Per. Mineral. (2004), *73*, 75-104 http://go.to/permin
SPECIAL ISSUE 1 : A showcase of the Italian research in petrology: magmatism in Italy

PERIODICO di MINERALOGIA
established in 1930

An International Journal of
MINERALOGY, CRYSTALLOGRAPHY, GEOCHEMISTRY, ORE DEPOSITS, PETROLOGY, VOLCANOLOGY
and applied topics on *Environment, Archaeometry* and *Cultural Heritage*

Petrochemical and magmatological characteristics of the Aeolian Arc volcanoes, southern Tyrrhenian Sea, Italy: inferences on shallow level processes and magma source variations

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ABSTRACT. — The Aeolian volcanic arc, constituted by seven islands and several seamounts, is emplaced on continental lithosphere. The islands are mainly formed by lava flows, domes and pyroclastic deposits, and emerged from the sea in a short time span, from around 200 ka ago at Filicudi, Lipari and Stromboli (Strombolicchio neck), to about 100 ka at Alicudi and Stromboli. At Panarea, an intense fumarolic activity is still present, the last eruptions at Lipari took place on 580 A.D., whereas Vulcano and Stromboli are still active. The rock compositions belong to different magmatic series and show a large silica range (48-76 wt%). Calc-alkaline (CA) and high-K calc-alkaline (HKCA) volcanics are present in all the islands, except for CA rocks at Vulcano. Shoshonitic (SHO) products are only lacking at Alicudi, Filicudi and Salina. Potassic (KS) volcanics have been erupted at Vulcano and Stromboli. Basalts are not found at Lipari, whereas a large amount of rhyolites are present in the central arc islands (Lipari, Vulcano, Salina, Panarea), having different petrochemical characteristics. $^{87}Sr/^{86}Sr$ increases from the western to the eastern sectors of the arc (0.70342-0.70757), whereas $^{143}Nd/^{144}Nd$ decreases (0.51289-0.51243). Pb isotope ratios show a large similar range in the western and central arc islands, but decrease at Panarea and Stromboli (e.g., $^{206}Pb/^{204}Pb$: 18.93-19.77). Among CA and HKCA rocks, incompatible trace element contents and ratios change passing from the central part of the arc to the external sectors. The isotopic and geochemical compositions of SHO and KS volcanics from Stromboli and Vulcano are distinct, with the Vulcano compositional characteristics resembling those of the CA and HKCA magmas from the central arc. Significant rock compositional variations are also observed within the single volcanoes.

Aeolian magmas underwent multiple differentiation processes during the ascent to the surface from their mantle source. Fractional crystallisation is often associated to crustal contamination which affected at higher extent either the most evolved magmas at Vulcano, Salina and Lipari or the most mafic magmas at Alicudi, Filicudi and Stromboli. Multiple mixing also played an important role often associated with the other differentiation processes. These evolutionary processes occurred at polybaric conditions, with higher crystallisation pressure for Filicudi and Salina.

The different parental magmas were originated in an heterogeneous mantle wedge, metasomatised by subduction-related components at increasing extent, going from west to east (= variation of Sr and Nd isotope ratios). It is also suggested that the mantle source of CA and HKCA magmas from central arc (Salina, Lipari and CA Panarea) is a MORB-like asthenospheric source, contaminated by aqueous

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fluids released by subducted oceanic crust + pelagic sediments. The same type of source can be envisaged for Vulcano SHO and KS parental magmas. In the external sectors of the arc, mass transfer from the subducted slab to mantle seems to be occurred by higher melt/fluid proportions. At west (Alicudi and Filicudi), the other components involved in the magma genesis remain similar to those proposed for the central arc source. On the contrary, the compositional characteristics of eastern magmas (HKCA Panarea and Stromboli) suggest a different pre-contamination mantle source (continental lithosphere?) and/or a different crustal contaminant (with low Pb isotopes) of the mantle wedge. A decreasing partial melting degree of distinct mantle sources is considered to generate magmas with an increasing potassic character at Vulcano and Stromboli.

RIASSUNTO. — L'Arco vulcanico Eoliano, che giace su litosfera continentale, è costituito da sette isole e vari vulcani sottomarini. Le isole sono formate soprattutto da flussi di lava, duomi e depositi piroclastici e sono emerse dal mare in un breve intervallo di tempo, da circa 200 ka fa a Filicudi, Lipari e Stromboli (Strombolicchio «neck») a circa 100 ka fa ad Alicudi e Stromboli. Un'intensa attività fumarolica è ancora presente a Panarea, l'ultima eruzione a Lipari ebbe luogo nel 580 A.D., mentre Vulcano e Stromboli sono ancora vulcani attivi. La composizione delle rocce appartiene a differenti serie magmatiche e mostra un'ampia variazione in silice (48-76 %). Vulcaniti calc-alcaline (CA) e calc-alcaline alte in potassio (HKCA) sono presenti in tutte le isole, ad eccezione delle rocce CA a Vulcano. I prodotti della serie shoshonitica (SHO) sono mancanti solo ad Alicudi, Filicudi e Salina, mentre quelli della serie potassica (KS) sono stati eruttati solo a Vulcano e Stromboli. Rocce basaltiche non sono presenti a Lipari, mentre una grande quantità di rioliti, con differenti caratterisitcihe petrologiche, sono state eruttate nella parte centrale dell'arco (Lipari, Vulcano, Salina, Panarea). Lo ^{87}Sr/^{86}Sr aumenta dai settori occidentali a quelli orientali dell'arco (0,70342-0,70757) e il ^{143}Nd/^{144}Nd diminuisce (0,51289-0,51243). I rapporti isotopici del Pb sono simili e molto variabili nei vulcani occidentali e centrali, ma diminuiscono verso Panarea e Stromboli (e.g., ^{206}Pb/^{204}Pb: 18,93-19,77). Fra le rocce CA ed HKCA, i contenuti ed i rapporti fra elementi in tracce incompatibili variano passando dalla parte centrale dell'arco ai settori esterni. Le composizioni isotopiche e geochimiche delle vulcaniti SHO e KS di Stromboli e Vulcano sono distinte e quelle di Vulcano sono simili alle caratteristiche dei magmi CA ed HKCA della parte centrale dell'arco. Variazioni composizionali significative sono anche osservate tra le rocce dei singoli vulcani.

I magmi Eoliani sono stati interessati da processi multipli di differenziazione durante la loro risalita. La cristallizzazione frazionata è spesso associata alla contaminazione crostale, la quale assume un ruolo maggiore in magmi più evoluti a Vulcano, Salina e Lipari, e in magmi più mafici ad Alicudi, Filicudi e Stromboli. Ripetuti mescolamenti fra magmi sono anche spesso associati agli altri processi di differenziazione. L'evoluzione dei magmi avviene in condizioni polibariche, con pressioni di cristallizzazione maggiori a Filicudi e Salina.

I differenti magmi genitori hanno avuto origine in un cuneo di mantello eterogeneo, metasomatizzato da componenti subduttivi, presenti in maggiore quantità da ovest verso est (= variazione negli isotopi dello Sr e del Nd). Il mantello sorgente dei magmi CA e HKCA dell'arco centrale (Salina, Lipari and CA Panarea) sembra essere una sorgente astenosferica tipo-MORB, contaminata da fluidi acquosi rilasciati da crosta oceanica + sedimenti pelagici subdotti. Lo stesso tipo di sorgente è ipotizzabile per i magmi parentali SHO e KS di Vulcano. Nei settori esterni dell'arco il trasferimento di massa dalla placca subdotta al mantello sembra essere avvenuto con maggiori proporzioni fuso/fluido. Ad ovest (Alicudi e Filicudi), gli altri componenti implicati nella genesi dei magmi rimangono simili a quelli proposti per la sorgente dei magmi nella parte centrale dell'arco. Al contrario, le caratteristiche composizionali dei magmi orientali (Panarea HKCA e Stromboli) suggeriscono un differente mantello sorgente pre-contaminazione (litosfera continentale?) e/o un diverso contaminante crostale del mantello (con bassi isotopi del Pb). La diminuzione dei gradi di fusione parziale di sorgenti mantelliche distinte è considerata generare magmi con progressivo aumento di potassio a Vulcano e Stromboli.

KEY WORDS: *Aeolian volcanic arc, Southern Tyrrhenian sea, geochemistry, isotopes, process of magma evolution, mantle source components.*

INTRODUCTION

The Aeolian Arc is constituted by seven volcanic islands (Alicudi, Filicudi, Salina, Lipari, Vulcano, Panarea, Stromboli) and seven seamounts (Lametini, Alcione, Palinuro, Marsili, Sisifo, Enarete, Eolo), which form an approximate ring-like structure (Fig. 1). It is located on the southeastern continental slope of the Tyrrhenian abyssal plain, lying up on a 15 to 20 km thick continental crust (Morelli *et al.*, 1975). The age of the subaerial and submergerd Aeolian volcanism ranges from 1.3 Ma (age of a basalt from the Sisifo seamount) to present time (Beccaluva *et al.*, 1985; Gillot, 1987; Santo *et al.*, 1995; De Rosa *et al.*, 2003). Vulcano and Stromboli volcanoes are still active, and historic eruptions have been recorded at Lipari and Panarea volcanoes. Magmas were erupted through several mechanisms which range from effusive (lava flows and domes) to highly explosive, emplacing different type of pyroclastic deposits (pyroclastic flow, surge, fall, lahars, etc.). Two different types of volcanic activity take the name after the recent and present days activities of Vulcano and Stromboli.

Many authors consider the Aeolian magmatism as related to the still active subduction of the Ionian plate beneath the Calabrian arc. A NW 50-60° dipping Benioff zone has been recognised by seismic data on the distribution of the intermediate and deep

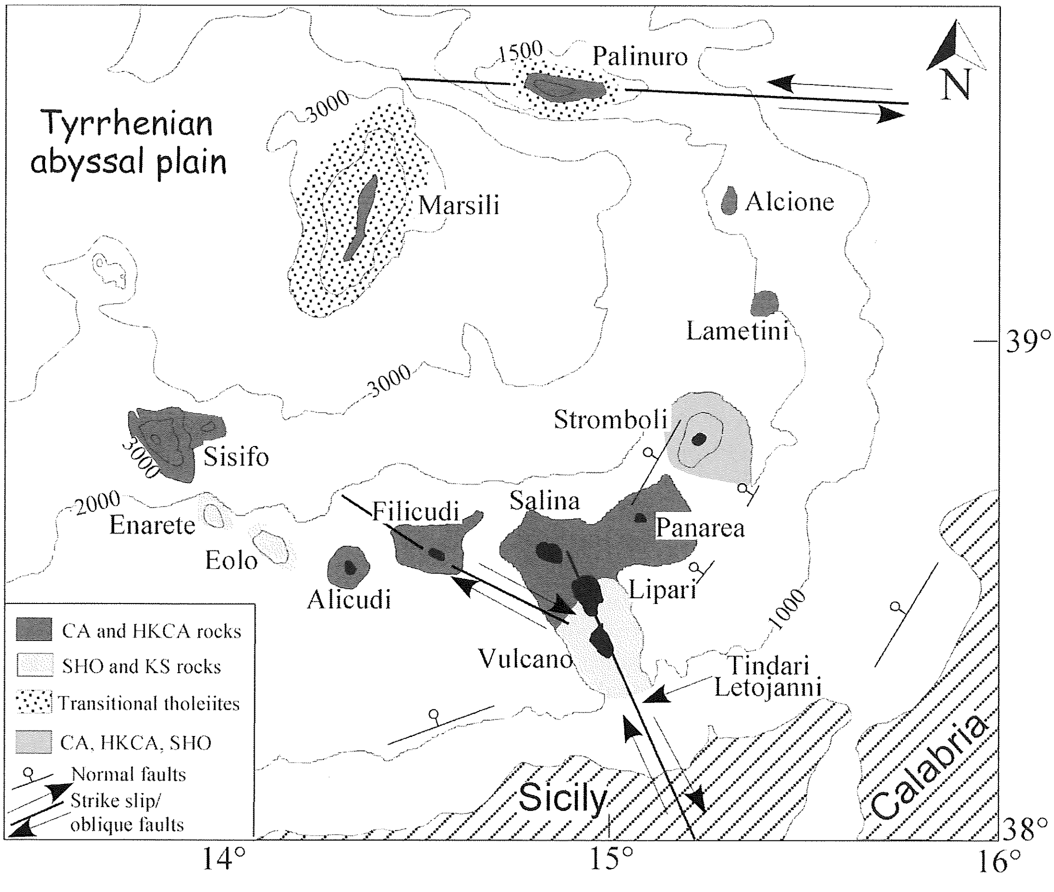

Fig. 1 – General map of the Aeolian arc islands (in black colour) and seamounts, Southern Tyrrhenian Sea, Italy. CA = calc-alkaline series; HKCA = high-K calc-alkaline series; SHO = shoshonitic series; KS = potassic series. Modified after Francalanci *et al.* (1993b).

earthquake hypocenters (Caputo *et al.*, 1970; Barberi *et al.*, 1974; Scandone, 1982; Boccaletti *et al.*, 1984; Beccaluva *et al.*, 1985; Patacca *et al.*, 1990; Mantovani *et al.*, 1996). The deep seismicity is limited to the eastern branch of the arc, whereas it is absent beneath the western islands and the Tindari-Letojanni-Malta escarpment transcurrent fault seems to play a fundamental role in this subdivision (Falsaperla *et al.*, 1999; Peccerillo and Panza, 1999). An alternative hypothesis proposes the Aeolian volcanism as the result of an asthenospheric uplift linked to the post-subduction extensional strain determined by the opening of the Tyrrhenian Sea (Wang *et al.*, 1989; Crisci *et al.*, 1991; Esperança *et al.*, 1992).

The Aeolian volcanic rocks belongs to the typical magmatic series from orogenic setting: arc tholeiitic, calc-alkaline (CA), high-K calc-alkaline (HKCA) and shoshonitic (SHO). A large variation in K_2O content exists among SHO rocks with similar silica abundance; a potassic series (KS) is usually also defined in order to distinguish the most potassium-enriched rocks (>3.5 wt% for silica < 56 wt%) of Stromboli and Vulcano. The remaining SHO rocks define a series which plots just above and/or across the boundary line between the HKCA and SHO fields (Figs. 1, 2). Tholeiitic rocks have been only dredged from seamounts (Beccaluva *et al.*, 1985). There are no clear time-dependent variations of rock composition in the different sectors of the arc, even if a general increase of potassium content with time is observed in several islands (e.g., Vulcano and Stromboli). The western, central and eastern branches of the arc are well distinct on the basis of petrological, geochemical and geophysical data (Ellam *et al.*, 1989; Francalanci *et al.*, 1993b; Falsaperla *et al.*, 1999; Peccerillo and Panza, 1999; De Astis *et al.*, 2000; Tonarini *et al.*, 2001).

The present paper reports the state of the art for the volcanological evolution and the petrochemical characteristics of the Aeolian island volcanoes. A general review on the differentiation processes which are suggested to affect the Aeolian magmas along their pathway to the surface is also reported. Furthermore, some hypotheses are proposed for the genesis of the different parental magmas and for the composition of their mantle source.

BRIEF VOLCANOLOGICAL AND PETROLOGICAL OUTLINE OF THE SINGLE ISLANDS

Stromboli

The island has an area of about 12 km^2, an elevation of 924 m above sea level (a.s.l.) and rises from about 2000 m below the sea level (b.s.l.), with a cone elongated in the NE-SW direction.

On the basis of structural changes and stratigraphic unconformities, seven main phases of activity have been recognised along the geologic history of the subaerial Stromboli volcano: Strombolicchio, Paleostromboli I, Paleostromboli II, Paleostromboli III, Vancori, Neostromboli and Recent period. Several collapses of different nature (crater, caldera, flank and sector collapse) alternated to periods of volcano building. The collapses occurred after Vancori period, during the last 13 ka, were only sector and flank collapses, and led to the formation of the peculiar feature of Sciara del Fuoco scar, a steep trough on the NW flank of the volcano (Hornig-Kjarsgaard *et al.*, 1993; Pasquarè *et al.*, 1993; Tibaldi, 2001).

Stromboli shows the largest rock compositional variation of the Aeolian islands (Fig. 2). The Strombolicchio neck, with a CA basaltic-andesitic composition, represents the remnants of an older volcano (about 204 ka), located NE, whose structure is directly connected with the submarine cone of Stromboli (Gabbianelli *et al.*, 1993). The Stromboli island was formed in the last 100 ka (all dating of Stromboli rocks are from Gillot and Keller, 1993). The oldest rocks are represented by HK andesitic lavas of Paleostromboli I period, during which HKCA pyroclastic fall and flow deposits were also erupted. Paleostromboli II rocks are mainly

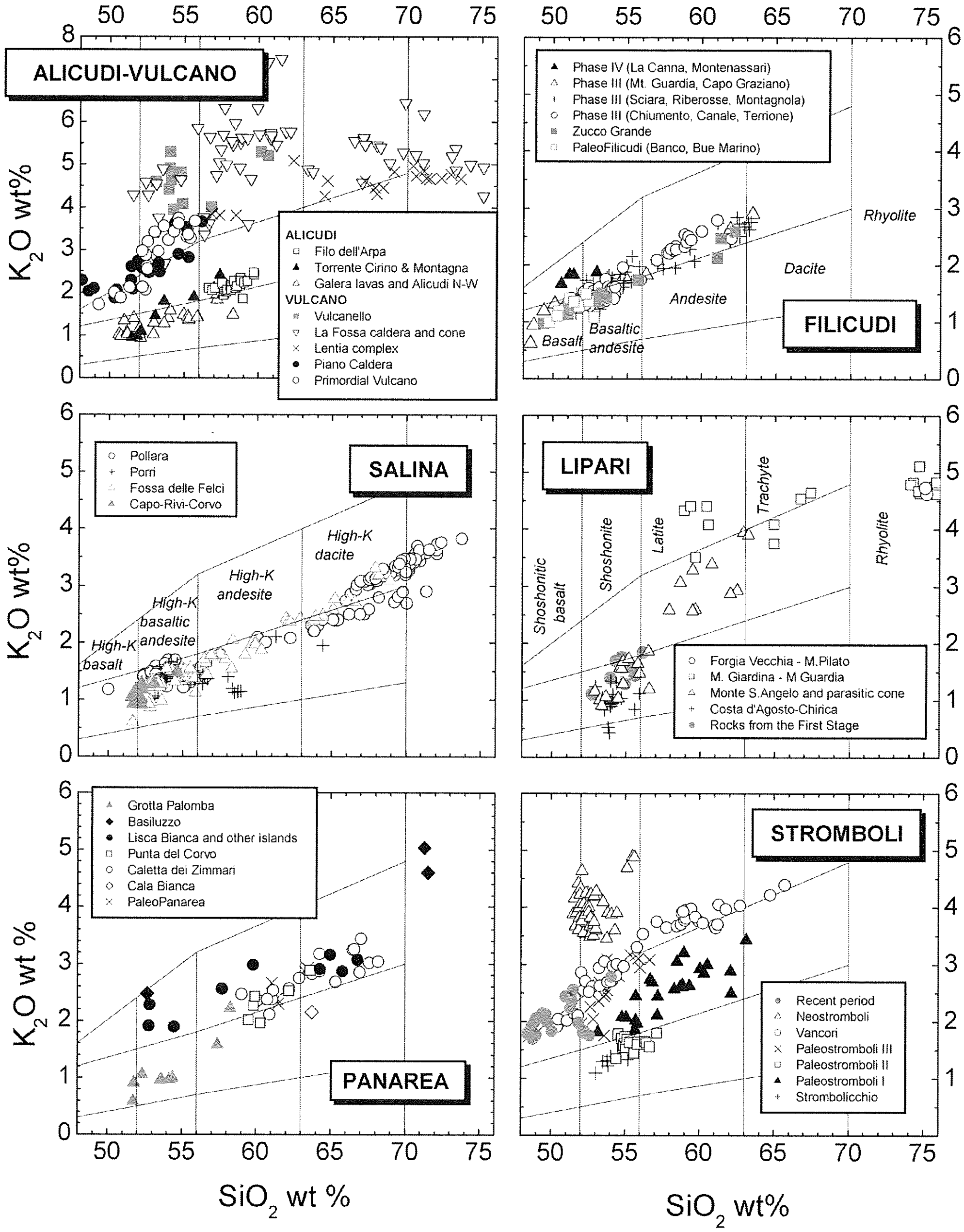

Fig. 2 – K_2O versus SiO_2 classification diagram for the rocks of the Aeolian arc volcanoes. Data, reported on water-free basis, are from Romano (1973); Keller (1980a,b); Lanzafame and Rossi (1984); Francalanci *et al.* (1988, 1989, 1993a,b); Bargossi *et al.* (1989); Ellam *et al.* (1989); Crisci *et al.* (1991); Esperança *et al.* (1992); Peccerillo and Wu (1992); Calanchi *et al.* (1993, 2002); Francalanci and Santo (1993); Peccerillo *et al.* (1993); Ventura (1995); De Astis *et al.* (1997, 2000); Del Moro *et al.* (1998); Gertisser and Keller (2000); Gioncada *et al.* (2003); Santo *et al.* (2004).

composed by thick lava flows of CA basaltic andesitic composition (about 55-64 ka). Paleostromboli III products (about 35 ka) are represented by lavas and pyroclastic fall and flow deposits, with HK basalt to HK andesite and SHO basalt to shoshonite compositions (Fig. 2). The successive activity (Vancori period, 13-26 ka) was characterised by the eruption of prevalent lava flows and minor pyroclastic deposits, forming the highest peak of Stromboli. From Lower, through Middle, to Upper Vancori, the rocks range from SHO basalts to latites and few trachytes. The Neostromboli rocks (13.8 - 5.6 ka) consist of thin scoriaceous lavas with a KS composition, whereas the Recent activity erupted HKCA and SHO basaltic lava flows and pyroclastic deposits.

The present day Strombolian activity takes place since about 1800 years from different vents, sited in a crater terrace at 750 m a.s.l. It consists of continuous degassing and periodic discrete explosions which erupt a small amount of scoriaceous bomb and lapilli, ashes and blocks. The normal activity is periodically broken by eruptive crises which include either lavas, flowing down along the Sciara del Fuoco, or much more violent explosions, rarely injuring the villages. The last crisis occurred in the period between December 2002 and July 2003, being characterised by a continuous lava flow eruption, a tsunami episode and a paroxysm.

All the rocks have seriate porphyritic textures with variable phenocryst content (10-55 vol%). The most abundant mineral is plagioclase, followed by clinopyroxene. Olivine is only found in the mafic rocks of the different series, while orthopyroxene occurs in the intermediate and more evolved CA and HKCA rocks and as microphenocrysts in the latites. Biotite occurs in HK andesites, along with rare amphibole, and latites. In KS rocks leucite sometimes appears both in the groundmass and as microphenocrysts (Francalanci *et al.*, 1989, 1993a; Hornig-Kjarsgaard *et al.*, 1993).

Passing from CA to KS series, incompatible trace element contents increase, whereas MgO, CaO and compatible trace element contents decrease. Sr isotope ratios are quite variable (0.70507 - 0.70757) and increase from CA to KS rocks, with large variations in the latter (Fig. 3). They are negatively correlated with Nd isotope ratios, which range from 0.51243 to 0.51261, and with Pb isotope ratios ($^{206}Pb/^{204}Pb$ = 18.93-19.17, $^{207}Pb/^{204}Pb$ = 15.65-15.69, $^{208}Pb/^{204}Pb$ = 39.01-39.16) (Francalanci *et al.*, 1988, 1989; 2004; Luais, 1988; De Astis *et al.*, 2000). Whole rock $\delta^{18}O$ values range from +6.1 to +7.9 ‰ and correlate negatively with Sr isotope ratios (Ellam and Harmon, 1990).

The petrochemical variations of Stromboli rocks indicate that magmas underwent variable and complex differentiation processes. Simple fractional crystallisation mainly affected SHO and HKCA magmas, KS melts seem to have evolved by crystallisation associated to crustal assimilation of most mafic magmas during ascent to the surface (AEC process), whereas mixing and a combination of the previous processes occurred among different types of magma. Two magma reservoirs, at least, sited at different depth, were proposed to be present during all the Stromboli history. Variable partial melting degrees of a heterogeneous mantle wedge have been also proposed in order to explain the genesis of the different parental magmas (Francalanci *et al.*, 1988; 1989; 1993a; Luais, 1988; Ellam *et al.*, 1989; Peccerillo, 2001; Vaggelli *et al.*, 2003).

Panarea

It is the smallest island of the Aeolian archipelago (about 3.3 km^2) (Fig. 1) and constitutes the emerged part (421 m a.s.l.) of a cone-shaped edifice, rising from about 1500 m b.s.l. Eastward, other emerged rocks of this edifice form the smallest islets of Lisca Bianca, Lisca Nera, Bottaro, Panarelli, Dattilo and Basiluzzo. An intense fumarolic activity has been discovered between the islets of Bottaro and Dattilo and at Calcara on the Panarea island (Gabbianelli *et al.*, 1990).

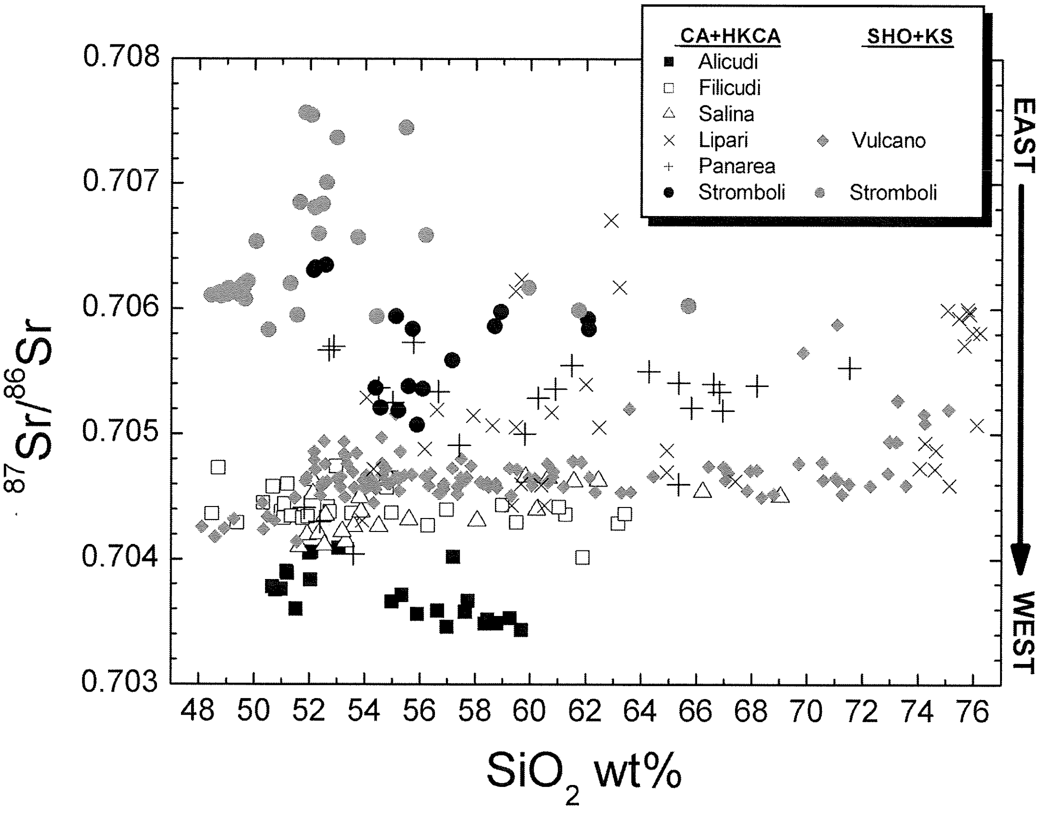

Fig. 3 – Sr isotope ratios versus silica diagram for all the data available on the Aeolian island rock. Silica is reported on water-free basis. Font of data as in figure 2.

The subaerial volcanic activity of Panarea developed in a period between about 190 ka and 54 ka (Gillot, 1987; Gabbianelli *et al.*, 1990; Calanchi *et al.*, 2002). The oldest rocks are constituted by lava flows alternated to layers of reworked black and red scoriae (Paleo-Panarea). After the emplacement of Paleo-Panarea, all the western part of the volcano collapsed along a NE-SW fault. The andesitic and dacitic lava flows and domes of the Cala Bianca and Caletta dei Zimmari synthems (about 130 ka) follow in stratigraphic sequence. Volcanic activity continued with the emplacement of Punta del Corvo rocks, which are constituted by andesitic lavas and dacitic domes and by banded dacitic pumice to andesitic scoriae. Grotta Palomba synthem is formed by a basaltic to basaltic andesitic scoriae fall layer associated with exotic tuffs. Basiluzzo is included in this synthem, with age of about 54 ka, whereas Lisca Bianca and the other minor islands seem to be coeval with the emplacement of Caletta dei Zimmari rocks. A large hiatus in the volcanic activity led to the formation of several marine terraces (Calanchi *et al.*, 2002).

Panarea volcanic rocks are mainly HK andesites and HK dacites, with lower amount of CA and HK basaltic andesites and few rhyolites (Fig. 2). Few basalts are also present among the youngest products. The rocks show seriate porphyritic textures with variable phenocryst content (20-50%). Plagioclase is the most abundant phenocryst phase, followed by clinopyroxene and orthopyroxene in the andesites. Rare resorbed olivine and few hornblende are also found. The latter is more abundant in dacites, along with hyperstene. Ti-magnetite, biotite and apatite are present as accessory mineral phases. Rhyolites have a glassy groundmass, with phenocrysts of plagioclase, augite, hornblende and biotite (Romano, 1973; Lanzafame and Rossi, 1984; Calanchi *et al.*, 2002).

The large potassium variation of mafic rocks is also associated with variable contents of incompatible trace elements. Sr isotope ratios range from 0.70404 to 0.70573 (Fig. 3) and correlates negatively with Nd isotope ratios (0.51256-0.51284). Pb isotope ratios are $^{206}Pb/^{204}Pb$ = 19.18-19.43, $^{207}Pb/^{204}Pb$ = 15.68-15.71, $^{208}Pb/^{204}Pb$ = 39.13-39.36. From CA to HKCA mafic rocks, $^{87}Sr/^{86}Sr$ ratios increase, whereas $^{143}Nd/^{144}Nd$ and $^{206}Pb/^{204}Pb$ ratios decrease. Assimilation + fractional crystallisation (AFC) and mixing processes are proposed for explaining the compositional variations of rocks from basalts to rhyolites. The different petrological characteristics of mafic magmas are assumed to derive from a heterogeneous mantle source (Calanchi *et al.*, 2002).

Salina

It is the second largest island of the Aeolian Arc (26.8 km^2) and the highest one, with its two steep volcanic cones of Fossa delle Felci (962 m a.s.l.) and Monte dei Porri (860 m a.s.l.).

The temporal evolution of volcanism is marked by several episodes of resumed activity in each volcano. Three main phases of activity are distinguished. Most of the Rivi-Capo, the Corvo and Fossa delle Felci volcanoes formed during the first stage of activity ranging from about 168 to 103 ka. The second phase (about 87-43 ka) began with the resumption of fissure eruptions at the Rivi-Capo and with the emergence of Porri volcano, forming a basal tuff-ring on the early Fossa delle Felci, and continued with the renewal of volcanism in the latter volcano and the development of Porri volcano cone. The last stage was only characterised by two main explosive eruptions which occurred during the last 24 ka and produced the Pollara depression. The stratocones are formed by sequences of lava flows and domes, strombolian scoriae and pyroclastic deposits. An ancient sea-shore deposit, cutting the base of Fossa delle Felci and Rivi-Capo, testifies an episode of marine ingression (Würm) (Keller, 1980a; Calanchi et al, 1993; Ventura, 1995; De Rosa *et al.*, 2003).

The oldest subaerial rocks from Salina range from basalts to basaltic andesites, followed by the eruption of few basalts to dacites and HK dacites; the youngest products vary from basalts to rhyolites (Fig. 2). Rocks are variably porphyritic, with a phenocryst content decreasing from basalts (15-50%) to rhyolites (nearly aphyric). Olivine is mainly present in basalts and is always resorbed in basaltic andesites. Clinopyroxene is ubiquitous, together with the dominant plagioclase, and usually forms the largest phenocrysts. Pigeonite is found in the groundmass. Orthopyroxene is common in andesites and dacites. Green and brown hornblende and biotite are present in dacitic and rhyolitic lavas and pumice, especially in those of Pollara centre. Fe-Ti oxides occur as microphenocrysts and in the groundmass of all the rock types (Keller, 1980a; Ventura, 1995).

CaO, MgO, FeO_{tot}, Al_2O_3, Ni and Cr contents decrease with increasing silica content, whereas the abundance of alkalis and incompatible trace elements (e.g., Rb, Zr, Ba, La and Ce) increase. Sr isotope ratios range from 0.70410 to 0.70463 (Fig. 3) and show a well defined negative correlation with Nd isotope ratios (0.51261-0.51282). Pb isotope compositions display relatively large variations in $^{206}Pb/^{204}Pb$ (19.15-19.77), fairly constant $^{207}Pb/^{204}Pb$ (15.60-15.76) and minor variations in $^{208}Pb/^{204}Pb$ (38.97-39.51). Whole rock $\delta^{18}O$ values range from + 6.4 to +8.5 ‰ and correlate positively with Sr isotope ratios (Ellam *et al.*, 1989; Ellam and Harmon, 1990; Francalanci *et al.*, 1993b; Gertisser and Keller, 2000).

Generally, the Sr, Nd, Pb and oxygen isotope ratios are correlated with the degree of magma evolution, indicating that crustal assimilation is associated with fractional crystallisation processes. Mixing between different evolved magmas was also active; in particular, a rhyolitic magma entered a shallower mafic magma chamber during the emplacement of Pollara tuff-ring (Calanchi *et al.*, 1993). It has been suggested that primary magmas of Salina derived from a depleted mantle source contaminated by slab-derived fluids and subducted sediments (Ellam and Harmon, 1990; Francalanci *et al.*, 1993b Gertisser and Keller, 2000).

Lipari

It is the largest among the Aeolian Islands (38 km^2) and rises from a depth of about 1000 m b.s.l. to an elevation of 602 m a.s.l. It is composed by several volcanic cones and dome structures (Fig. 1). The subaerial activity took place from 223 ka to 580 A.D. and an intense submarine fumarolic activity is present along the western and eastern coasts of the island (Gillot, 1987; Crisci *et al.*, 1991; De Rosa *et al.*, 2003).

All the volcanic history of Lipari has been divided in three major stages of activity on the basis of new K-Ar dating (De Rosa *et al.*, 2003). The first stage (~ 223-188 ka) includes the rocks along the western coast (Timponi, Chiesa Vecchia), mainly constituted by lavas, domes and dykes of CA basaltic andesitic composition. During the second stage (~102-55 ka), the two major stratovolcanoes of Costa d'Agosto – Chirica and San Angelo were formed, together with the Monte Rosa volcano and the lacustrine deposits, composed of reworked pyroclastic products and filling a large depression into the central part of the island. Basaltic andesitic to HK andesitic lava flows associated with scoria fall deposits and pyroclastic surges were erupted by these volcanoes, along with andesitic to dacitic lava flows, characterised by the presence of minerals such as cordierite, sillimanite, andalusite and garnet. The third stage (~ 40 ka to 580 A.D) is characterised by rhyolitic eruptions forming the southern and eastern sector of Lipari island. The activity shifts to South (Mt. Giardina and Mt. Guardia), where two cycles of endogenous lava dome extrusions were preceded by hydromagmatic eruptions originating pyroclastic deposits. The final activity moves again towards the north-eastern part of the island, with a hydromagmatic prehistoric stage and the emplacement of the medieval (~ 580 A.D.) rhyolitic pumice cone of Monte Pilato.

Lipari rocks are mainly CA basaltic andesites, HK andesites and rhyolites with a fairly high K_2O content. Few latites and HK dacites are also found. Basalts are not present (Fig.2). From a petrographic point of view, the basaltic andesitic lavas have seriate porphyritic textures with a phenocryst content from 20% to 60%. Plagioclase phenocrysts have often complex compositional zoning. Clinopyroxene ranges between diopside, pigeonite and augite and shows moderate zoning. Olivine is rarely resorbed and few hyperstene is also found. Increasing of plagioclase/pyroxene ratios and orthopyroxene content and decreasing of olivine is shown by the andesites. Small resorbed amphibole and Ti-magnetite phenocrysts are also present. Rhyolitic rocks are mainly constituted by glass, with few phenocrysts of zoned plagioclase, corroded sanidine and amphibole.

The erupted rocks show an increase of K_2O and SiO_2 with time up to dacitic compositions. An increase of potassium and incompatible element contents with time is also observed among recent latitic to rhyolitic compositions (after 42 ka) probably imputable to a modification of the primary magma composition. Sr isotope ratios are quite high and variable (0.7042 - 0.7067) (Fig. 3) and are negatively correlated with Nd isotope ratios (0.5128 - 0.5124); Pb isotope ratios do not display significant variations ($^{206}Pb/^{204}Pb$ = 19.22-19.45, $^{207}Pb/^{204}Pb$ = 15.65-15.71, $^{208}Pb/^{204}Pb$ = 39.26-39.43) (Bargossi *et al.*, 1989; Crisci *et al.*, 1991; Esperança *et al.*, 1992; Gioncada *et al.*, 2003).

A complex combination of polybaric fractional crystallisation, crustal assimilation and mixing between differently evolved magmas are the evolutionary processes affecting the Lipari magmas. The presence of cordierite-bearing lavas and clear positive correlations between Sr isotope ratios and the degree of magma evolution are strong evidence of crustal assimilation (Crisci *et al.*, 1991; Esperança *et al.*, 1992; Gioncada *et al.*, 2003).

Vulcano

It is the southernmost island, with an area of 22 km^2 and a maximum elevation of 500 m a.s.l. and of about 1500 m b.s.l. (Fig. 1). The last eruption occurred in very recent time (1889-1890 A.D.) and an intense fumarolic activity of high temperature (up to about 650°C) is still present. The Vulcano island is characterised by two volcano-tectonic sub-circular depression: the Piano Caldera at SE and the Fossa Caldera at NW.

Six main stages of volcanic activity were recognised: the Primordial Vulcano, the Piano Caldera, the Lentia Complex, the Fossa Caldera, the Fossa cone and Vulcanello (Keller, 1980b; De Astis *et al.*, 1997). The earliest rocks of the Primordial Vulcano (136-100 ka) are constituted by a thick sequence of lava flows alternated to red and black scoria fall deposits. These products are HKCA and SHO basalts and shoshonites (Fig. 2). The collapse of the summit part of this volcano, formed the sub-circular depression of Piano Caldera, which was subsequently (98-20 ka) filled by SHO basalts and shoshonites pyroclastic deposits and lava flows. The volcanic activity shifted towards N with the eruption of the Lentia Complex (24-15 ka) latitic, trachytic and mainly rhyolitic lava domes and flows and pyroclastic fall deposits. The Lentia Complex appears to be the remnant of a larger structure cut by the ring faults of the Fossa Caldera. Several effusive and pyroclastic volcano-stratigraphic units, also formed by shallow submarine explosive eruptions constitute the Fossa caldera deposits (15-8 ka), which were mainly erupted from a NW-SE eruptive fracture along the western rim of the Piano Caldera. Their composition (shoshonites, latites and trachytes) became more mafic and alkaline with time. The active composite tuff cone, 391 m high, of Fossa cone developed, in the middle of the Fossa Caldera, in the last 6 ka, with the youngest eruption occurred in 1888-1890. It was constructed by at least four volcanic cycles (Punte Nere, Palizzi, Commenda and Pietre Cotte), each characterised by a different volcanic vent and by a similar sequence of activity: hydromagmatic eruptions, mainly pyroclastic fall activity and effusion of lava flows (Frazzetta *et al.*, 1984). These rocks range in composition from trachytes to rhyolites. Since 1890, Vulcano activity is only characterised by an intense fumarolic field. Vulcanello, the northern peninsula of Vulcano, is composed by a tabular lava platform and by three mainly pyroclastic cones. It appeared as a new islet in 183 B.C.; recent eruptions occurred in the 6th and 16th centuries and an intense fumarolic activity persisted until 1878. Around 1550 A.D., Vulcanello islet was connected with Vulcano island by sand accumulation originating the isthmus area between the two islands. The platform lava flows were erupted after the formation of the first and easternmost pyroclastic cone. The pyroclastic rocks and lavas of the last and westernmost cone show a trachytic composition, whereas all the other rocks are leucite-bearing KS (Keller, 1980; Frazzetta *et al.*, 1984; De Astis *et al.*, 1997).

Most of the rocks is considered to belong to a same SHO series, even though basalts and basaltic andesites form a single cluster straddling the boundary line between HKCA and SHO fields (Fig. 2). Samples with higher K_2O contents (e.g., K_2O>3.5 wt% for silica <56 wt%) form the leucite-bearing K-series (Fig. 2). SHO rocks with silica <56 wt% represent the oldest rocks (120-30 ka), whereas more silicic SHO rocks and KS rocks are the youngest products (<30 ka) (De Astis *et al.*, 2000).

The textures are variably porphyritic. Most of the rhyolites are obsidians. Plagioclase and clinopyroxene phenocrysts are ubiquitous. Orthopyroxene is lacking. Fresh olivine is regularly found in all the mafic rocks and persists in resorbed grains in some rhyolitic rocks. Biotite is only found as phenocryst in some pumices. Sanidine is usually present associated to plagioclase in the groundmass of all the Vulcano rocks. It is found as phenocryst only in the trachytes of Fossa and Vulcanello and in the rhyolites of Lentia. Leucite appears in the groundmass and as microphenocryst in the KS rocks (Keller, 1980b; De Astis *et al.*, 1997).

All major and trace elements show smooth trends in interelemental diagrams, especially for the rocks of a same volcanic period. Incompatible trace element contents increase together with potassium content. $^{87}Sr/^{86}Sr$ values range from 0.70417 to 0.70587 (Fig. 3) and increase with decreasing MgO and $^{143}Nd/^{144}Nd$ values (0.51240-0.51277). $^{206}Pb/^{204}Pb$ values display significant variations (19.28-19.76) and are positively correlated with $^{207}Pb/^{204}Pb$ (15.66-15.82) and $^{208}Pb/^{204}Pb$ (39-39.51). Whole rock $\delta^{18}O$ values range from + 6.2 to +8.1 ‰ and correlate positively with Sr isotope ratios (Ellam and Harmon, 1990).

A very complex evolution is pointed out for the Vulcano magmas by the petrochemical data. AFC + continuous mixing with mafic magmas occurred before 30 ka, whereas a prevalent fractional crystallisation, sometimes associated to mixing and to rare crustal contamination, is suggested for the evolution of younger magmas. These processes occur in several reservoirs sited at different pressures. The transition from HKCA-SHO to KS rocks with time is mainly ascribed to mantle source processes. Mafic magmas are supposed to derive from a metasomatised fertile asthenospheric mantle before 30 ka and from a metasomatised residual lithospheric mantle later on (De Astis *et al.*, 1997, 2000; Del Moro *et al.*, 1998; Gioncada *et al.*, 2003; Zanon *et al.*, 2003).

Filicudi

Filicudi is a small island (9.5 km^2) with an elevation of 750 m a.s.l. It represents the emergent part of a complex 20 km long structure, elongated NW-SE, parallel to the main regional lineaments (Calanchi *et al.*, 1995).

The volcano consists of several monogenic and polygenic centres built up through four major phases of explosive and effusive activity (Manetti *et al.*, 1995; Santo, 2000). The oldest rocks (phases I and II) are represented by basaltic and basaltic andesitic lavas and minor pyroclastic deposits of Filo del Banco and Grotta del Bue Marino formations and by the evolved andesites of Punta dello Zucco Grande (Fig. 2). Disagreement exists about the age of these rocks. A $^{39}Ar/^{40}Ar$ value of 1.0±0.1 Ma has been measured in a rock sample from Zucco Grande formation (Santo *et al.*, 1995), whereas a K-Ar age of 211±5 ka is considered to represent the oldest activity by De Rosa *et al.* (2003). Most of the volcanic centres of Filicudi were built up during the third phase (about 230-100 ka). The Sciara stratocone, with basaltic and andesitic lavas and pyroclastic rocks, forms most of the NW part of the island. The dacitic dome of Mt. Montagnola and associated basal pyroclastic deposits were emplaced, at around 100 ka, in the southern flank of the Sciara cone. At SE, explosive and effusive activity formed the Monte Guardia volcanic centre, mainly constituted by basalt to andesite pyroclastic deposits, and the Capo Graziano dacitic dome. The Chiumento stratocone is located between the previous ones and is constituted by black and red scoriae deposits with intercalated lava flows (basalt to basaltic-andesite). Exogenous andesitic domes (Monte Terrione and Canale lavas) were emplaced at around 100 ka, along a collapse rim of Chiumento centre. La Canna center, located offshore NW of Filicudi, represents the remnant of a basaltic volcanic neck, and is considered to be the youngest known magmatic event of the area around Filicudi, even if the age is quite uncertain (40±40 Ka; Santo *et al.*, 1995).

The Filicudi rocks are highly porphyritic (30-50 vol%) with phenocrysts consisting of plagioclase, clinopyroxene and olivine in the basaltic rocks and plagioclase, clinopyroxene, orthopyroxene, biotite and brown hornblende in the andesites. Few microphenocrysts of orthopyroxene are also sometimes present in basalts and basaltic andesites. Ti-magnetite, ilmenite and apatite are found as accessory minerals.

A characteristic of Filicudi basalts and basaltic andesites is the low MgO, Ni and Cr contents, associated to the high Al_2O_3 contents (18-21 wt%). $^{87}Sr/^{86}Sr$ is poorly but significantly variable (0.704016 - 0.704740) and shows overall higher values in the mafic than in the sialic rocks (Fig. 3) (Francalanci and Santo, 1993). Nd isotope ratios range from 0.512670 to 0.512760 and are negatively correlated with $^{87}Sr/^{86}Sr$. Pb isotope ratios cluster around $^{206}Pb/^{204}Pb$ = 19.31-19.67, $^{207}Pb/^{204}Pb$ = 15.64-15.69, $^{208}Pb/^{204}Pb$ = 39.11-39.47 (Santo *et al.*, 2004).

Petrological and geochemical data reveal multistage polybaric evolutionary processes for the Filicudi magmas. A complex interplay of prevailing fractional crystallisation, crustal assimilation and magma mixing processes originated the different composition of Filicudi rocks. Geochemical and field evidence indicates that the evolution of each eruptive centre took place separately in time and/or space. The plumbing system has been figured as a deep mafic magma chamber that fed several small-sized scattered reservoirs situated at shallower depths (Francalanci and Santo, 1993; Santo *et al.*, 2004). It has been suggested that Filicudi primitive magmas derive from a mantle MORB-like source that underwent contamination trough slab derived fluids. The mafic magmas erupted during the first three phases of activity display a common geochemical signature, whereas those from the last activity phase (lavas forming La Canna neck) display some different geochemical characteristics (higher K/Na, Mg/Al, Rb/Sr and lower Ba/Nb, Ba/Rb ratios). These differences are considered to reflect a derivation from a different mantle source (Santo *et al.*, 2004).

Alicudi

Alicudi is located in the westernmost end of the Aeolian archipelago (Fig. 1) and it is the upper part of a submerged stratocone with an elevation of 654 m a.s.l. It has a nearly rounded shape, with an area of about 6 km^2.

The oldest outcropping rocks of the island are the Galera lavas (< 90 - 87 ka; Gillot, 1987). They consist of olivine-rich basalts interbedded with pyroclastic flows. The successive activity (<60 ka) mainly erupted basaltic and basaltic andesite agglutinated lava flows and scoriae (Fig. 2), cropping out in the western and northern slope of the island (Alicudi N-W formation)(Manetti *et al.*, 1995). A succession of andesitic and basaltic andesite lavas and pyroclastic deposits (Torrente Cirino formation; <55 ka) follows in stratigraphic sequence, filling a previously formed volcano-tectonic collapse depression. Lava flows and domes with andesitic composition were erupted later on (Montagna formation). The volcanic rocks of the final activity consist of a thick succession of andesitic lava flows, filling an other volcano-tectonic depression (Filo dell'Arpa formation; about 28 ka)(Manetti *et al.*, 1995).

The Alicudi rocks range in composition from CA basalts to basaltic andesites and HK andesites (Fig. 2) (Villari, 1980). The mafic rocks display the most primitive petrological and geochemical characteristics (Mg-value up to 73) over the entire Aeolian arc.

The rocks are porphyritic with phenocryst content in the range 30-50 vol%. Plagioclase is the dominant phenocryst phase in all the rocks, whereas olivine is abundant only in basalts. Clinopyroxene is present in moderate amount and orthopyroxene occurs in basaltic andesite and HK andesites. Hornblende is sporadically found in basaltic andesite and its amount increases in HK andesites. Apatite and Ti-magnetite are present as accessory mineral phases.

Major and trace elements display good correlation with silica. $^{87}Sr/^{86}Sr$ ratios range between 0.70342 and 0.70410 (Fig. 3) and show a negative correlation with Nd isotope ratios (0.51289-0.51279). The highest $^{87}Sr/^{86}Sr$ and lowest $^{143}Nd/^{144}Nd$ ratios have been measured in the less evolved lavas. Melt $\delta^{18}O$ values, calculated from data obtained on plagioclase and clinopyroxene separates, are low and poorly variable (around + 6.1 ‰). Pb isotope ratios are around $^{206}Pb/^{204}Pb$ = 19.20-19.67, $^{207}Pb/^{204}Pb$ = 15.62-15.68 and $^{208}Pb/^{204}Pb$ = 39.07-39.36 (Peccerillo and Wu, 1992; Francalanci *et al.*, 1993b; Peccerillo *et al.*, 1993).

Peccerillo and Wu (1992) suggested that the petrological and geochemical characteristics of Alicudi magmas are better explained in terms of the following hypothesis: calc-alkaline mafic liquids, evolving in a magma chamber, originated different liquids, which interacted with wall rocks. The more mafic magmas, due to the higher temperature, were able to assimilate higher proportions of crustal material in respect with the high-K andesitic liquids acquiring higher Sr isotopic ratios (AEC process). An alternative hypothesis is proposed by Peccerillo *et al.* (1993): a heterogeneous mantle generated mafic magmas displaying distinct isotopic signatures; the basaltic magmas underwent increasing degree of evolution as their isotopic signature decreased.

GENERAL PETROCHEMICAL VARIATIONS AT THE AEOLIAN ISLANDS

The Aeolian island volcanics show complex petrochemical variations which occur within each of the single volcanoes between rocks of different magmatic series and among rocks of similar serial affinity, going from the western to the eastern sector of the arc. It is evident from Figure 2 that, with a few exceptions (e.g., La Canna rocks at Filicudi), Alicudi, Filicudi and Salina rocks belong to single magmatic series, starting from CA mafic members to HKCA more evolved magmas. Panarea and Lipari rocks display more scattered compositions, from CA, through HKCA, up to some SHO, without forming continuous series. Vulcano is mainly characterised by SHO and KS rocks, with a spread variation in K_2O contents. Finally, Stromboli shows a large petrological variability with samples ranging from CA to KS, through HKCA and SHO series.

The least evolved magmas are basalts with silica 47-50 wt% (Filicudi, Vulcano and the SHO series of Stromboli); basalts with silica >50 wt% are present at Alicudi, Salina and very few at Panarea, whereas the most mafic rocks of Lipari are basaltic andesites. The highest MgO contents are found at Alicudi, with Mg-values [molecular Mg/(Mg+Fe)*100] up to 73.

In order to point out the petrochemical variations in space and time occurring among mafic rocks of the Aeolian islands, the samples with silica <56 wt% and MgO>3 wt% have been selected. This quite large choice comes from the necessity of including the CA rocks of Stromboli and the KS rocks of Vulcano.

Major variations within mafic magmas of single volcanoes

Stromboli is by far the volcano with the largest petrological variations occurring among mafic rocks. From the silica oversaturated CA basaltic andesites to the slightly silica undersaturated KS rocks, there is a general increase of all the incompatible elements; the KS, however, is completely distinct from the SHO series as for K_2O, Rb and Ba contents. Some KS and SHO rocks having the same silica abundance display similar LREE (Light Rare Earth Element), HFSE (High Field Strenght Elements) and Sr contents. Al_2O_3 increases from CA to HKCA and SHO, through KS samples, whereas MgO, Ni, Cr, Co and Sc decrease from CA to SHO and KS rocks (Fig. 4). Sr isotope ratios increase from CA to KS, whereas Nd, Pb (especially $^{206}Pb/^{204}Pb$) and oxygen isotope ratios decrease (Figs. 3, 5,

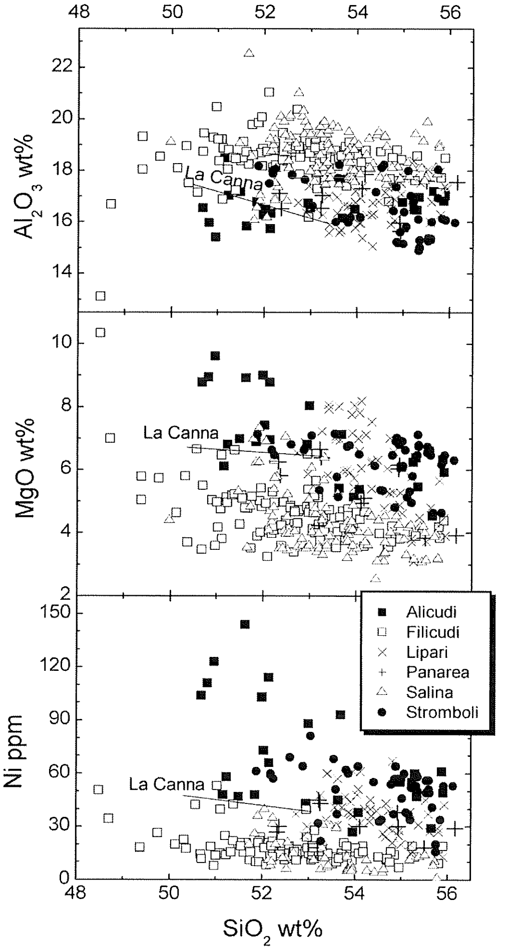

Fig. 4 – MgO, Ni and Al_2O_3 versus silica diagrams for calc-alkaline + high-K calc-alkaline mafic rocks, having $SiO_2 < 56$ wt% and MgO > 3 wt%. Silica is reported on water-free basis. Font of data as in figure 2.

6). Tb_N/Yb_N values smootly increase from 0.9-1.2 in CA rocks to 1.5-2.2 in the KS samples. Eu/Eu* is around 1 for CA rocks but arrives to 0.8 for the KS volcanics.; Ba/La, Ce/Sr, Ba/Nb, Nb/Y and Rb/Zr, increase from CA to KS rocks (Figs. 7-9).

KS rocks from ***Vulcano*** (K_2O >3.5 wt%) are slightly silica undersaturated, whereas SHO are slightly oversaturated. KS magmas have higher Rb, HFSE, LREE contents, Nb/Y, Rb/Zr, slightly higher Ba contents, La_N/Sm_N, Ce/Sr, and slightly lower Ba/Nb and La/Nb than SHO magmas with the same silica contents. Eu/Eu* is mostly around 1 (0.8 - 1.2) in rocks with silica <56 wt%. (Figs. 4, 7-9). Sr isotope ratios of more mafic SHO rocks increase from basalts to shoshonites, and the latter rocks have $^{87}Sr/^{86}Sr$ similar to those of KS magmas. Nd isotope ratios exhibit a good negative correlation with Sr isotope ratios. SHO rocks encompass a larger isotopic variation range and reach higher values in $^{206}Pb/^{204}Pb$ with respect to KS (Figs. 3, 5, 6).

A significant compositional variation is also observed among mafic rocks of ***Panarea***. CA mafic volcanics have been erupted during the youngest activity, whereas HKCA basaltic andesites are mainly found in Lisca Bianca, Basiluzzo and other minor islands. These rocks display variable compatible and incompatible element contents and ratios and isotope values. Ba/La values, for example, range between 20-35, La_N/Sm_N between 2.5-4 and Ba/Nb between 30-130. $^{87}Sr/^{86}Sr$ and incompatible element contents of mafic rocks are lower in CA (0.7040-0.7044) than HKCA (0.7052-0.7058) rocks, whereas the opposite is observed for Pb isotope ratios. The petrochemical characteristics of CA products generally resemble those of CA rocks of Salina, whereas the composition of HKCA samples is more strictly similar to that of CA and HKCA rocks of Stromboli (Figs. 3-6).

Variations among CA + HKCA mafic rocks

Major and trace elements, such as Al_2O_3, MgO, Ni, Cr, Co, Sc and partially Sr, lead to distinguish Filicudi and Salina from the other islands. Indeed, most of the Filicudi (except for La Canna rocks) and Salina mafic rocks are high-Al_2O_3 basalts and basaltic andesites with Al_2O_3 >18 wt%. At the opposite, most of the mafic samples of the other islands display Al_2O_3 contents between 15-18 wt% (Fig. 4). This difference negatively correlates with the MgO and compatible element variations, especially comparing rocks with the same silica contents. Sr behaves like alumina, but Alicudi and some Panarea rocks display high Sr content, similar to those of Salina and Filicudi. The higher modal plagioclase/olivine + pyroxene values of Salina and Filicudi petrographically reflect these geochemical differences.

Significant geographical variations are also observed in the incompatible trace element contents and ratios. Comparison is performed among samples with the same silica content. REE and HFSE contents are higher at Alicudi, Filicudi and Stromboli and lower at Salina, CA Panarea and some Lipari rocks. Tb_N/Yb_N values are similar in all the islands. Eu/Eu* is around 1, except for some higher values (1.2-1.4) found in the Alicudi and Filicudi rocks. La/Sm is higher at Alicudi and lower in Salina, Lipari and CA Panarea rocks. On the basis of incompatible trace element ratios, the central sector of the arc (Salina, Lipari and CA Panarea) is distinguished from the eastern and western sector, being preferentially enriched in those elements with lower ionic potential (e.g., higher Ba/La and lower Ce/Sr; Figs. 7, 8), which are believed to be strongly enriched in H_2O-rich fluids (Loughnan, 1969; Tatsumi *et al.*, 1986; Woodhead, 1989).

Sr isotope ratios increase from West to East, being lower at Alicudi, intermediate at Filicudi, Salina, CA Panarea and Lipari, and higher at Stromboli and HKCA Panarea. Nd isotope ratios decrease in the same direction. The lowest $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ values are found at Stromboli and HKCA Panarea rocks (Figs. 3, 5, 6).

Variations among SHO and KS mafic rocks

SHO and KS mafic rocks are mostly found at Vulcano (Fossa caldera and cone and Vulcanello) and Stromboli (Neostromboli period). SHO series display large silica content variation, from basalts to trachytes at Stromboli and to rhyolites at Vulcano, whereas KS rocks show smaller silica range. At Stromboli, all KS rocks are compositionally well defined with silica between 51-56 wt% and K_2O between 3.5-5 wt%, whereas at Vulcano they are not well distinct from the SHO series and falls in the 51-63 wt% silica range; K_2O varies between 3.5-7.5 (Fig. 2). KS rocks from Stromboli and Vulcano are often misleading termed «leucite-tephrites» (e.g., Barberi *et al.*, 1974; Keller, 1980b; De Astis *et al.*, 1997, 2000; Peccerillo, 2001). The term leucite-tephrite refers to a strongly silica-undersaturated, ultrapotassic rock, with abundant leucite both as phenocrysts and in the groundmass (Le Maitre *et al.*, 2002). Aeolian KS are not ultrapotassic, never contain leucite phenocrysts, foids are usually restricted to the groundmass, and vary from silica-saturated to slightly silica-undersaturated (e.g., Francalanci *et al.*, 1989, 1993a; De Astis *et al.*, 1997, 2000). According to Le Maitre *et al.* (2002), the Aeolian KS rocks should be named «shoshonite» at Stromboli (i.e., Francalanci *et al.*, 1989, 1993a) and «shoshonite» to «trachyte» (through «latite») at Vulcano.

For most of the geochemical characteristics, SHO and KS rocks vary in a same way from one volcano to the other. Thus, comparing SHO + KS rocks with the same silica content between Stromboli and Vulcano, at Stromboli they display lower Sr, La/Nb, $^{143}Nd/^{144}Nd$, $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ and higher Ba, HFSE, heavy REE, Ba/La, Ce/Sr, Nb/Y and $^{87}Sr/^{86}Sr$. There are, however, some geochemical features that vary distinctly among SHO and KS rocks. The Vulcano SHO samples have similar compatible trace element content, higher MgO and Ba/Nb, and lower Al_2O_3 and LREE than the Stromboli SHO products. Among KS rocks, Al_2O_3, MgO, Ni, Cr, Co, Sc and Ba/Nb are lower at Vulcano (Figs. 3-8).

Variations in rhyolites

The most silicic products of the Aeolian island arc are rhyolites, with silica up to 76 wt%. They were erupted in the central part of the arc, at Salina, Lipari, Panarea and Vulcano. They show distinct petrochemical characteristics in the different islands. Rhyolites from Vulcano, Lipari and Panarea (Basiluzzo), for example, show higher K_2O, Rb and Y and lower Ba and Sr contents than Salina rhyolites. Panarea HK dacites, moreover, are compositionally similar to the Salina dacites (Figs. 2, 10). These variations are not correlated with Sr isotope ratios which are quite variable also in single islands (Fig. 3). Rocks also display different modal composition, with K-feldspar + plagioclase + clinopyroxene ± hornblende ± biotite in Lipari and Vulcano rhyolites and with plagioclase + hornblende + pyroxenes ± biotite in Salina and Panarea dacites and rhyolites.

DISCUSSION

A complex volcanological, geochemical and petrological picture has been described in the previous sections for the Aeolian arc islands. No clear systematic correlations seem to exist with age of volcanism. Indeed, the onset of subaerial activity at the Aeolian volcanoes started on Filicudi (probably at ≈ 219 ka ago), Strombolicchio (≈ 200 ka) and Lipari (≈ 223 ka), followed by Salina (≈ 168 ka), Panarea (≈ 149 ka), Vulcano (≈ 136 ka), Alicudi and Stromboli (<100 ka). Thus, in a time span of 100 ka all the volcanoes seem to be emerged from the sea, without any geographical trend, as it occurred for the end of activity, which probably firstly ceased at Filicudi (≈ 40 ka). At Panarea, an intense fumarolic activity is still present, the last eruptions at Lipari took place on 580 A.D., whereas Vulcano and Stromboli are active.

Correlations between age and compositional parameters in a same sector of the arc are also few. At Salina, Lipari and Vulcano, in the central part of the archipelago, the most acidic rocks of the arc are generally erupted by the youngest activity, and even at Alicudi there is a silica content increase with decreasing time. At Panarea and Stromboli, on the contrary, the youngest rocks have a more mafic composition. In addition, at Vulcano, Stromboli, Lipari and Panarea (Basiluzzo) there is a general increase of potassium content with time, but returns to less potassic compositions also occur at Panarea, Stromboli and Vulcanello.

On the contrary, most of the geochemical and isotopic characteristics appears to follow geographical drifts, changing from West to East of the arc. A decoupling between the behaviour of isotope ratios and element contents and ratios, however, is observed, especially among mafic CA rocks, but also in rhyolites (Figs. 3, 9). Indeed, isotope ratios mostly change from the western to the eastern sector of the arc, whereas element contents and ratios vary passing from the central to the external parts of the archipelago (Francalanci *et al.*, 1993b).

The magma differentiation processes considered responsible for the large compositional variability found in the Aeolian rocks are numerous. Many petrochemical variations are clearly determined by shallow level evolutionary processes, whereas others are clearly due to magma source variations. Some compositional characteristics of mafic magmas, however, cannot be univocally interpreted, because both categories of processes could well explain them.

Magma differentiation processes during the pathway to the surface

As usually found, fractional crystallisation plays the main role in determining the large compositional variations along the single series of evolution. In particular, this process played a more intensive role in producing rhyolitic magmas. Aeolian rhyolites, in fact, are considered to be generated by evolutionary processes starting from dacitic magmas, rather than by crustal anatexis (e.g., Calanchi *et al.*, 1993, 2002; De Astis *et al.*, 1997, 2000; Dal Moro *et al.*, 1998; Gioncada *et al.*, 2003). Indeed, in most of the volcanoes, rhyolite compositions plot at the most acidic extreme of continuous series of evolution (Figs. 2, 9, 10). In this light, the different element contents of Aeolian rhyolites can be easily explained by fractional crystallisation of the main mineral phases, starting from the respective less evolved magmas. Lipari and Vulcano rhyolites have higher potassium, Rb and most of incompatible element contents, in respect with Salina and Panarea dacites and rhyolites, because they derive from more potassic parental magmas. Even the different modal composition of these rocks is due to their different serial affinity, which leads to preferentially stabilise K-feldspar in SHO magmas and hornblende in CA + HKCA magmas, which are usually more enriched in aqueous fluids. Accordingly, the lower Y contents of Salina and Panarea and lower Ba contents of Lipari and Vulcano acidic rocks are mainly due to the fractionation of hornblende in the former magmas and K-feldspar in the latter ones.

Fractional crystallisation is, moreover, often accompanied by crustal assimilation (AFC process). As previously described for the single islands, this process was found to have affected the evolution of most of the intermediate and acidic Aeolian magmas (see reference above). AFC probably had a minor role in Alicudi and Stromboli. The AFC processes generated different isotope ratios within acidic magmas of a single island (Fig. 3). Thus, among rhyolitic rocks, decoupling between trace element and isotope ratio behaviour partially depends on the different isotope ratios of parental magmas and partially on the AFC processes.

The presence of cordierite-, garnet-, sillimanite- and andalusite-bearing andesitic and dacitic lavas at Lipari, the widespread occurrence in most of the Aeolian island rocks of restitic quartzite nodules and general partial melted crustal xenoliths are all evidence indicating that Aeolian magmas were able to partially melt the crustal basement. Thus, crust assimilation plays a significant role in differentiating Aeolian magma composition.

Crustal assimilation seems to have also occurred as AEC (Assimilation + Equilibrium Crystallisation), in which hotter and more mafic magmas, during their way to the surface, were able to assimilate at higher extent the continental crust, than more evolved magmas (Huppert and Spark, 1985; Devey and Cox, 1987). This mechanism seems to be the most reasonable explanation for interpreting the reverse correlations between Sr isotope ratios and degree of magma evolution found at Alicudi, KS Stromboli, Filicudi and in part at Panarea (Fig. 3) (Francalanci *et al.*, 1988, 1989; Peccerillo and Wu, 1992; Peccerillo *et al.*, 1993; Francalanci and Santo, 1993).

Mixing between different magmas is an other recurrent process of evolution. It has been largely proved in most of the Aeolian volcanoes and it seems also to occur as repeated inputs of fresh magma in a continuously replenished, crystallising, assimilating and tapped magma chamber (RTFA)(Francalanci *et al.*, 1989, 1993a; De Astis *et al.*, 1997; 2000). Mixing plus crystallisation is the leading process of evolution in the magmas feeding the present day activity of Stromboli, which allows to maintain steady state conditions with a nearly continuous volcanic activity (Francalanci *et al.*, 1999).

On the basis of geochemical and mineralogical data, polybaric magma evolution was proposed by several authors for different islands (e.g., Stromboli: Francalanci *et al.*, 1989; Salina: Calanchi *et al.*, 1993; Filicudi: Francalanci and Santo, 1993; Vulcano: De Astis *et al.*, 1997). From the different Al_2O_3, MgO, Ni, Cr and Co contents of CA magmas (Fig. 4), crystallisation at higher depth for Filicudi and Salina magmas than for other CA magmas was inferred (Francalanci, 1994). Indeed, the high rest pressure, associated to the significant H_2O contents of arc magmas, is found to suppress the plagioclase crystallisation, enlarging the stability field of olivine (e.g., Nicholls and Ringwood, 1973; Sisson and Grove, 1993). Delayed plagioclase nucleation and the extensive fractionation of mafic phases drive the residual liquids to high Al_2O_3 and low MgO abundances. Plagioclase appears on the liquidus at low pressure and a large amount of this phase crystallises in the high alumina magmas during their ascent to the surface. Studies on fluid inclusions found in restitic quartzite nodules and on crystal chemistry of clinopyroxene have been later on performed in order to check polybaric crystallisation in the different islands and to give an estimation of the pressure values (Vaggelli *et al.*, 1991, 2003; Nazzareni *et al.*, 2001 and reference therein; Frezzotti *et al.*, 2003; Zanon *et al.*, 2003). They confirm polybaric rests in most of the islands, giving a total pressure range of 0.6-0.1 GPa. In particular, on the basis of crystal-chemical variations in clinopyroxenes, Nazzareni *et al.* (2001) found that Filicudi, older Salina and, at lesser extent, Alicudi magmas crystallised at high pressure, in the lower crust or at the mantle-crust boundary. On the contrary, the central and eastern volcanoes of Lipari, Vulcano, Panarea and Stromboli generally show higher values of clinopyroxene cell parameters, suggesting crystallisation in shallow magma chambers. It is noteworthy that these results agree with the previous described estimation of crystallisation pressure performed on the basis of alumina, MgO and compatible element differences. Nevertheless, fluid inclusions pressure data performed on quartzite nodules of Alicudi, Filicudi, Salina and Vulcano have given opposite results, with higher pressure for Alicudi and Vulcano and lower for Salina and Filicudi (Frezzotti *et al.*, 2003; Zanon *et al.*, 2003). It is difficult to understand the reason of this pressure data discrepancy among different methodologies. The agreement between two of them (whole rock geochemical and crystal-chemical data) leads to consider as more probable these estimations of crystallisation pressure. In addition, Filicudi and older Salina display other common characteristics that could be in favour of deep rest and high pressure of crystallisation: 1) no caldera collapses, like those present in the central and western islands, were formed during their volcanological history (Nazzareni *et al.*, 2001); 2) together with Alicudi, they appear as the Aeolian volcanoes with the oldest cessation of activity; 3) they are characterised by a nearly single series of evolution (Fig. 2). On the other hand, fluid inclusion data are usually important tools for recognising mineral phase crystallisation pressure. Considering that the studied fluid inclusions show partial decrepitation textures, a possible cause might be ascribed to a not carefully interpretation of the data relatively to P-T condition of re-equilibration during ascent of nodules towards the surface. An alternative and more probable explanation, however, could be searched in the possible different meaning of the two kinds of pressures, crystallisation pressure given by whole rock geochemical and crystal-chemical data and (rest?) pressure where the crustal whole rock is melted (crustal assimilation?), given by fluid inclusion data in restitic quartzite nodules.

Treating with differentiation processes leading to compositional variations among intermediate and acidic rocks, it is extremely likely that they occur during the ascent of magmas to shallow levels. Nevertheless, more uncertainness arises when compositional variations occurr among mafic rocks. Indeed, if evolutionary processes are something like RTFA, even parameters such as silica and MgO contents are not capable to discriminate between the two types of differentiation processes. It is suggested, in fact, that RTFA processes are able to increase incompatible trace element contents, leaving nearly constant the major element composition and decreasing, at lower extent than FC, the compatible trace element abundances. RTFA-like processes were already proposed for Stromboli and Vulcano magma evolution (Francalanci *et al.*, 1989, 1993 and references therein; De Astis *et al.*, 2000). As for KS rocks, it is noteworthy that they have a quite evolved character, with silica between 52-55 wt% and the highest Mg-values of 63 in Stromboli and 55 in Vulcano. They also plot in the same evolutionary trend of the respective SHO rocks for major and compatible trace element contents versus silica. These characteristics lead to suspect that KS magmas could derive from mafic SHO melts by RTFA-like processes. On the other hand, the quite low oxygen isotopes of Stromboli KS and of some Vulcano KS rocks lead different authors to hypothesise mantle source processes for the origin of KS compositional characteristics (Ellam and Harmon, 1990; De Astis *et al.*, 2000). The same hypothesis has been proposed on the basis of similarities between the KS rocks of Stromboli and Campanian region (Peccerillo, 2001). Accordingly, in the following section, they will be considered as quite evolved magmas, the parental melts of which differentiated from mafic SHO magmas by mantle source processes.

Magma differentiation processes in the mantle source

Many factors can play a role in the genesis of magmas occurring in orogenic settings, where crustal material is re-cycled into the mantle wedge via subduction. These factors include the composition of the subducting lithosphere (oceanic or continental, presence of subducted sediments), the type of mass transfer of crustal material into the mantle wedge (fluids or melts, amount of metasomatising material added to the mantle) and the process of partial melting of the metasomatised mantle (e.g., degree of partial melting). Finally, some components are relative to the nature of the mantle wedge before the event of metasomatism (lithosphere, asthenosphere, intraplate component). Several hypotheses have been proposed in order to explain the genesis of the different Aeolian parental magmas, taking in mind the complex petrochemical variations observed along the arc.

Regarding to the nature of the subducted lithosphere, some authors proposed the subduction of continental crust under the Calabrian arc (e.g., Boccaletti *et al.*, 1984). Nevertheless, several lines of petrochemical and geodynamic evidence agree in considering an oceanic nature for the subducted slab (e.g., Francalanci *et al.*, 1993b; Faccenna *et al.*, 1997). A petrochemical constraint is derived from the high Sr contents associated with the relatively low Sr isotope ratios of most of the CA Aeolian mafic magmas. Indeed, considering the quite high partial melting degrees (20-30%) necessary to originate CA magmas (e.g., Green, 1976), a high Sr content (about 200 ppm) of the mantle source is necessary for obtaining the high Sr abundances of the CA magmas (400-800 ppm). This high concentration of low radiogenic Sr in the mantle wedge, can be only achieved by adding melts or fluids deriving from a subducted oceanic lithosphere.

Mantle contaminant of oceanic nature by itself, however, cannot account for the high $^{87}Sr/^{86}Sr$ of Stromboli CA rocks and the relatively low $^{143}Nd/^{144}Nd$ of all the Aeolian volcanics, which are lower than those usually found in basaltic oceanic crust (lower than Nd isotopes of MORB) (Fig. 5). Accordingly, associated with the oceanic crustal component, with high content of low radiogenic Sr and high Nd isotope ratios, an other mantle contaminant with high $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ is needed. The latter is considered by several authors to be represented by oceanic sediments, which should also account for the higher $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ of Aeolian magmas in respect with MORB values (e.g., Ellam *et al.*, 1989; Francalanci *et al.*, 1989; 1993b).

The two metasomatising crustal components interact with the mantle wedge in a complex way, as testified by the wide compositional variation displayed by the Aeolian mafic magmas. The decoupling between the behaviour of trace elements and the isotope ratios among CA and HKCA rocks was firstly pointed out by Francalanci *et al.* (1993b) on the basis of limited geochemical and isotopic data and it was ascribed to a combination of interrelated genetic processes. The more complete data set reported in the present paper strengthens the previously discovered variations and allows to better constrain possible interpretative models. The variation in incompatible element ratios reveals a different role for aqueous fluids and melts released from the subducted slab in the different sectors of the arc. Indeed, fluids modify the

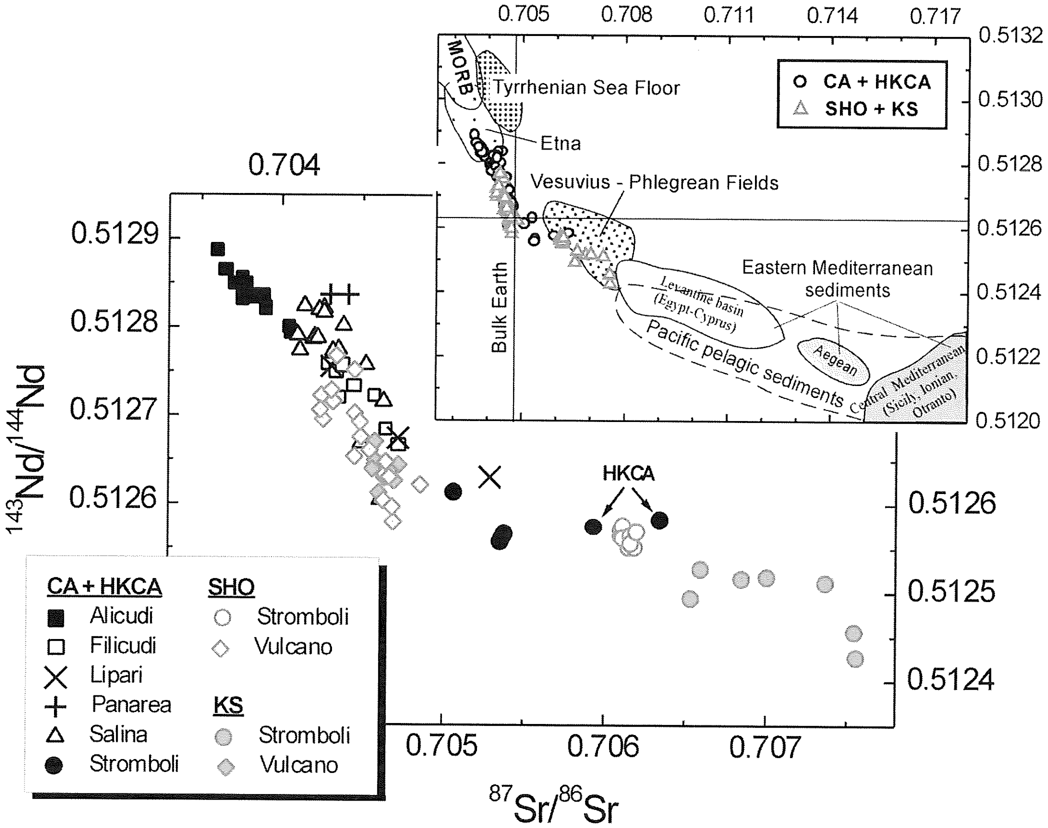

Fig. 5 – ^{143}Nd/^{144}Nd versus ^{87}Sr/^{86}Sr diagram for the Aeolian mafic rocks, having $SiO_2 < 56$ wt% and $MgO > 3$ wt%. CA = calc-alkaline series; HKCA = high-K calc-alkaline series; SHO = shoshonitic series; KS = potassic series. Font of Aeolian data as in figure 2. Font of data for comparison fields from Francalanci *et al.* (1993b) and references therein. Data of Eastern Mediterranean sediments are from Weldeab *et al.* (2002).

compositional characteristics of the mantle in a different way with respect to melts. The trace elements with lower ionic potentials (preferentially LILE) are usually more mobile and enriched in aqueous fluids, whereas all incompatible trace elements, even those with higher ionic potential and immobile for aqueous fluids (preferentially HFSE), are enriched in silicate melts. Thus, the incompatible trace element ratios of mantle wedge change if the metasomatising agents are preferentially fluids or melts released from the subducted slab. It has been shown that the central arc islands have always higher mobile/immobile element ratios (except for La/Sm) in comparison with the eastern and western islands (Figs. 9, 11), suggesting as contaminant of the mantle wedge, preferentially aqueous fluids in the central arc (Salina, Lipari and CA Panarea), and melts in the external sectors (Alicudi, Filicudi, HKCA Panarea and Stromboli). A higher proportion of aqueous fluids in the mantle could also promote higher degrees of source partial melting, thus contributing to generate magmas with lower REE and HFSE contents and La/Sm values as the CA magmas from the central arc (Figs. 7, 8). LILE (e.g., Sr, Ba, Rb) contents do

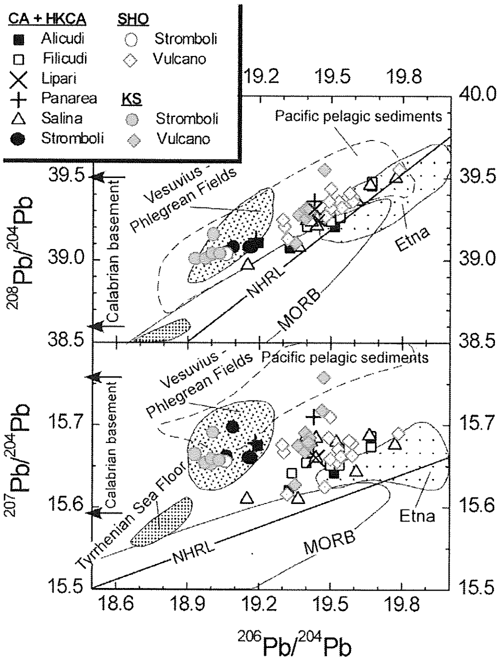

Fig. 6 – Pb isotope inter-ratios diagrams for the Aeolian mafic rocks, having $SiO_2 < 56$ wt% and $MgO > 3$ wt%. CA = calc-alkaline series; HKCA = high-K calc-alkaline series; SHO = shoshonitic series; KS = potassic series. Font of Aeolian data as in figure 2. Font of data for comparison fields from Francalanci *et al.* (1993b) and references therein.

not show systematic geographical variations (Fig. 8) because they are both the most mobile and incompatible elements. Thus, the higher amount of these elements in the source due to contamination by aqueous fluids, is balanced by the higher source partial melting degrees, leading to lower the LILE contents in magmas. On the other hand, the increase of $^{87}Sr/^{86}Sr$ and the decrease of $^{143}Nd/^{144}Nd$ from west to east are practically independent from the mechanism of mass transfer into the mantle wedge, due to the both mobile and incompatible behaviour of LREE and LILE, and they have been attributed to the increase in the amount of crustal contaminant added to the mantle wedge.

Interestingly, the rocks from the central island of Vulcano, in spite of their belonging to different magmatic series, tend to plot in the same area of CA and HKCA rocks of the central arc in diagrams of interelemental ratios versus Sr isotopes (Fig. 9). This fact seems to confirm an important role of aqueous fluids in the mantle source of all the central Aeolian arc magmas (including Vulcano magmas) and helps to propose specific hypotheses for the genesis of SHO and KS magmas of Vulcano (see below).

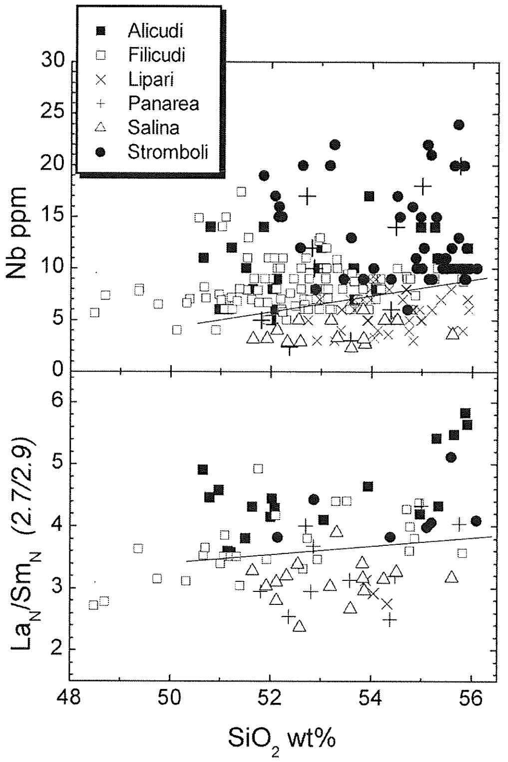

Fig. 7 – Nb and La_N/Sm_N versus silica diagrams for calc-alkaline + high-K calc-alkaline mafic rocks, having $SiO_2 <$ 56 wt% and $MgO > 3$ wt%. The respective ionic potentials (multiplied by 100) of La and Sm are also reported in parentheses. Silica is reported on water-free basis. Font of data as in figure 2.

The implication of aqueous fluids in the magma genesis of Salina, Panarea, Lipari and Vulcano is also definitely confirmed by the higher $\delta^{11}B$ (‰) and B/Th, B/Nb ratios found in these islands by Tonarini *et al.* (2001). The latter authors, moreover, point out a negative

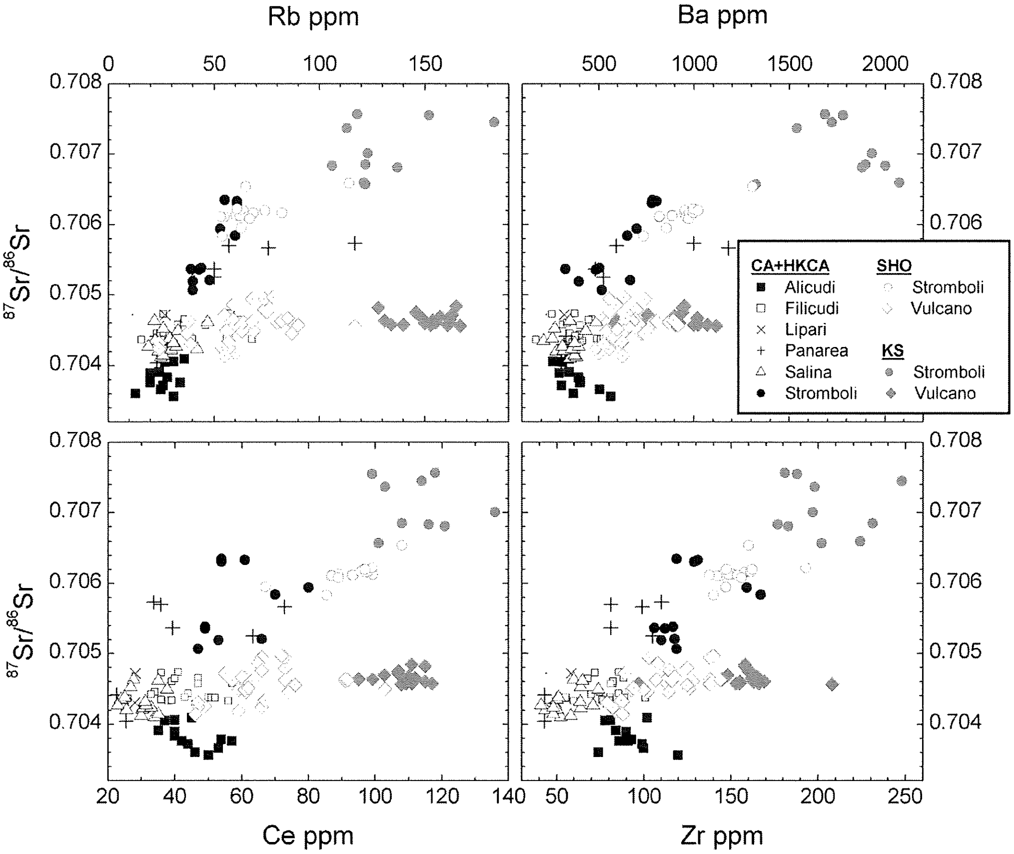

Fig. 8 – Rb, Ba, Ce and Zr versus $^{87}Sr/^{86}Sr$ diagrams for the Aeolian mafic rocks with $SiO_2 < 56$ wt% and $MgO > 3$ wt%. CA = calc-alkaline series; HKCA = high-K calc-alkaline series; SHO = shoshonitic series; KS = potassic series. Font of data as in figure 2.

correlation among Aeolian CA rocks between the depth of Benioff zone and the $\delta^{11}B$ (‰) or mobile/immobile element ratios. This correlation is in agreement with the two type of metasomatising agents: aqueous fluids at lower depth and addition of sediment melts at higher depth.

Different hypotheses have been proposed regarding to the nature of the mantle wedge before the subduction metasomatism. According to Ellam *et al.* (1989) the high $^{206}Pb/^{204}Pb$ values reflect those of the pre-contamination mantle source considered to be similar to an OIB source. Peccerillo and Panza (1999) and Peccerillo (2001) point out that Stromboli, Vesuvius and Phlegrean Fields share many geochemical and isotopic characteristics, which are intermediate between arc and intraplate alkaline volcanics. They suggest for these magmas a common mantle source consisting of a mixture of intraplate- and slab-derived components. The intraplate component was proposed to be provided by the inflow of asthenospheric material into the wedge above the subducting Ionian Sea plate, either from east (Apulian Plate) and/or from the Tyrrhenian sea area, as a consequence of the Ionian slab rollback (Gvirtzman and Nur,

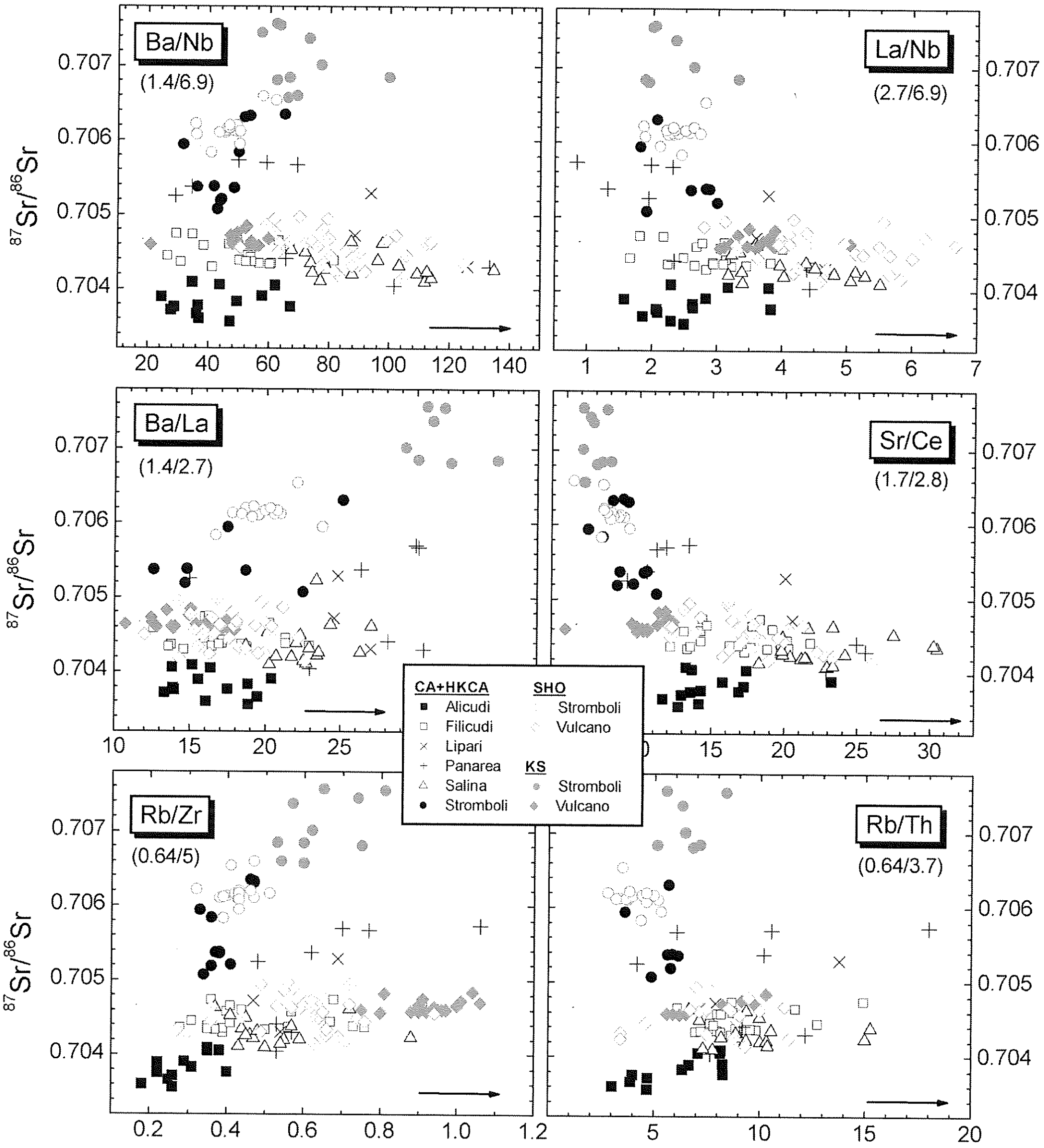

Fig. 9 – Incompatible trace element ratios versus $^{87}Sr/^{86}Sr$ diagrams for the Aeolian mafic rocks with $SiO_2 < 56$ wt% and $MgO > 3$ wt%. CA = calc-alkaline series; HKCA = high-K calc-alkaline series; SHO = shoshonitic series; KS = potassic series. The respective ionic potentials (multiplied by 100) of the different elements are also reported in parentheses. The arrows indicate the direction of aqueous fluids increase. Font of data as in figure 2.

1999). On the basis of isotopic data, even Gasperini *et al.* (2002) suggest that the mantle-derived end-member is a mixture of the standard HIMU and DM components, with the plume-type magmas channelled from the lower mantle through a subducted-plate window.

On the other hand, a MORB-like pre-contamination source is instead proposed by other authors on the basis of trace element content and quantitative estimations (Francalanci *et al.*, 1989; 1993a,b; Serri, 1990; Santo *et al.*, 2004; Schiano *et al.*, 2004). CA mafic rocks of the central arc display similar HFSE and HREE contents and higher LREE and LILE abundance in respect with MORB. This is a typical characteristic of CA magmas whose genesis is related to a MORB-like mantle source metasomatised by aqueous fluids, mainly enriched in LILE and LREE contents (more mobile elements). This is the simplest and more probable explanation for the genesis of CA magmas of the central Aeolian arc. Indeed, assuming an OIB-like pre-contamination source, unrealistic high degrees (>80%) of mantle partial melting would be necessary in order to obtain the low HFSE contents of these magmas (Francalanci and Manetti, 1994). Alternatively, HFSE-retaining residual phases during mantle partial melting should be necessary. Nevertheless, Schiano *et al.* (2004) have shown that Nb remains a highly incompatible element during the source melting, thus proving the absence of these residual phases and the low abundance of Nb in the magma source.

The higher HFSE abundance and Ta/Yb (or Nb/Y) and lower LILE/LREE, LILE/HFSE and LREE/HFSE ratios for the eastern and western volcanoes (Figs. 7-9, 11, 12), however, might be explained also suggesting a different pre-contamination mantle source, with possibly an OIB-like component. Nevertheless, this hypothesis conflicts with the similar ^{206}Pb/^{204}Pb values of the western and central island rocks. Indeed, an increase of ^{206}Pb/^{204}Pb values passing from the central arc towards Alicudi would be expected considering the higher Pb isotope values of intraplate magmatism in the area (Etna and Ustica; Fig. 6). An inflow of intraplate component from the Tindari-Letojanni fault system could be also geologically possible (Gvirtzman and Nur, 1999), but it is again in contrast with the similar Pb isotope ratios of the western and central islands and the low HFSE of the latter.

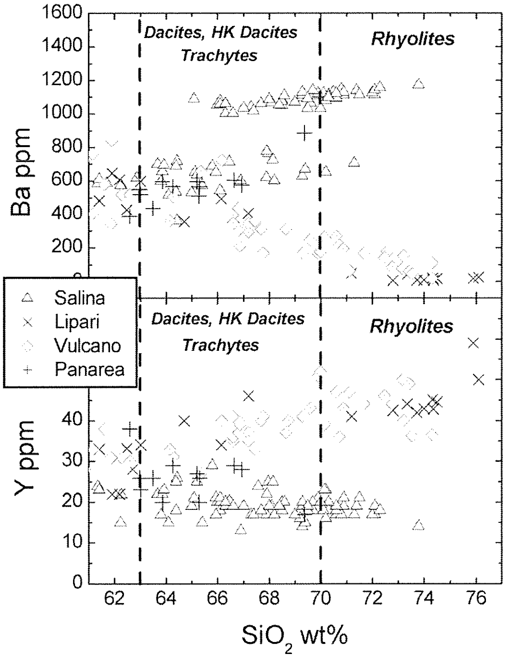

Fig. 10 – Ba and Y versus silica diagrams for the most acidic rocks of the Aeolian islands. Silica is reported on water-free basis. Font of data as in figure 2.

In this view the lower Pb isotope ratios of Stromboli suggest a completely different scenario. If the intraplate component exists in the Stromboli magma source, there are two possibilities to account for the ^{206}Pb/^{204}Pb variations: a) this intraplate component has lower Pb isotope ratios; b) the increase of ^{206}Pb/^{204}Pb values is balanced by the higher amount of crustal material, with low ^{206}Pb/^{204}Pb (Fig. 6), added to the mantle wedge. The latter hypothesis agrees with the negative correlation between ^{206}Pb/^{204}Pb and ^{87}Sr/^{86}Sr (Fig. 12) from CA to KS rocks of Stromboli, but it disagrees with the negative correlation of ^{206}Pb/^{204}Pb and Nb/Y (=Ta/Yb). Indeed, if the increase of Nb/Y is taken as indicative of an intraplate component, it should decrease with increasing crustal component.

According to the previous considerations, a pre-contamination MORB-like source would

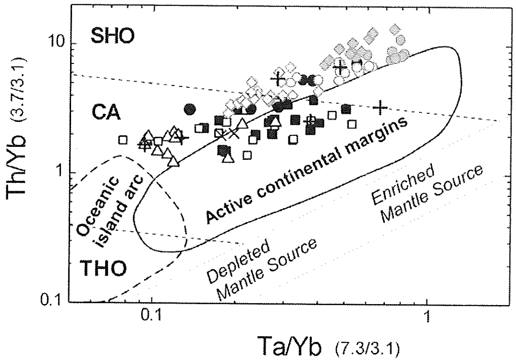

Fig. 11 – Th/Yb versus Ta/Yb diagram for the Aeolian mafic rocks with SiO_2 < 56 wt% and MgO > 3 wt%. Symbols as in figures 5,6,8,9. The respective ionic potentials (multiplied by 100) of the different elements are also reported in parentheses. Font of data as in figure 2.

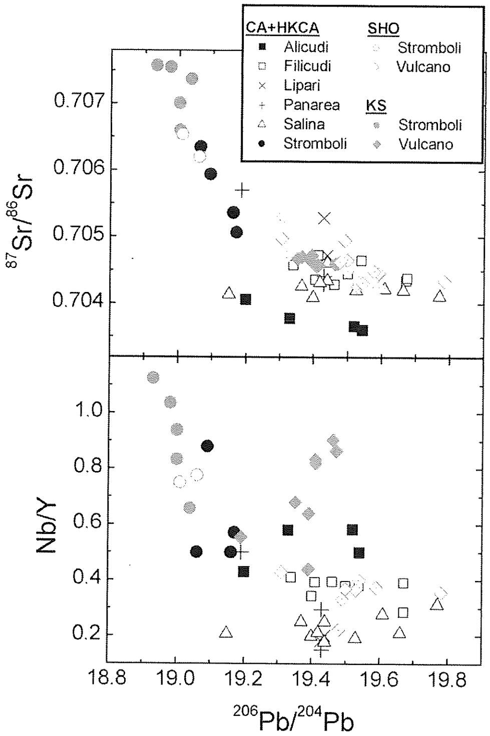

Fig. 12 – Nb/Y and $^{87}Sr/^{86}Sr$ versus $^{206}Pb/^{204}Pb$ diagrams for the Aeolian mafic rocks with SiO_2 < 56 wt% and MgO > 3 wt%. CA = calc-alkaline series; HKCA = high-K calc-alkaline series; SHO = shoshonitic series; KS = potassic series. Font of data as in figure 2.

be the preferred interpretation for the Aeolian volcanoes. In this light, the quite high Pb isotope ratios of western and central islands could be attributed to a slab derived crustal contaminant with these isotopic characteristics (= oceanic sediments). The lower Pb isotope ratios of Stromboli rocks, and the correlations with Sr and Nd isotope variations, could either indicate a different pre-contamination mantle source or a different mantle contaminant having low values of Pb isotope ratios (subducted Calabrian continental lithosphere?). In the former case, a continental lithospheric mantle wedge could be envisaged as the mantle source of Stromboli magmas, as opposite to the asthenospheric mantle source of the other island magmas. A more complete set of combined isotope data, however, will help in shed lights on this unresolved problem.

Some further considerations regard to the genesis of SHO and KS magmatism. Low partial melting degrees of a metasomatised phlogopite-bearing mantle source are usually believed to generate potassic magmas. Vulcano and Stromboli SHO and KS rocks display very different petrochemical characteristics (Figs. 2-9, 11, 12), as also pointed out by De Astis *et al.* (2000), which can be partially ascribed to the different petrogenetic processes already proposed for the different sectors of the arc.

As for Vulcano, a fluid metasomatised, fertile asthenospheric mantle was proposed for the source of the early SHO magmas, whereas a fluid metasomatised residual lithospheric mantle was suggested for the younger KS magmas (De Astis *et al.*, 2000). According to the similar Nd, Pb and Sr isotope ratios of SHO and KS magmas, however, a common source (probably asthenospheric) seems to be more appropriate for these magmas. The variable incompatible element contents and ratios between SHO and KS magmas could be generally ascribed to different source partial melting degrees, which are lower for the genesis of KS than SHO parental magmas. Even the increase of Ta/Yb (or Nb/Y) values (Figs. 11, 12), which is usually considered to indicate a different mantle source, could be determined by lower degrees of mantle partial melting, due to the more incompatible behaviour of Ta than Yb (see also Schiano *et al.*, 2004).

On the contrary, at Stromboli, there are good correlations among different isotope ratios and the other geochemical parameters (Figs. 2-9, 11, 12). It is also notable that most of the compositional characteristics changing from central arc to Stromboli among CA rocks, vary with the same tendency towards KS rocks. Different partial melting degrees, decreasing from CA to KS magmas, of a vertically zoned heterogeneous mantle have been already proposed for the Stromboli magma source (Ellam *et al.*, 1989; Francalanci *et al.*, 1988, 1989, 1993a). Due to the extreme heterogeneity of the mantle and to the strict correlations between isotope ratios and incompatible element contents and ratios, a possible model for this mantle source could be a veined, probably lithospheric, mantle (Foley, 1992). An increasing partial melting degree of this mantle leads to melt a higher portion of peridotite in respect with the metasomatised veins, which are rich in K_2O, radiogenic isotopes and incompatible elements. Thus, magmas changing from KS to CA affinity will be formed. The good negative correlation between $^{206}Pb/^{204}Pb$ and $^{87}Sr/^{86}Sr$ (Fig. 12) is a clear indication that the decrease of Pb isotope ratios is due to a major implication of the crustal mantle contaminant, having low $^{206}Pb/^{204}Pb$ values. This fact suggests again a different mantle contaminant toward east, which also would explain the lower Pb isotope ratios in CA magmas of Stromboli than in the other islands.

Most of the proposed modifications of the magma source passing from the central sector of the arc to Stromboli are already evident in Panarea, where large petrochemical variations are present. Calanchi *et al.* (2002) proposed that the mantle source of Panarea magmas is a mixture of western-type and resident eastern-arc mantle material. The presence of the western-type component would be linked to the inflow, generated by the slab rollback, through the Tindari-Letojanni fault zone considered to be the boundary between the active subducting plate in the east and the African plate and western Aeolian arc in the west (Falsaperla *et al.*, 1999; Gvirtzman and Nur, 1999). According to our previous considerations, it is not clear whether the Aeolian magmas are affected by the proposed inflow of mantle material from the Tindari-Letojanni fault system or not, but surely, the mantle source beneath Panarea area is strongly heterogeneous (probably vertically and spatially) and signs the passage to the eastern mantle source.

SUMMARY

The Aeolian magmas are characterised by complex petrochemical and isotopic variations, occurring either from west to east of the arc or within the single volcanoes. The rock geochemical characteristics are typical of an orogenic setting, with high LILE/HFSE, LREE/HFSE and LILE/LREE values. CA to KS rocks and a large silica variation in the single series are present. Different and complex evolutionary processes originated intermediate and acidic magmas, whereas multiple mantle source processes were responsible for the parental magma variations.

The large amount of rhyolites, erupted by the central arc volcanoes, derives from less evolved magmas by FC and AFC processes. Due to the different petrological affinity of the respective parental magmas, the amphibole crystallisation plays an important role in Salina and Panarea rhyolites, in alternative to the K-feldspar crystallisation occurring in Lipari and Vulcano rhyolites.

A polybaric magma evolution, by fractional crystallisation often associated to mixing and crustal contamination (AFC, AEC and RTFA processes), characterises most of the volcanoes, with a probably higher crystallisation pressure for Filicudi and Salina high-Al_2O_3 magmas.

The increase of $^{87}Sr/^{86}Sr$ and the decrease of $^{143}Nd/^{144}Nd$ from west to east are interpreted as due to mantle source processes, suggesting a higher amount of subducted crustal component added to the mantle wedge. Considerations based on combined isotopic and inter-elemental variations, try to account for the high Pb isotope ratios of central and western island rocks and their decrease towards east (Panarea HKCA and Stromboli). Different crustal mantle contaminants are probably responsible for the Pb isotope variation, which are represented by oceanic sediments in the central and western sectors and by a probable continental crustal contaminant, having low $^{206}Pb/^{204}Pb$ values, in the eastern arc.

A pre-contamination astenospheric MORB-like mantle source seems to be more appropriate in order to account for the petrochemical characteristics of the mafic magmas from the central and western arc, whereas a possible continental lithospheric mantle could be the source of the eastern mafic magmas.

Inter-elemental variations also provide evidence that the mass transfer mechanism from the subducted slab to the mantle wedge was different passing from the central arc islands to the external ones. Prevalent aqueous fluids seem to be released to the mantle source from subducted oceanic crust + sediments at Salina, Lipari and CA Panarea, promoting higher degrees of source partial melting. On the contrary, higher melt/fluid proportions characterise the mantle contaminant at the external sectors of the arc.

A decreasing degree of partial melting of a metasomatised mantle source is believed to originate CA to KS parental magmas. SHO + KS magmas display distinct compositional characteristics in the different volcanoes, which lead to hypothesise distinct mantle source. A fluid-metasomatised astenospheric mantle source at Vulcano and a possible continental lithospheric mantle source at Stromboli.

ACKNOWLEDGMENTS

We wish to thank Rosanna De Rosa, Giovanni Ruggieri, Angelo Peccerillo and Gloria Vaggelli for focusing and stirring discussions. The paper was greatly improved by toughtful revision performed by G. Chazot and an anonymous referee. Financial support was provided by G.N.V.-I.N.G.V., M.I.U.R. (Cofin 2002), and C.N.R. - Istituto di Geoscienze e Georisorse – sezione di Firenze.

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