Coexistence of IAB-type and OIB-type magmas in the southern Tyrrhenian back-arc basin: evidence from recent seafloor sampling and geodynamic implications

Coesistenza di magmi di tipo IAB e di tipo OIB nel bacino di retro-arco del Tirreno meridionale

TRUA T. (*), SERRI G. (*), ROSSI P.L. (**)

ABSTRACT - We present a review of petrological data on the submarine volcanic samples up to now recovered from the Southern Tyrrhenian basin. This area represents one example of an active arc/back-arc system where IAB- and OIB-type magmas coexist. IAB-type magmatism is the most common, in both arc and back-arc settings, whereas OIB-type magmas are restricted to few areas. We show how the geochemistry and isotopic characteristics of the more basic Southern Tyrrhenian submarine lavas, especially the volcanic samples recently recovered from Marsili seamount and Prometeo lava field, provide constraints on the mantle sources of the Southern Tyrrhenian submarine magmatism. The geochemical and isotopic features of these basic lavas are used to map mantle structure beneath the Southern Tyrrhenian basin thus providing an important insight into the possible geodynamic scenario able to explain the coexistence of IAB and OIB magmas in this area.

KEYWORDS: Southern Tyrrhenian, calc-alkaline magmas, alkaline magmas

RIASSUNTO - In questo lavoro viene presentata una revisione dei dati petrologici relativi alle vulcaniti sottomarine fino ad oggi recuperate dal bacino meridionale del Tirreno. Quest'area rappresenta un esempio di sistema "arco vulcanico attivo/bacino di retro-arco" dove coesistono magmi di tipo IAB e OIB. I magmi IAB sono i più diffusi, sia in ambiente di arco che di retro-arco, mentre i magmi OIB si rinvengono in poche aree. Le caratteristiche geochimiche ed isotopiche delle lave sottomarine più basiche del Tirreno meridionale, ed in particolare quelle recuperate durante le recenti campionature del vulcano sottomarino Marsili e dal campo lavico Prometeo, permettono di caratterizzare le sorgenti mantelliche dei magmi IAB e OIB di quest'area. Le caratteristiche geochimiche ed isotopiche di queste lave basiche sono usate per definire la struttura del mantello al di sotto del bacino meridionale del Tirreno e forniscono una importante introspezione sul possibile scenario geodinamico che ha controllato la co-esistenza in quest'area di magmi IAB e OIB.

PAROLE CHIAVE: Tirreno meridionale, magmi calcalcalini, magmi alcalini

(*) Dipartimento di Scienze della Terra, Università degli Studi di Parma, Parco Area delle Scienze, 157A, I-43100 Parma, Italy
(**)Dipartimento di Scienze della Terra e Geologico-Ambientali, Piazza di Porta S. Donato 1, I 40126 Bologna, Italy

1. - INTRODUCTION

The southern Tyrrhenian basin represents an example of an active volcanic arc/back-arc system where there is the coexistence of Island Arc Basalt (IAB)-type and Ocean Island Basalt (OIB)-type magmas (fig. 1). In the last decade several authors focused their attention on the geochemical and petrological characteristics of this magmatism with the aim to unravel its geodynamic significance (BECCALUVA et alii, 1982, 1985; ELLAM et alii, 1989; SERRI, 1990; FRANCALANCI & MANETTI,1994; PECCERILLO, 2001; SERRI et alii, 2001; CALANCHI et alii, 2002). However, most of these studies focused on the emerged part of this magmatism whereas the knowledge of the sub-merged part is still mottled and incomplete, being referred to the pioneer seafloor explorations of this area carried out between the 70s-80s (SELLI et alii, 1977; BARBERI et alii, 1978; COLANTONI et alii, 1981; BECCALUVA et alii, 1985; ROBIN et alii, 1987; BECCALUVA et alii, 1990).

In the southern Tyrrhenian region, IAB-type lavas are widespread, occurring in the Aeolian volcanic arc, the Marsili and Aeolian seamounts and as seamount remants and lava flows flooring the basement of the Marsili and Vavilov Basins. By contrast, the few OIB-type lavas are represented by isolated volcanic centres or lava flows (i.e., Magnaghi, Vavilov and Aceste seamounts; Ustica island; rocks drilled, dredged and cored in the East Sardinia rifted margin and the
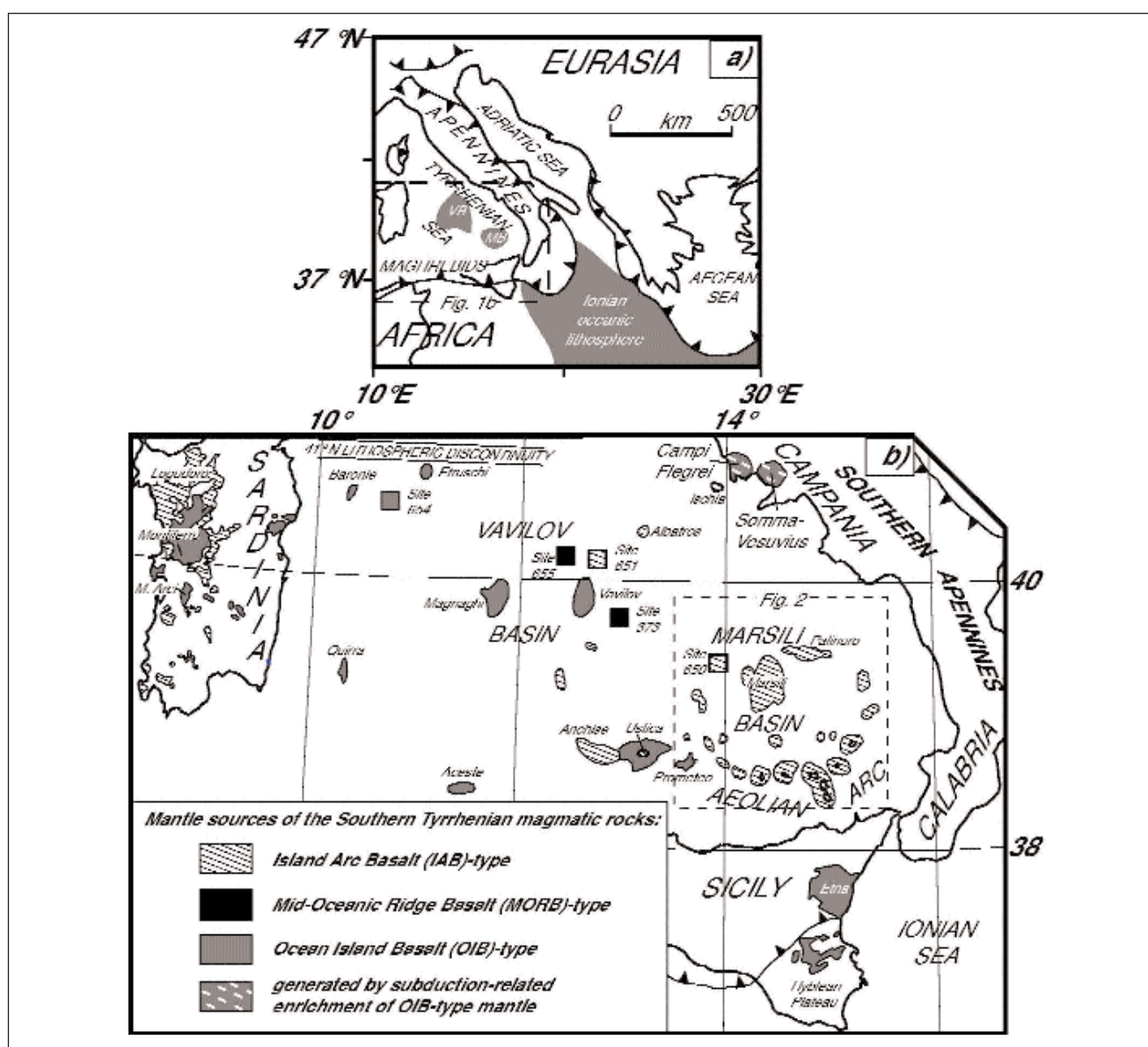

Fig. 1 – a) Schematic outline showing the main thrust fronts (barbed line) that bound Neogene fold and thrust belts of the central Mediterranean region (modified after MARANI & TRUA, 2002). VB, Vavilov basin. MB, Marsili basin. b) Schematic map of the Cenozoic magmatic rocks of the southern Tyrrhenian region according to their inferred dominant magma sources (modified after SERRI et alii, 2001).
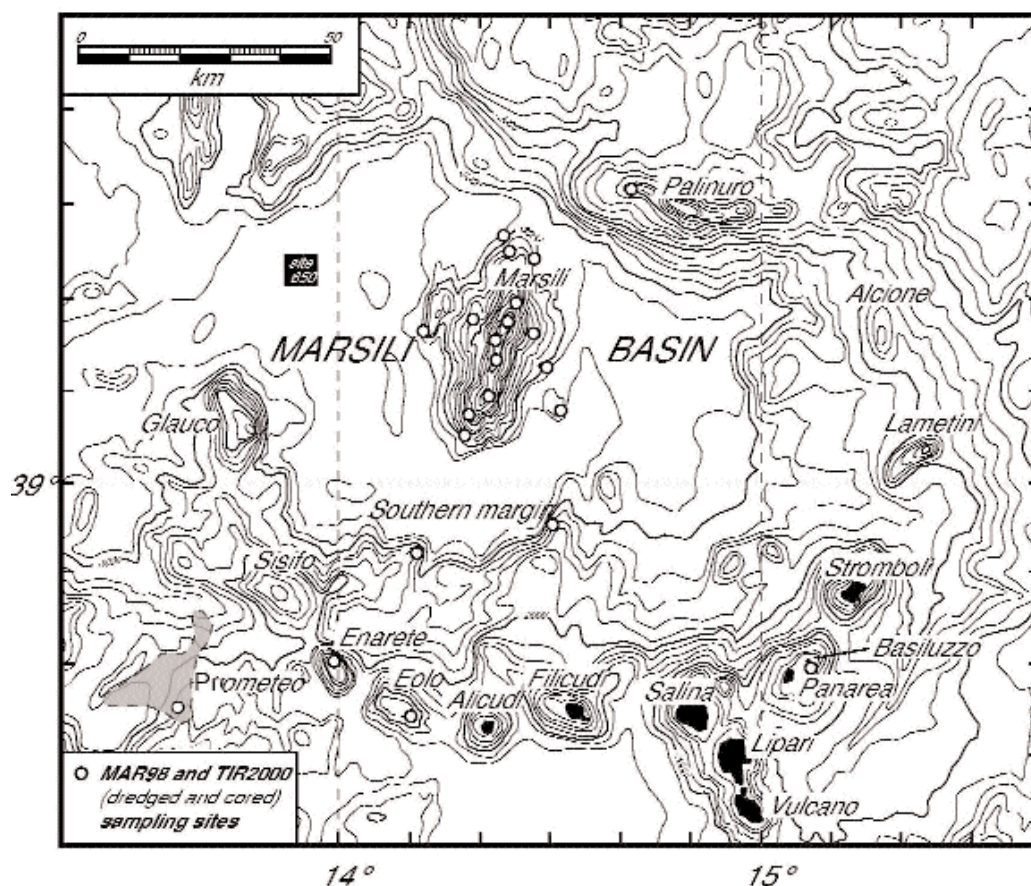
Fig. 2 – *Sampling areas of MAR98 and TIR2000 cruises discussed in the text (modified after* MARANI *et alii,* 1999). *Isobaths every 200 m.*

recently discovered (TRUA *et alii*, 2003) Prometeo submarine lava field) (fig. 1). There is a general consensus in considering the IAB-type magmatism of this area related to northwestward subduction of the narrow Mesozoic Ionian oceanic slab occurring within a general context of Africa and Euroasia convergence (SERRI *et alii*, 2001 and references therein). By contrast, the occurrence of the OIB-type magmatism in this complex subduction-related environment is a still matter of discussion (GVIRTZMAN & NUR, 1999; SERRI *et alii*, 2001; TONARINI *et alii*, 2001a; GASPERINI *et alii*, 2002; MARANI & TRUA, 2002; TRUA *et alii*, 2003).

During the MAR98 and TIR2000 cruises, on board the Consiglio Nazionale delle Ricerche (CNR) ship R/V Urania, a large number of submarine samples of volcanic rocks from the southern Tyrrhenian basin were recovered (fig. 2). Owing to their location and their elevated number, these samples represent a potential reservoir of petrogenetic information on the submarine volcanism which took place in the last 2 Ma in this region.

In this paper, we present petrological and geochemical data on newly collected samples and compare them with available literature data on the Neogene-Quaternary magmatism of the southern Tyrrhenian basin. We show how the recent, more detailed study of the submarine magmatism provides a breakthrough to

understand (i) the relationships between areal distribution and petrogenetic affinity of magmatism and (ii) the geotectonic processes which are still active in this complex area.

2. - GEOLOGICAL SETTING AND REGIONAL VARIATION OF NEOGENE-QUATERNARY SUBDUCTION-RELATED MAGMATISM

Since Early Miocene, a fragment of the Hercynian Alpine orogenic belt began to separate from the Corsica-Sardinia area leading to the opening of the Tyrrhenian Sea basin (GUEGUEN *et alii*, 1998) which occurred differently in its northern and southern sector (SERRI *et alii*, 2001 and references therein). In the northern Tyrrhenian, rifting and crustal thinning developed entirely within a continental realm (SERRI *et alii*, 1993), whereas, in the southern Tyrrhenian, rifting gave way to seafloor spreading which was first focused in the western sector to form the Vavilov back-arc basin (4.3-2.6 Ma) and then in the eastern sector to form the Marsili back-arc basin (2.0-1.8 Ma) (KASTENS *et alii*, 1990) (fig. 1). Most authors agree that the diachronous opening of the Marsili and Vavilov basins was related to the very rapid acceleration in the subduction roll-back of the Ionian oceanic lithosphere below the

southern Tyrrhenian (KASTENS *et alii*, 1988, 1990; SARTORI, 1990; GUEGUEN *et alii*, 1998; SERRI *et alii*, 2001).

In step with back-arc basin development, the subduction related magmatism of the southern Tyrrhenian basin migrated from west to south-east, from Sardinia (32-13 Ma) to the currently active Aeolian island arc (SERRI *et alii*, 2001 and references therein) (fig. 1). This magmatism is characterized by the coeval eruptions of IAB-and OIB-type magmas. IAB-type magmatism is by far the most common. Calc-alkaline (CA) and shoshonite (SHO) suites characterize both the submarine and subaerial magmatism of this region, notably Marsili (site 650) and Vavilov (site 651) basins and Marsili seamount, Anchise seamount, Aeolian islands and related seamounts. Arc tholeiites (A-Th) have been only recovered from Lametini seamount and they seem to be present also along the lowermost northern Aeolian slope, interpreted by MARANI *et alii* (1999) as the faulted southern margin of the Marsili basin. Transitional Mid Oceanic Ridge Basalts (T-MORB) were recovered from Vavilov basin (sites 655 and 373). Both A-Th and T-MORB are absent among the subaerial rocks. Potassic rocks (KS) occur in two Aeolian volcanoes (*i.e.,* Vulcano and Stromboli) and along the eastern margin of the southern Tyrrhenian Sea (*i.e.,* Phlegrean Fields and Mt. Somma-Vesuvius volcano). Unlike the widespread IAB-type magmas, OIB-type magmas are restricted to few areas: Magnaghi, Vavilov and Aceste seamounts; rocks drilled (site 654), dredged and cored in the East Sardinia rifted margin, Ustica island and Prometeo submarine lava field (figs. 1,2).

3. - RESULTS OF RECENT SEAFLOOR SAMPLING

The submarine volcanic samples recovered during the recent oceanographic cruises (MARANI *et alii*, 1999; TRUA *et alii*, 1999; TRUA *et alii*, 2002a,b,c) include samples from Marsili, Palinuro, Eolo and Enarete seamounts, the Basiluzzo area and the faulted southern margin of the Marsili basin (fig. 2). Moreover, some samples derive from Prometeo, a recently discovered lava flow (TRUA *et alii*, 2003) located between Ustica and Alicudi (figs. 1,2)

3.1. - MARSILI SEAMOUNT

Marsili seamount is located in the central, youngest part of the Marsili back-arc basin (fig. 1). The newly collected volcanic rocks (TRUA *et alii*, 2002a,b,c) were dredged/cored from several sites covering the entire depth range of the volcano (fig. 2). Both recent and newly collected samples (SAVELLI & GASPAROTTO, 1994; TRUA *et alii*, 2002a,b,c) reveal that Marsili volcano is entirely made up of CA volcanic rocks (fig. 4) which range from basalts to basaltic andesites to trachyandesites in terms of Total Alkalis *vs.* Silica (TAS) diagram (fig. 3). On the K2O *vs.* SiO2 diagram (fig. 4),

the basalts plot within the medium-K CA series whereas the basaltic andesites range between medium-K and high-K CA fields; the evolved trachyandesites, only erupted from small cones on the summit axis zone of the volcano, plot within the high-K CA andesite field.

Petrological and geochemical characteristics of the least differentiated Marsili CA basalts reveal that at least two types of magmas have been erupted on the volcano (TRUA *et alii*, 2002a,b,c): *group 1* basalts have plagioclase and olivine as dominant phases (tab. 1) and show lower Al, Ca, K, Ba, Rb, Sr and higher Fe, Na, Ti, Zr with respect to *group 2* basalts, which reveal the presence of clinopyroxene as additional phenocryst phase (tab. 1).

Geochemically, both types of magmas are enriched in large-ion lithophile elements (LILE) relative to high field strength elements (HFSE) typical of IAB lavas, but they show very different LILE/HFSE ratios (*i.e., group 1* basalts have Ba/Nb=20 whereas *group 2* basalts have Ba/Nb which ranges from 30 to 80) (fig. 5a). Nevertheless, only *group 2* basalts display primitive-mantle normalized patterns similar in shape, but enriched in all the incompatible elements, in respect to the low-lying CA oceanic crust (site 650) of Marsili basin (fig. 5a).

Sr-Nd isotope ratios of Marsili lavas range from 0.7358 to 0.70493 and 0.51267 to 0.51289 respectively, with the two varieties of Marsili IAB magmas representing the two end-members of Marsili Sr-Nd isotopic range (TRUA *et alii*, 2002a,b) (fig. 6). Notably, the least differentiated *group 2* Marsili basalt has Sr-Nd isotopic compositions similar to the less radiogenic composition of Stromboli basic IAB lavas field, whereas the least differentiated *group 1* Marsili basalt displays less radiogenic Sr isotopic composition and higher [143]Nd/[144]Nd values, resulting isotopically similar to Alicudi lavas, which represent the least radiogenic composition of the whole Aeolian Arc (fig. 6).

The Marsili high-K andesites display primitive-mantle normalized patterns similar in shape to the *group 2* basalts, but enriched in all the incompatible elements (fig. 5a). Moreover, these evolved rocks have Sr-Nd isotopic ratios similar to *group 2* basalts (TRUA *et alii*, 2002 a,b). Therefore one could envisage a derivation of andesites from *group 2* basalts mainly by fractional crystallization. Geochemical modelling, based on correlation between trace elements and isotopic compositions, are required to test quantitatively the validity of this hypothesis. However, it is to note that preliminary fractional crystallization calculations obtained from MELTS (GHIORSO & SACK, 1995) reveal that the evolved andesites can only exclusively be derived from a low-pressure fractionation of magmas compositionally similar to the least evolved *group 2* basalts (TRUA *et alii*, 2002c).

3.2. - VAVILOV BASIN AND SEAMOUNTS

Data obtained on igneous rocks drilled on the basement of Vavilov basin (BARBERI *et alii*, 1978; BECCALUVA *et alii*, 1990) show a complex petrogenetic frame, typical of back-arc basins floored with oceanic
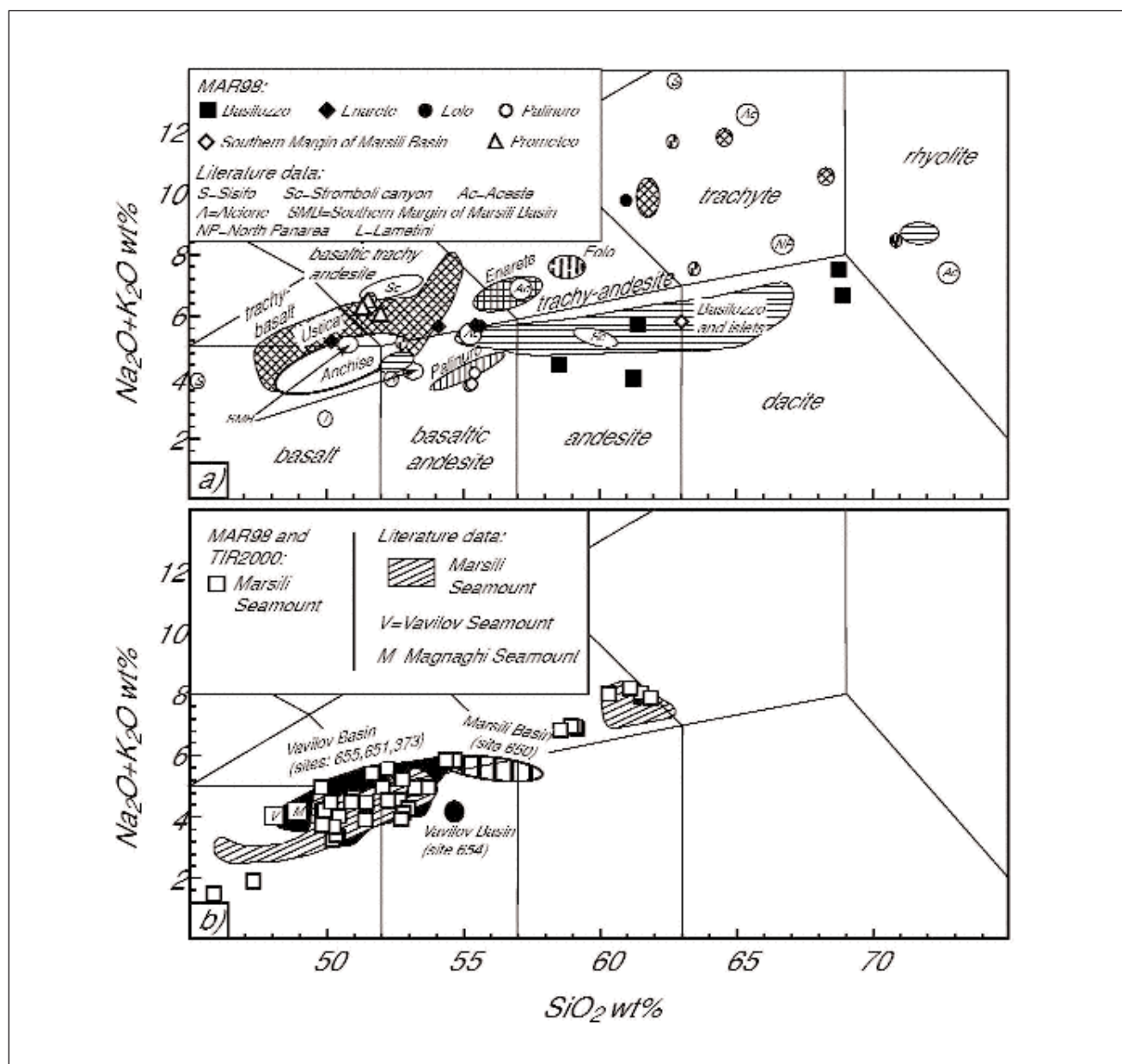
Fig. 3 – *Total alkalis-silica diagram* (LE BAS *et alii*, 1986) *for the Neogene-Quaternary southern Tyrrhenian volcanic rocks. MAR98 and TIR2000 data are from* TRUA *et alii* (1999, 2002c). *Literature data: Sisifo, Alcione, Lametini, Stromboli canyon, southern margin of Marsili basin, Enarete and Eolo* (BECCALUVA *et alii*, 1985); *Palinuro* (COLANTONI *et alii*, 1981; BECCALUVA *et alii*, 1985); *Aceste* (BECCALUVA *et alii*, 1984); *Ustica* (CALANCHI *et alii*, 1984; CINQUE *et alii*, 1988; TRUA *et alii*, 2003); *Vavilov and Magnaghi seamounts* (SELLI, 1977; ROBIN *et alii*, 1987; SERRI, 1990); *Marsili seamount* (SELLI, 1977; SAVELLI & GASPAROTTO, 1994); *Anchise* (CALANCHI *et alii*, 1984); *Vavilov basin, sites: 373, 651, 654 and 655* (BARBERI *et alii*, 1978; BECCALUVA *et alii*, 1982; BECCALUVA *et alii*, 1990; SERRI, 1990; GASPERINI *et alii*, 2002); *Marsili basin, site 650* (BECCALUVA *et alii*, 1990); *Basiluzzo and islets* (CALANCHI *et alii*, 1999). *Note that Marsili basin, Sisifo and southern margin of Marsili basin samples, although reported in this classification digram, are too altered (i.e., LOI>3 wt%) to be classified according to these chemical parameters.*

crust. Most of the Vavilov basin samples (*i.e.,* Sites 373, 651, 655) have suffered a variable degree of hydrothermal alteration that prevent to derive their magmatic affinity from TAS or K2O *vs.* SiO2 diagrams (figs. 3,4). However, least altered samples have ratios of elements, whose secondary mobilization is negligible (*i.e.,* Ti, Zr, Hf, Nb, Ta, Y, Rare Earth Elements (REE)), that can be used for this purpose (BARBERI *et alii*, 1978; BECCALUVA *et alii*, 1982; BECCALUVA *et alii*, 1990; SERRI, 1990).

Basalts which show T-MORB type geochemical (in terms of light REE enrichment and Zr/Nb ratio: $1<(La/Sm)_N<1.5$, normalizing values for chondrite from SUN & MCDONOUGH, 1989; $16<Zr/Nb<25$) and isotopic features have been so far recovered at Sites 655 and 373 (high-Ti basalts) (figs. 5b,6). Only one sample from site 655, having the lowest Zr/Nb ratio (=16), shows relatively little tendency for light REE depletion ($(La/Sm)_N=0.88$) approaching normal
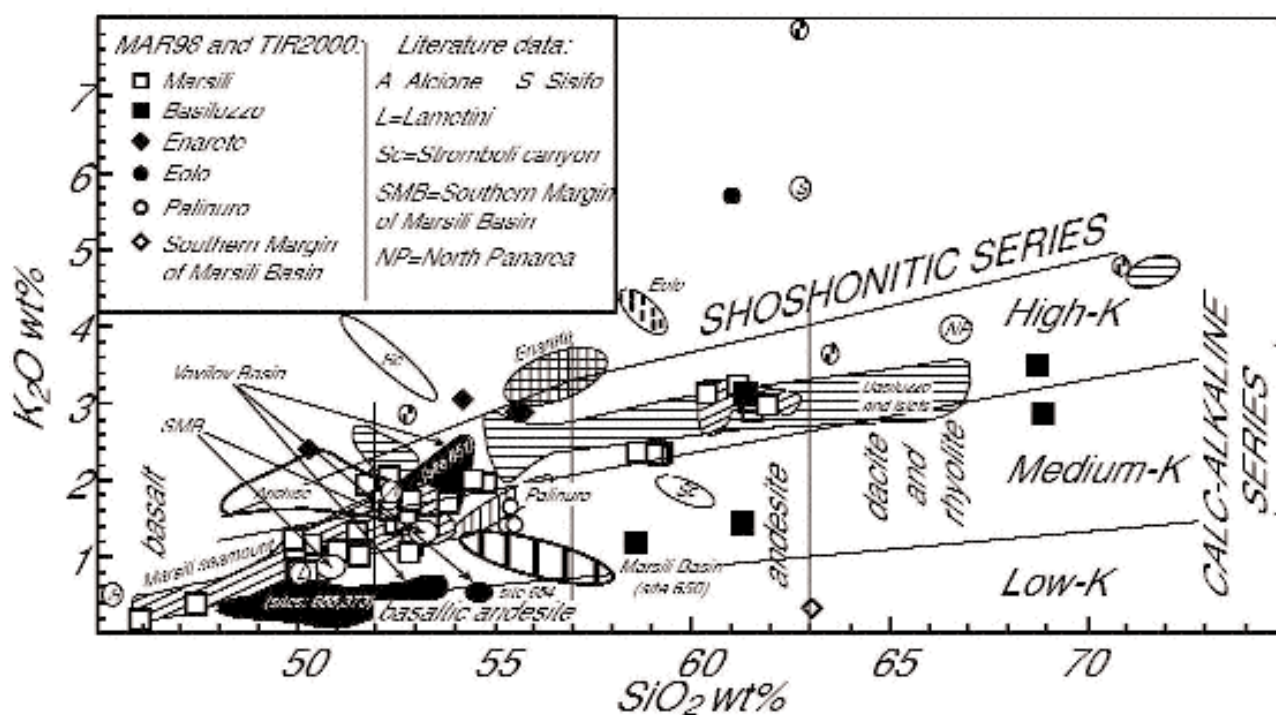
Fig. 4 – *K2O vs SiO2 diagram, showing the major subdivision of the island-arc volcanic rock suites* (WILSON, 1989), *for the Neogene-Quaternary southern Tyrrhenian volcanic rocks. Data source as in figure 3.*

MORB more than any other Tyrrhenian sea basalt (BECCALUVA *et alii*, 1990). Moreover, these basalts show distinct incompatible element pattern (fig. 5b) with positive anomalies for elements partitioned into the fluid phase (such as Cs, Ba, Th, U, K, Pb and light REE) and a depletion in Nb and Ta compared to average E-MORB of SUN & McDONOUGH (1989). The geochemical features of Site 373-low Ti basalts as well as that of basic rocks from Site 651 (high K-CA basaltic andesites, fig. 4) are best explained with the addition of a small amount of subducted slab fluids to a T-MORB type mantle source akin to that of Sites 655 and 373 (high-Ti) basalts (BECCALUVA *et alii*, 1982, 1990). The Sr-Nd isotopic compositions of Sites 655 and 651 rocks are distinct from the rest of the southern Tyrrhenian primitive rocks (MgO>5 wt%) (fig. 6). According to BECCALUVA *et alii* (1990), hydrothermal alteration suffered by these samples does not affect their Nd isotopic composition which approaches that of Mid Atlantic Ridge E-MORB, whereas their Sr isotopic ratio was modified by basalt/seawater interaction (fig. 6). A similar process has also been invoked to explain the genesis and alteration of the oceanic crust of the Marsili basin (Site 650) which shows a medium K-CA basaltic andesites composition (figs. 4,5a).The two large central volcanoes of Vavilov basin, Magnaghi (3.0-2.7 Ma) and Vavilov (Late Pliocene - 0.1 Ma) seamounts, were built after cessation of the seafloor-spreading tectonic regime (ROBIN *et alii*, 1987; KASTENS *et alii*, 1988, 1990; SAVELLI,

1988). Few samples recovered from these seamounts reveal a basaltic composition (SELLI *et alii*, 1977; ROBIN *et alii*, 1987) and show incompatible trace element patterns indicating a derivation by partial melting of typical OIB-source (SERRI, 1990 and references therein) (fig. 5b).

A derivation from an OIB-type mantle source has been also suggested for the basaltic andesite rocks recovered from the eastern Sardinia rifted margin (Site 654) in spite of their tholeiitic affinity (figs. 3,4,5b) (SERRI, 1990).

3.3. - AEOLIAN SUBMARINE VOLCANISM: EOLO AND ENARETE SEAMOUNTS AND BASILUZZO AREA

Eolo and Enarete together with Sisifo represent volcanic seamounts oriented in a NW-SE direction and located to the west of the emerged Aeolian arc (MARANI *et alii*, 1999; MARANI & TRUA, 2002) (fig. 1).

Following the K2O *vs.* SiO2 diagram, most of the samples recently recovered from Enarete seamount plot in the SHO field and range from shoshonitic basalts to shoshonites, with some intermediate rocks displaying a high-K CA affinity and a basaltic andesite composition (fig. 4). Also samples recovered from Eolo seamount belong to the SHO series but they show a more evolved composition (latite) if compared to Enarete products. Several samples have been recovered from Basiluzzo area. All of them have a CA affi-

Tab. 1 – *Synthetic petrographic features of dredged and cored magmatic rocks from the Southern Tyrrhenian Basin during MAR98-TIR2000 cruises and comparison with literature data.*

Locality	Magma series (1)	Rock type (2)	Phenocrysts and micro-phenocrysts (3)	Age (Ma) (4)	Reference
Marsili seamount	CA	MK-/HK- B and BA	*group 1:* pl, ol, opq *group 2:* pl, ol, cpx, opq	0.7-<0.1	SELLI *et alii*, 1977; SERRI, 1990; SAVELLI & SCHREIDER, 1991; SAVELLI & GASPAROTTO, 1994; TRUA *et alii*, 2002c
		HKA	pl, cpx, opq ±opx ±ol		
Eolo seamount	SHO	B	pl, cpx, ol, ap	0.85-0.66	BECCALUVA *et alii*, 1985; TRUA *et alii*, 1999
		S	pl, cpx, bt, opx, ol, opq, ap		
		L	pl, cpx, ol, opq, ap +bt +opx		
		T	pl, bt, ap, opq		
	CA	HKD	pl, hb, cpx, bt, opx, opq, ap		
		R	pl, bt, cpx, opq, ap		
Enarete seamount	SHO	B	pl, bt, cpx	0.78-0.67	BECCALUVA *et alii*, 1995; TRUA *et alii*, 1999
		S	pl, bt, cpx +opx, +opq, +ap		
Basiluzzo and islets	CA	MK-/HK-A	pl, cpx, opx, hb, opq	0.05	CALANCHI *et alii*, 1999 TRUA *et alii*, 1999
		MK-/HK-D	pl, cpx, opx, hb, opq		
		KHR	pl, cpx, hb		
Palinuro seamount	CA	MK-BA	pl, cpx, opx, ol, opq	0.35	COLANTONI *et alii*, 1981; TRUA *et alii*, 1999
Southern margin	TH	B	pl, cpx, ol	n.a.	BECCALUVA *et alii*, 1985; TRUA *et alii*, 1999
	CA	tonalite	qz, pl, opq		
Prometeo	A	Mug	pl, ol, cpx, opq	n.a.	TRUA *et alii*, 1999; TRUA *et alii*, 2003
Ustica	A	B	pl, ol, cpx	0.75-0.13	CALANCHI *et alii*, 1984; CINQUE *et alii*, 1988; SERRI, 1990; DE VITA *et alii*, 1998
		Haw	pl, ol, cpx		
		Mug	pl, ol, cpx, opq		

(1) A= alkaline; CA= calcalkaline; TH= tholeiitic; SHO= shoshonitic. (2) LK-= low K; MK-= medium K; HK-= high K; B= basalt, BA= basaltic andesite; A= andesite; D= dacite; R= rhyolite; S=shoshonite; L=latite; T=trachyte; Haw= hawaiite; Mug= mugearite. (3) ol=olivine, opx=orthopyroxene; cpx=clinopyroxene, pl=plagioclase, bt=biotite, hb=hornblende, opq=opaque, ap=apatite, qz=quartz. (4) n.a.=not available.
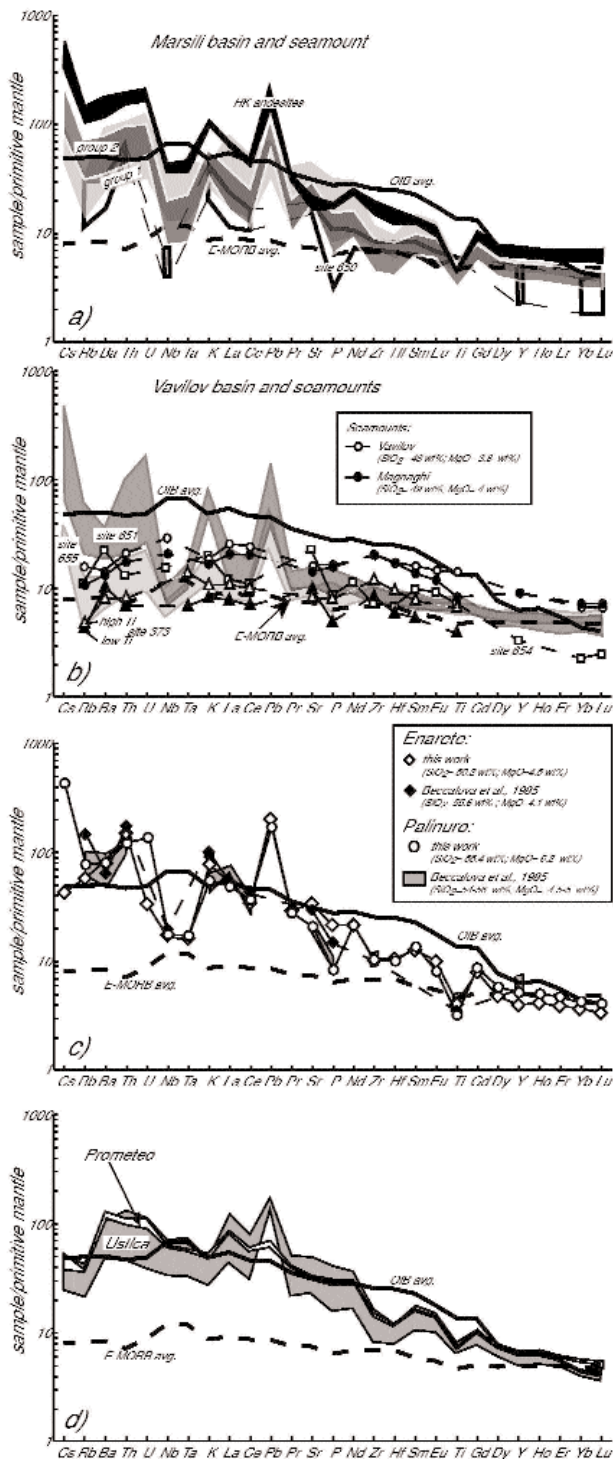
Fig. 5 – *Primordial mantle normalized incompatible element variation diagrams (normalizing values from SUN & MACDONOUGH, 1989). Trace element pattern for: a) Marsili basin and seamount lavas); b) Vavilov basin and seamounts lavas; c) Enarete and Palinuro seamounts; d) Prometeo lava field samples and Ustica lavas. Southern Tyrrhenian data source as in figure 3. Average OIB and E-MORB from SUN & MACDONOUGH (1989).*

Fig. 6 – *$^{87}Sr/^{86}Sr$ vs. $^{143}Nd/^{144}Nd$ diagram for Neogene-Quaternary southern Tyrrhenian and African foreland lavas (MgO>5 wt%). Marsili (TRUA et alii, 2002a,b); Vavilov basin: sites 651, 654, 655 (BECCALUVA et alii, 1990); Prometeo and Ustica (TRUA et alii, 2003); Alicudi, Filicudi, Salina, Lipari, Vulcano, Panarea and Stromboli (ELLAM et alii, 1988, 1989; FRANCALANCI et alii, 1993; PECCERILLO et alii, 1993; DE ASTIS et alii, 2000; CALANCHI et alii, 2002); Hyblean OIB-type alkaline rocks (TRUA et alii, 1998); recent Etnean lavas (TONARINI et alii, 2001a); Vesuvius (AYUSO et alii, 1998; SOMMA et alii, 2001). MORB field (WILSON, 1989). HIMU, EMI and EMII: OIB end-member mantle components (ZINDLER & HART, 1986).*

comparable, both in petrographical and geochemical characteristics, to previous samples recovered from these areas (tab. 1; figs. 3,4). However, it is worth to note that among the samples dredged from Enarete seamount by the MAR98 cruise there is a fragment of lava which resulted the most primitive basalt so far recovered from the seamount (figs. 3,4). The primitive mantle-normalised trace element pattern of this sample is very similar to that of the least differentiated Enarete sample studied by BECCALUVA et alii (1985). Both these samples display troughs at Nb, Ta and Ti and high LILE/HFSE ratios which are distinct features of island arc magmas (fig. 5c).

3.4. - PALINURO SEAMOUNT

Palinuro seamount is a volcanic complex consisting of five coalesced edifices straddling the eastern margin of the southern Tyrrhenian Sea in a W-E direction (MARANI et alii, 1999). It is located in a crucial position between the oceanic-crust floored Marsili basin and the Campanian-Calabrian continental slope (fig. 1). Despite the fact that it represents one of the main volcanic complex in the Tyrrhenian basin, it is still poorly studied from a petrological point of view.

Among the few samples recovered from the seamount during previous seafloor explorations, only two have been chemically studied (COLANTONI et alii, 1981). Furthermore, only three volcanic samples were recovered from the summit and in the south-eastern flank of the Palinuro volcanic complex (fig. 2) during the MAR98 cruise, since the principal target of that cruise was to sample hydrothermal deposits from this

nity and range from medium-K andesites up to medium- or high-K dacites in composition (fig. 4).
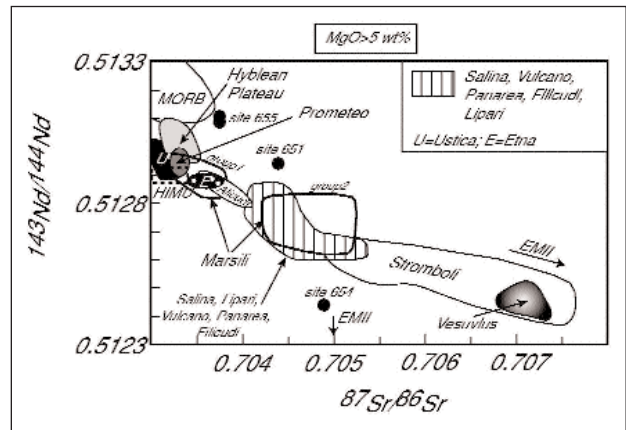
Eolo, Enarete and Basiluzzo samples are strictly

volcanic area (MARANI *et alii*, 1999). These newly collected volcanic samples from Palinuro belong to the CA series and show a basaltic andesite composition similar to that observed in previously studied rocks (fig. 4). Also their petrographic features are strictly comparable to previous samples recovered by COLANTONI *et alii* (1981) from this area (tab. 1). Moreover, Palinuro samples have IAB-type pattern which results very similar to that also displayed by the western Aeolian seamounts (*e.g.,* Enarete) (fig. 5c).

3.5. - SOUTHERN MARGIN OF THE MARSILI BASIN

Few dredge hauls were made during MAR98 cruise in this still poorly studied area (fig. 2). Fragments of volcanic microbreccia, basic lavas and intrusive (tonalite, tab. 1) rocks have been recovered. Both lavas and the tonalite are affected by a strong degree of hydrothermal alteration, petrographically and chemically evidenced by the presence of abundant secondary minerals and high (from 4 up to 13 wt%) LOI respectively. The less altered sample (tonalite, LOI=4wt%) shows geochemical features similar to the low-K CA andesites (fig. 4).

From this area BECCALUVA *et alii* (1985) recovered two samples of basalts which suffered a strong degree of hydrothermal alteration. According to these authors, the petrochemical characteristics of these basalts are analogous to those of tholeiitic basalts, with IAB affinity. These samples would represent together with the tholeiitic basalt recovered from the north Lametini seamount, the only A-Th rocks so far recovered from the southern Tyrrhenian basin (fig. 4).

3.6. - PROMETEO LAVA FIELD

Few samples recovered during the MAR98 cruise derive from a lava flow located between Ustica and Alicudi islands (figs. 1,2) and erupted from a submarine eruptive centre recently discovered through the interpretation of multibeam reflectivity data (MARANI *et alii*, 1999). This previously unknown submarine lava field was named Prometeo by TRUA *et alii* (2003).

Prometeo samples are Na-alkaline basic rocks with a mugearite composition (fig. 3) and result petrographically and geochemically similar to the mugearites of Ustica island (tab. 1; fig. 3) (TRUA *et alii*, 2003). Prometeo mugearites show distinct patterns, with positive anomalies for elements partitioned into the fluid phase (*i.e.,* Ba, Th, U, Pb and La) and a relative depletion in less incompatible elements (from Zr to Ti) compared to average OIB-magmas (fig. 5d). In this respect, Prometeo lavas are similar to the OIB-type lavas from the nearby Ustica island (fig. 5d).

Prometeo and Ustica lavas have Sr and Nd isotopic compositions that are more consistent with OIB-type magmas than their trace-element concentrations (fig. 6). These lavas have a small range in $^{87}Sr/^{86}Sr$ (0.70304-0.70329) and 143Nd/144Nd (0.51291–0.51300) isotopic

ratios approaching the isotopic composition of HIMU (high-μ) OIB-type basalts (Weaver, 1991). Interestingly, an HIMU-type component is also present in the source of the Plio-Pleistocene Hyblean and the most recent (post-1970) Etna OIB-type magmas (BECCALUVA *et alii*, 1998; TRUA *et alii*, 1998; SCHIANO *et alii*, 2001; TONARINI *et alii*, 2001a) (fig. 6), both erupted on the side of the African plate adjacent to the subduction-related Aeolian island arc (fig. 1).

We will discuss below how this observation provides strong useful geochemical tracers that can infer mantle structure beneath the southern Tyrrhenian basin.

4. – DISCUSSION

The geochemical complexities of southern Tyrrhenian volcanic rocks exemplify an important, debated issue of active volcanic arc systems: why do OIB-type basalts erupt in subduction related environments?

The coexistence of OIB and IAB magmatism is a long-standing petrological problem of the southern Tyrrhenian magmatism and has important implications not only for models of magma generation in this complex area but also for understanding its geodynamic evolution. The generation of OIB-type magmas in a volcanic arc system can occur where pristine asthenospheric material replaces mantle domains previously modified by subduction processes. The mechanisms proposed to explain this replacement are arc rifting (LEEMAN *et alii*, 1990; MARQUEZ *et alii*, 1999), slab window opening (HOLE *et alii*, 1991) or tear development along the subducting slab (TURNER & HAWKESWORTH, 1998). Alternatively, OIB-like signatures of some rocks occurring in arc environments may simply be related to low degree of partial melting of mantle wedge material that had undergone a low degree of contamination by slab components (REINERS *et alii*, 2000).

In the southern Tyrrhenian, IAB-type volcanic activity is widespread, being represented in the Vavilov and Marsili basins, Marsili seamount, Aeolian volcanic arc and related seamounts, whereas OIB-type magmatism is restricted to few areas (fig. 1): Magnaghi, Vavilov and Aceste seamounts; rocks drilled (site 654), dredged and cored in the East Sardinia rifted margin; Ustica island and Prometeo submarine lava field.

The petrological study of samples recently recovered from the southern Tyrrhenian will provide a much-needed insight into the relative role of OIB-type and IAB-type mantle sources in determining the unusual magmatic scenario offered by this region. In the following sections we discuss the petrological implications of preliminary geochemical and isotopic data for these samples, taking into account the key Marsili IAB-type seamount and Prometeo OIB-type volcanic rocks, and compare them with the literature data from the other volcanic areas in and around the southern Tyrrhenian region.

4.1. - Upper mantle structure beneath the southern Tyrrhenian: geochemical and isotopic constrains.

In the last decade it has become well established that geochemical tracers that distinguish between the sources of magmas (OIB, MORB, IAB) may provide a useful tool for mapping upper-mantle structure. Here we use incompatible element ratios coupled with isotope compositions of the most primitive southern Tyrrhenian rocks (MgO>5.0 wt%) to constrain variation in the magmas source composition of this region. Our arbitrary cut off of 5.0 wt% MgO was chosen to maximize the available data.

Pearce & Parkinson (1993), Pearce & Peate (1995) have advocated the use of graph of the type M (=conservative element)/Yb *vs.* Nb/Yb, where Yb is used as the normalising element to minimize the effects of partial melting and fractional crystallization, to estimate the mantle source composition of arc basalts, prior to its modification by slab-derived components. Both Nb and Zr may be considered as conservative elements for southern Tyrrhenian IAB-type magmas because the great majority of them plot within the MORB array in the Zr/Yb *vs.* Nb/Yb diagram, suggesting a derivation from sources enriched with respect to an average normal MORB and broadly comparable to T-/E-MORB sources (fig. 7a).

It is to be noted that only Stromboli samples have Zr/Yb ratios comparable with E-MORB lavas, thus approaching that of literature OIB-type lavas (Weaver, 1991). Moreover, according to these ratios, Stromboli and *group-2* Marsili basalts have the strongest OIB affinity among the southern Tyrrhenian IAB-lavas, resulting similar to that of the OIB-lavas of Prometeo, Ustica and Vesuvius. These observations suggest that the southern Tyrrhenian mantle wedge is laterally inhomogeneous and that such heterogeneity was present prior to modification related to subduction processes.

The involvement of OIB-like mantle in the genesis of southern Tyrrhenian subduction-related magmatism was previously suggested by several studies (Beccaluva *et alii*, 1982; Ellam *et alii*, 1988, 1989; Serri, 1990; 1997; De Astis *et alii*, 2000; Serri *et alii*, 2001; Tonarini *et alii*, 2001b; Calanchi *et alii*, 2002; Gasperini *et alii*, 2002).

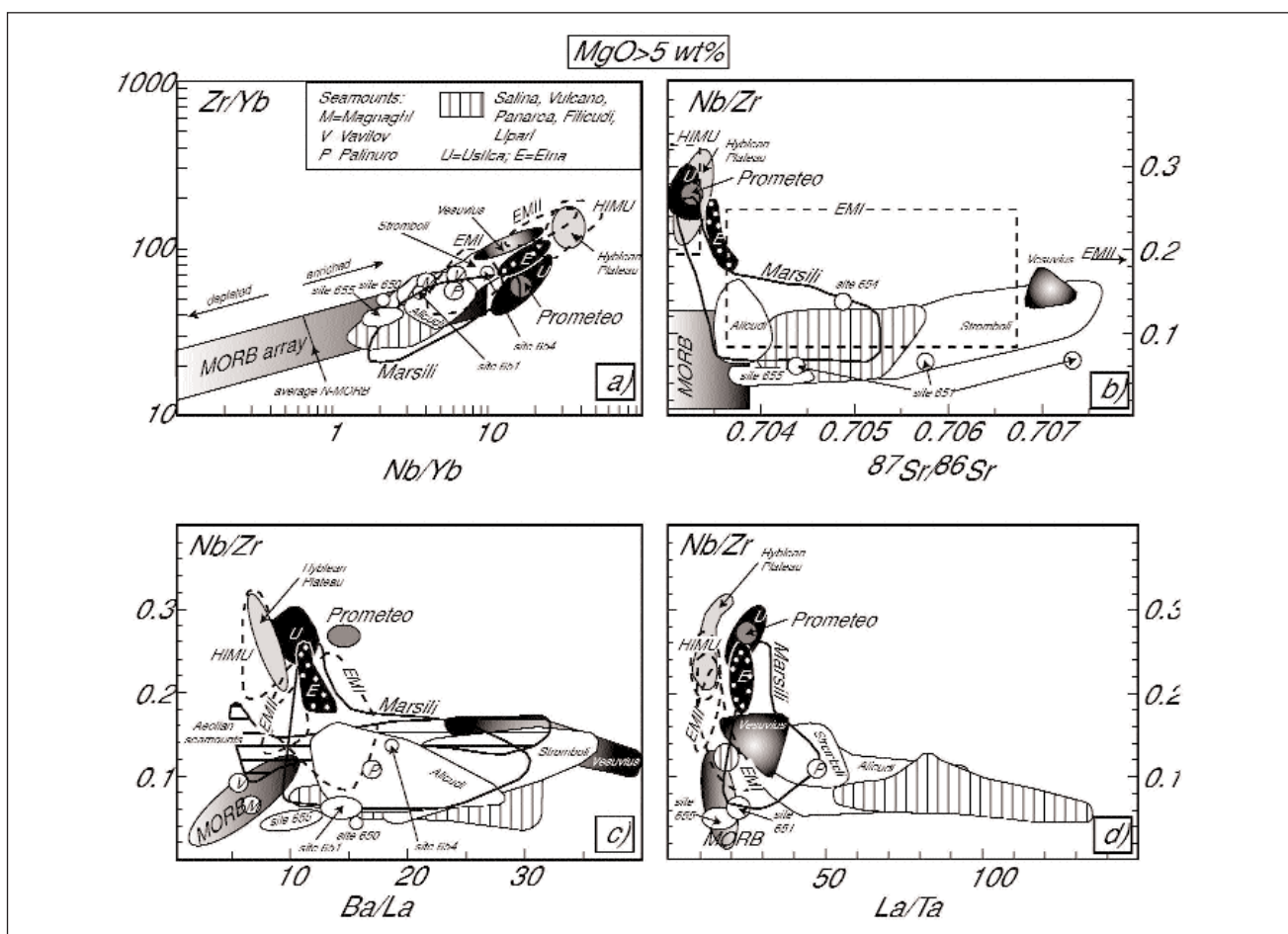We will show below that differences in incompatible element and isotopic ratios of the most primitive

Fig. 7 – *Regional variation of some key incompatible trace element ratios and $^{87}Sr/^{86}Sr$ ratios in mafic rocks (MgO >5 wt%) from the Neogene-Quaternary southern Tyrrhenian and African foreland volcanic areas. MORB array in Zr/Yb vs. Nb/Yb diagram* (Pearce & Parkinson, 1993); *HIMU, EMI and EMII OIB fields* (Weaver, 1991; Zindler & Hart, 1986). *Aeolian seamounts* (Beccaluva *et alii*, 1985). *Other data source as in figures. 3 and 6.*

(MgO>5wt%) southern Tyrrhenian IAB-type lavas, especially those from Marsili seamount, reflect the presence of two distinct OIB-type components in the mantle wedge above the subducting Ionian slab.

These rocks are characterised by a wide range of Sr and Nd isotopic signatures (fig. 6). Notably, Marsili seamount and Aeolian IAB-type rocks have radiogenic isotope signatures that plot along a continuous trend extending from Ustica-Prometeo OIB-type magmatism to potassic rocks from Vesuvius. Two important observations arise from this diagram.

1) Unlike the Aeolian arc, Marsili seamount magmas erupted on oceanic crust and it is likely that they preserved the geochemical and isotopic characteristics of mantle-derived primitive melts. Thus, the Sr-Nd isotopic similarity between Marsili seamount and Aeolian rocks suggest that the main compositional differences between primitive Aeolian magmas are mostly inherited from an heterogeneous mantle source, akin to that involved in the genesis of Marsili seamount magmas, instead of acquired during shallow-level magma contamination.

2) Several studies have pointed that the potassic rocks from Stromboli and Vesuvius are derived from an originally OIB-type mantle metasomatized by subduction-related fluids or melts (SERRI, 1990; BECCALUVA *et alii*, 1991; PECCERILLO, 2001). Thus, if we accept this interpretation, the variations in Sr-Nd isotopes encountered within the southern Tyrrhenian IAB-type magmatism could reflect the interaction between two distinct OIB-type components: one akin to that involved in the genesis of Ustica/Prometeo magmas (HIMU-like) and one more similar to that involved in the genesis of potassic magmas from Vesuvius (Vesuvius-like). These two OIB-like components were added to the pre-existing mantle wedge which had T-MORB isotopic signature, as evinced by the isotopic compositions of the samples drilled from the basement of the Vavilov basin (sites 373 and 655).

Combined evaluation of Sr isotope and ratios between some highly incompatible trace elements brings a further strong argument in support of the involvement of different mantle-derived components (OIBs HIMU-like and Vesuvius-like, T-MORB) as the cause of geochemical and isotopic variations in the most primitive southern Tyrrhenian magmas. Note that, for the most primitive rocks (MgO>5wt%) within each volcanic area of the southern Tyrrhenian basin, the chosen incompatible element ratios are constant with decrease of MgO content. Therefore, in absence of crustal contamination processes, they closely reflect those of their source.

From the previous discussion, we can assume that Nb/Zr ratio in the southern Tyrrhenian IAB-lavas is mantle-derived (fig. 7a). Different Nb/Zr ratios are generally interpreted in terms of variations in source composition or changes in degree of partial melting of the mantle. Since variable Nb/Zr ratio amongst these lavas nicely correlates with $^{87}Sr/^{86}Sr$, it can not be the consequence of variable partial melting of a single mantle source, but it requires that three different kinds

of mantle-derived components were implicated in the genesis of southern Tyrrhenian magmatism (fig. 7b). Systematic variations in La/Ta (Ba/Nb and La/Nb, not shown) and Ba/La (Ba/Zr, not shown) ratios against Nb/Zr among the southern Tyrrhenian mafic lavas (fig. 7 c,d) further supply a straightforward test for this hypothesis and give fundamental information on the nature and possible origin of the three distinct mantle components involved in the genesis of the southern Tyrrhenian primitive magmas: (1) a depleted mantle wedge with T-MORB geochemical and isotopic signatures, probably somewhat modified by the incorporation of sedimentary and subduction-related material (mostly evident in Site 651 volcanics from Vavilov Basin); (2) a high Nb/Zr, low LREE/HFSE, Ba/La, Ba/Zr and $^{87}Sr/^{86}Sr$ OIB-type mantle component best developed in Ustica an Prometeo lavas; (3) an intermediate Nb/Zr, high LREE/HFSE, Ba/La, Ba/Zr and $^{87}Sr/^{86}Sr$ OIB-type mantle component best developed in Stromboli and Vesuvius lavas.

However, it is to note that in these trace element ratio diagrams the involvement of Vesuvius OIB-type mantle beneath the southern Tyrrhenian region may mask the contribution from the addition of Ionian subduction-related components (*i.e.,* fluids or melts derived from oceanic crust and subducted sediments) that several studies have documented to have occurred in both OIB (TRUA *et alii*, 2003) and IAB (SERRI, 1997; TONARINI *et alii*, 2001b) mantle sources of this region. This does not happen only for lavas from the central Aeolian arc (*i.e.,* Vulcano, Lipari, Salina and Panarea) that derived from more fluid-rich metasomatized mantle sources (FRANCALANCI *et alii*, 1993; DE ASTIS *et alii*, 2000; TONARINI *et alii*, 2001b). Geochemical modelling involving both incompatible trace element ratios and isotopic ratios is able to discriminate between the contribution from the various mantle reservoirs recognised beneath the southern Tyrrhenian basin and their interaction with Ionian slab-derived sediments and fluids. But this interaction represents a second-order process in the petrogenesis of the southern Tyrrhenian magmatism which, in terms of geochemical and isotopic components, reflects the presence of two distinct OIB-type components in the T-MORB mantle wedge prior to the addition of subduction-related components.

4.2. - GEODYNAMIC IMPLICATIONS

The geochemical tracers discussed in the previous section can be used to map mantle structure in the southern Tyrrhenian basin and represent an important contribution to the debate on the recent geodynamics of mantle flow in this region (GVIRTZMAN & NUR, 1999; DOGLIONI *et alii*, 2001; GASPERINI *et alii*, 2002; MARANI & TRUA, 2002, TRUA *et alii*, 2003).

GVIRTZMAN & NUR (1999) suggested that several geological features of the southern Tyrrhenian basin could be explained by suction of intraplate mantle from the African plate margin into the mantle wedge

above the subducting Ionian slab. According to Gvirtzman and Nur's model, Etna and Vesuvius magmatism would be a main surface effect of the African asthenospheric inflow along the southern and the northern tear of the subducted Ionian plate, respectively. The evidence here discussed reveals that GVIRTZMAN & NUR's (1999) hypothesis could effectively account for the presence of distinct OIB-type components in the mantle wedge of the southern sector of the southern Tyrrhenian basin (MARANI & TRUA, 2002).

The OIB HIMU-like components seem to be restricted to a roughly NW-SE trending belt across the Sicilian Maghrebide orogen which is composed of Ustica, Prometeo and Etna volcanoes (fig. 1) (TRUA *et alii*, 2003). According to MARANI & TRUA (2002) the volcanic alignment defined by these OIB-type volcanoes is the surface evidence of the southern slab tear of the Ionian subducted slab. It is noteworthy that BECCALUVA *et alii* (1982) were the first to raise the issue that OIB-type magmas from Ustica could be associated with a first order lateral discontinuity of the subducted Ionian slab. The authors based their hypothesis mainly on the similar geochemical characteristics shared by Ustica and Etna OIB-type lavas. The finding of Prometeo HIMU-type submarine lava field along the same NW-SE volcanic alignment defined by Ustica and Etna strongly supports this idea.

The similarity between most of the geochemical features of the primitive potassic magmas from Stromboli and Vesuvius in terms of geochemical and isotopic signatures likely points to compositionally similar mantle sources (SERRI, 1990; PECCERILLO, 2001 and references therein). These mantle sources, which define the OIB Vesuvius-like component (figs. 5, 6), consist of a mixture of an OIB-type and slab-derived components. However, unlike the HIMU OIB-type component, the origin of the OIB Vesuvius-like component in this sector of the southern Tyrrhenian is still unclear. A detailed petrological study on the poorly known submarine volcanic areas (e.g., Palinuro, Aceste, Anchise, Albatros, Alcione and Lametini) are required to better define the mantle dynamics and magma-generation processes occurring in southern Tyrrhenian back-arc basin.

REFERENCES

AYUSO R.A., DE VITO B., ROLANDI G., SEAL II R.R. & PAONE A. (1998) – *Geochemical and isotopic (Nd-Pb-Sr-O) variations bearing on the genesis of volcanic rocks from Vesuvius, Italy.* Journal of Volcanology and Geothermal Research, **82**: 53-78.

BARBERI F., BIZOUARD H., CAPALDI G., FERRARA G., GASPARINI P., INNOCENTI F., JORON J.L., LAMBERT B., TREUIL M. & ALLÈGRE C. (1978) - *Age and nature of basalts from the Tyrrhenian Abyssal Plain.* In: HSU K., MONTADERT L. *et alii* (Eds.): "*Initial Reports of the Deep Sea Drilling Project*". Washington, **42**: 509-514.

BECCALUVA L., ROSSI P.L. & SERRI G. (1982) - *Neogene to Recent volcanism of the Southern Tyrrhenian-Sicilian area: Implications for the geodynamic evolution of the Calabrian arc.* Earth Evolutionary Sciences, **3**: 222-238.

BECCALUVA L., MORLOTTI E. & TORELLI L. (1984) – *Notes on the geology of the Elimi Chain area (Southwestern margin of the Tyrrhenian Sea).* Mem. Soc. Geol. It., **27**: 213-232.

BECCALUVA L., GABBIANELLI G., LUCCHINI F., ROSSI P.L. & SAVELLI C. (1985) - *Petrology and K/Ar ages of volcanics dredged from the Aeolian seamounts: implications for geodynamic evolution of the Southern Tyrrhenian basin.* Earth and Planetary Science Letters, **74**: 187-208.

BECCALUVA L., BONATTI E., DUPUY C., FERRARA G., INNOCENTI F., LUCCHINI F., MACERA P., PETRINI R., ROSSI P.L., SERRI G., SEYLER M. & SIENA F. (1990): *Geochemistry and mineralogy of volcanic rocks from ODP sites 650, 651, 655 and 654 in the Tyrrhenian Sea.* In: KASTERNS K & MASCLE J. (Eds.): "*Proceeding of the ODP*". Scientific Results, **107**:' 49-74.

BECCALUVA L., DI GIROLAMO P. & SERRI G. (1991) – *Petrogenesis and tectonic setting of the Roman volcanic province.* Lithos, **26**: 191-221.

BECCALUVA L., SIENA F., COLTORTI M., DI GRANDE A., LO GIUDICE A., MACCIOTTA G., TASSINARI R. & VACCARO C. (1998) – *Nephelinitic to tholeiitic magma generation in a transtensional tectonic setting: an integrated model for the iblean volcanism, Sicily.* Journal of Petrology, **39**: 1547-1576.

CALANCHI N., COLANTONI P., GABBIANELLI G., ROSSI P.L. & SERRI G. (1984) – *Physiography of Anchise Seamount and of the submarine part of Ustica Island (south Tyrrhenian): petrochemistry of dredged volcanic rocks and geochemical characteristics of their mantle sources.* Miner. Petrogr. Acta, **XXVIII**, 215-241.

CALANCHI N., TRANNE C.A., LUCCHINI F., ROSSI P.L. & VILLA I.M. (1999) – *Explanatory notes to the geological map (1:10,000) of Panarea and Basilizzo islands (Aeolian Arc, Italy).* Acta Vulcanologica, **11**(2): 223-243.

CALANCHI N., PECCERILLO A., TRANNE C.A., LUCCHINI F., ROSSI P.L., KEMPTON P., BARBIERI M. & WU T.W. (2002) - *Petrology and geochemistry of volcanic rocks from the island of Panarea: implications for mantle evolution beneath the Aeolian island arc (southern Tyrrhenian sea).* Journal of Volcanology and Geothermal Research, **115**: 367-395.

CINQUE A., CIVETTA L., ORSI G. & PECCERILLO A. (1988) - *Geology and geochemistry of the island of Ustica (Southern Tyrrhenian Sea).* Rendiconti della Società Italiana di Mineralogia e Petrologia, **43**: 987-1002.

COLANTONI P., LUCCHINI F., ROSSI P.L., SARTORI R. & SAVELLI C. (1981) - *The Palinuro Volcano and magmatism of the south-eastern Tyrrhenian Sea (Mediterranean).* Marine Geology **39**: M1-M12.

DE ASTIS G., PECCERILLO A., KEMPTON P., LA VOLPE L. & WU T.W. (2000) - *Transition from calc-alkaline to potassium-rich magmatism in subduction environments: geochemical and Sr, Nd, Pb isotopic constraints from the island of Vulcano (Aeolian arc).* Contribution to Mineralogy and Petrology, **139**: 684-703.

DE VITA S., LAURENZI M.A., ORSI G. & VOLTAGGIO M. (1998) – *Application of $^{40}Ar/^{39}Ar$ and ^{230}Th dating methods to the chronostratigraphy of Quaternary basaltic volcanic areas: the Ustica Island case history.* Quaternary International, **47/48**, 117-127

DOGLIONI C., INNOCENTI F. & MARIOTTI G. (2001) - *Why Mt. Etna?* Terra Nova, **13**: 25-31.

ELLAM R.M., MENZIES M.A., HAWKESWORTH C.J., LEEMAN W.P., ROSI M. & SERRI G. (1988) - *The transition from calc-alkaline to potassic orogenic magmatism in the Aeolian Islands, Southern Italy*. Bullettin of Volcanology, **50**: 386-398.

ELLAM R.M., HAWKESWORTH C.J., MENZIES M.A. & ROGERS N.W. (1989) − *The volcanism of Southern Italy: role of subduction and the relationship between potassic and sodic alkaline magmatism*. Journal of Geophysical Research, **94**: 4589-4601.

FRANCALANCI L., TAYLOR S.R., McCULLOCH M.T. & WOODHEAD J.D. (1993) - *Geochemical and isotopic variations in the calc-alkaline rocks of Aeolian arc, southern Tyrrhenian Sea, Italy: constraints on magma genesis*. Contribution to Mineralogy and Petrology, **113**: 300-313.

FRANCALANCI L. & MANETTI P. (1994) − *Geodynamic models of the Southern Tyrrhenian region: constraints from the petrology and geochemistry of the Aeolian volcanic rocks*. Bollettino di Geofisica Teorica ed Applicata, **XXXVI**, 141-144, 283-292.

GASPERINI D., BLICHERT-TOFT J., BOSCH D., DEL MORO A., MACERA P. & ALBEREDE F. (2002) - *Upwelling of deep mantle material through a plate window: evidente from the geochemistry of Italian basaltic volcanics*. Journal of Geophysical Research, **107**: B12, 2367, doi: 10.1029/2001JB000418.

GHIORSO M.S. & SACK R.O. (1995) - *Chemical transfer in magmatic processes IV. A revised and internally consistent thermodynamic model for the interpolation and extrapolation of liquid-solid equilibria in magmatic systems at elevated temperatures and pressures*. Contribution to Mineralogy and Petrology **119**: 197-212.

GUEGUEN E., DOGLIONI C. & FERNANDEZ M. (1998) - *On the post-25 Ma geodynamic evolution of the western Mediterranean*. Tectonophysics, **298**: 259-269.

GVIRTZMAN Z. & NUR A. (1999) - *The formation of Mount Etna as the consequence of slab rollback*. Nature, **401**: 782-785.

HOLE M.J., ROGERS G., SAUNDERS A.D. & STOREY M. (1991) - *Relation between alkalic volcanism and slab-window formation*. Geology, **19**: 657-660.

KASTENS K.A. et alii (1988) - *ODP Leg 107 in the Tyrrhenian Sea: insights into passive margin and back-arc basin evolution*. Geological Society of America Bulletin, **100**, 1140-1156.

KASTENS K.A. et alii (1990) - *The geological evolution of the Tyrrhenian Sea: an introduction to the scientific results of ODP Leg 107*, In: KASTENS K.A., MASCLE J. et alii (Eds.): "*Proceedings of the ODP*". Scientific Results **107**: 3-26.

LE BAS M.J., LE MAITRE R.W., STRECKEISEN A. & ZANETTIN B. (1986) - *A chemical classification of volcanic rocks based on the total alkali-silica diagram*. Journal of Petrology, **27**: 745-750.

LEEMAN W.P., SMITH D.R., HILDRETH W., PALACI Z. & ROGERS N. (1990) - *Compositional diversity of Late Cenozoic basalts in a transect across the southern Washington Cascades: implications for subduction zone magmatism*. Journal of Geophysical Research, **95**: 19,561-19,582.

MARANI M.P. & TRUA T. (2002) - *Thermal constriction and slab tearing at the origin of a superinflated spreading ridge: Marsili volcano (Tyrrhenian Sea)*. Journal of Geophysical Research, 107(B9): 2188, doi: 10,1029/ 2001JB000285.

MARANI M.P., GAMBERI F., CASONI L., CARRARA G., LANDUZZI V., MUSACCHIO M., PENITENTI D., ROSSI L. & TRUA T. (1999) - *New rock and hydrothermal samples from the southern Tyrrhenian sea: the MAR-98 research cruise*.

Giornale di Geologia, **61**: 3-24.

MARQUEZ A., OYARZUM R., DOBLAS M. & VERMA S.P. (1999) - *Alkalic (ocean-island basalt type) and calc-alkalic volcanism in the Mexican volcanic belt: a case for plume-related magmatism and propagating rifting at an active margin?* Geology, **27**: 51-54.

PEARCE J.A. & PEATE D.W. (1995) − *Tectonic implications of the composition of volcanic arc magmas*. Annu. Rev. Earth Planet. Sci., **23**: 251-285.

PEARCE J.A. & PARKINSON I.J. (1993) − *Trace element models for mantle melting: application to volcanic arc petrogenesis*. Geol. Soc. London Spec. Publ., **76**: 373-403.

PECCERILLO A., KEMPTON P.D., HARMON R.S., SANTO A.P., BOYCE A.J. & TRIPODO A. (1993) - *Petrological and geochemical characteristics of the Alicudi Volcano, Aeolian Islands, Italy: implications for magma genesis and evolution*. Acta Vulcanologica, **3**: 235-249.

PECCERILLO A. (2001) − *Geochemical similarities between the Vesuvius, Phlegraean Fields and Stromboli Volcanoes: petrogenetic, geodynamic and volcanological implications*. Mineralogy and Petrology, **73**: 93-105.

REINERS P.W, HAMMOND P.E., McKENNA J.M. & DUNCAN R.A. (2000) - *Young basalts of the central Washington Cascades, flux melting of the mantle, and trace element signatures of primary arc magmas*. Contribution to Mineralogy and Petrology, **138**: 249-264.

ROBIN C., COLANTONI P., GENNESSEAUX M. & REHAULT J.P. (1987) - *Vavilov seamount: a mildly alkaline quaternary volcano in the Tyrrhenian Basin*. Marine Geology, **78**: 125-136.

SARTORI R. (1990) − *The main results of ODP Leg 107 in the frame of Neogene to Recent geology of perityrrhenian areas*. In: KASTENS K.A., MASCLE J. et alii (Eds.): "*Proceedings of the ODP*". Scientific Results **107**: 715-730.

SAVELLI C. & GASPAROTTO G. (1994) - *Calc-alkaline magmatism and rifting of the deep-water volcano of Marsili (Aeolian back-arc, Tyrrhenian Sea)*, Marine Geology, **119**: 137-157.

SAVELLI C. & SCHRIEDER A.A. (1991) - *The opening processes in the deep Tyrrhenian basins of Marsili and Vavilov, as deduced from magnetic and chronological evidence of their igneous crust*. Tectonophysics **189**: 1-13.

SAVELLI C. (1988) − *Late Oligocene to Recent episodes of magmatism in and around the Tyrrhenian Sea: implications for the processes of opening in a young inter-arc basin of intra-orogenic (Mediterranean) type*. Tectonophysics, **146**: 163-181.

SCHIANO P., CLOCCHIATTI R., OTTOLINI L. & BUSÀ T. (2001) - *Transition of Mount Etna lavas from a mantle-plume to an island-arc magmatic source*. Nature, **412**: 900-904.

SELLI R., LUCCHINI F., ROSSI P.L., SAVELLI C. & DEL MONTE M. (1977) - *Dati geologici, petrochimici e radiometrici sui vulcani centro-tirrenici*. Giornale di Geologia **42**: 221-246.

SERRI G. (1990) - *Neogene-Quaternary magmatism of the Tyrrhenian region: characterization of the magma sources and geodynamic implications*. Mem. Soc. Geol. It. **41**: 219-242.

SERRI G., INNOCENTI F. & MANETTI P. (1993) − *Geochemical and petrological evidence of the subduction of delaminated Adriatic continental lithosphere in the genesis of the Neogene-Quaternary magmatism of central Italy*. Tectonophysics, **223**: 117-147.

SERRI G. (1997) - *Neogene-Quaternary magmatic activity and its geodynamic implications in the Central Mediterranean region*. Annali di Geofisica, **XL**, 3, 681-703.

SERRI G., INNOCENTI F. & MANETTI P. (2001) - *Magmatism from Mesozoic to Present: petrogenesis, time-space distribution and geodynamic implications*. In: VAI G.B. & MARTINI P.I. (Eds.): "*Anatomy of a mountain: the Apennines and the adjacent Mediterranean Basins*". Kluwer Academic Publishers (Great Britain), 77-104.

SOMMA R., AYUSO R.A., DE VIVO B. & ROLANDI G. (2001) – *Major, trace element and isotope geochemistry (Sr-Nd-Pb) of interplinian magmas from Mt. Somma-Vesuvius (Southern Italy)*. Mineralogy and Petrology, **73**: 121-143.

SUN S.S. & McDONOUGH W.F. (1989) - Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In: SAUNDERS A.D. & NORRY M.J. (Eds.): *"Magmatism in the ocean basins"*. Geological Society of London Special Publication, **42**: 313-345.

TONARINI S., ARMIENTI P., D'ORAZIO M. & INNOCENTI F. (2001a) - *Subduction-like fluids in the genesis of Mt. Etna magmas: evidence from boron isotopes and fluid mobile elements*. Earth and Planetary Science Letters, **192**: 471-483.

TONARINI S., LEEMAN W.P. & FERRARA G. (2001b) - *Boron isotopic variations in lavas of the Aeolian volcanic arc, South Italy*. Journal of Volcanology and Geothermal Research, **110**: 155-170.

TRUA T., ESPERANCA S. & MAZZUOLI R. (1998) - *The evolution of the lithospheric mantle along the N. African Plate: geochemical and isotopic evidence from the tholeiitic and alkaline volcanic rocks of the Hyblean plateau, Italy*. Contribution to Mineralogy and Petrology, **131**: 307-322.

TRUA T., SERRI G., RENZULLI A., MARANI M. & GAMBERI F. (1999) - *The volcanism in and around the Marsili basin (southern Tyrrhenian Sea): geochemical characteristics of new dredged rocks*. Geoitalia, 2° Forum FIST, Riassunti, **1**: 193-194.

TRUA T., SERRI G., DENIEL C., MARANI M., RENZULLI A. & GAMBERI F. (2002a) - Marsili volcano: an active calcalkaline seamount along the spreading axis of the southern Tyrrhenian backarc basin. *Montagne Pelee 1902-2002 – Explosive volcanism in subduction zones, Saint-Pierre, Martinique, May 12-16, 2002*. Abstracts volume, pag.63.

TRUA T., SERRI G., DENIEL C., MARANI M., RENZULLI A. & GAMBERI F. (2002b) - An active calcalkaline seamount along the quaternary to recent spreading axis of the southern Tyrrhenian backarc basin: the Marsili volcano. *82° Congresso Nazionale S.I.M.P., Cosenza, 18-20 settembre 2002*. Plinius, pag. 283-284.

TRUA T., SERRI G., MARANI M., RENZULLI, A. & GAMBERI F. (2002c) - *Volcanological and petrological evolution of Marsili seamount (southern Tyrrhenian Sea).* Journal of Volcanology and Geothermal Research, **114**: 441-464.

TRUA T., SERRI G. & MARANI M. (2003) - *"Lateral flow of African mantle below the nearby Tyrrhenian plate: geochemical and isotopic evidence"*. Terra Nova, doi: 10.1046/j.1365-3121.2003.00509.x.

TURNER S. & HAWKESWORTH C. (1998) - *Using geochemistry to map mantle flow beneath the Lau Basin*. Geology, **26**: 1019-1022.

WEAVER B.L. (1991) - *Trace element evidence for the origin of ocean-island basalts*. Geology, **19**: 123-126.

WILSON M. (1989) – *Igneous petrogenesis. Harper Collins Academic*, London, pp. 466.

ZINDLER A. & HART S. (1986) – *Chemical geodynamics*. Ann. Rev. Earth Planet. Sci., **14**: 493-571.