique. Journal de microscopie et de spectroscopie électroniques 9, 99-100.

Pouchou J.L. and Pichoir L., 1985. Les éléments très légers en microanalyse X - Possibilités des modèles récents de quantification. Journal de microscopie et de spectroscopie électroniques 11, 229-250.

Sun S. and McDonough W.F., 1989. Chemical and isotopic systematic of oceanic basalts: implications for mantle composition and processes. in: Saunders A.D. and Norry M.J. (eds.) Magmatism in ocean basins. Geological Society of London, Spec. publ. 42, 313-345.

Stampfli G.M. and Borel G.D., 2002. A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrons. Earth and Planetary Science Letters 196, 17-33.

Stampfli G.M., Hochard C., Verard C., Wilhelm C., Von Raumer J., 2013. The formation of Pangea. Tectonophysics 593, 1-19.

Tanguy J.C., 1978. Tholeiitic basalt magmatism of Mount Etna and its relation with the alkaline series. Contributions to Mineralogy Petrology 66, 51-67.

Traversa G., Ronca S., Del Moro A., Pasquali C., Buraglini N., Barabino G., 2003. Late to post-Hercynian dyke activity in the Sardinia-Corsica Domain: a transition from orogenic calcalkaline to anorogenic alkaline magmatism. Bollettino della Società Geologica Italiana 2, 131-152.

Trua T., Esperanca S., Mazzuoli R., 1998. The evolution of the lithospheric mantle along the North African Plate: geochemical and isotopic evidence from the tholeiitic and alkaline volcanic rocks of the Hyblean Plateau, Italy. Contributions to Mineralogy and Petrology 131, 307-322.

Winchester J.A. and Floyd P.A., 1977. Geochemical discrimination of different magma series and their different products using immobile elements. Chemical Geology 20, 325-343.