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Sr ISOTOPIC VARIATION ALONG THE AEGEAN ARC: CONTRAINTS ON MAGMA GENESIS ON THE BASIS OF NEW Sr ISOTOPE DATA

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ABSTRACT

$^{87}Sr/^{86}Sr$ ratios for a number of rocks from all the main volcanic centres of the Aegean Arc were determined. It is clear that there is a variation of the- $^{87}Sr/^{86}Sr$ ratio along the arc as it increases from east (0.704) to west (0.706). As the crustal thickness is lower in the central sector of the arc (Santorini) than in both the western and eastern sectors, it is apparent that the Sr isotopic ratio along the arc is not simply a function of the different crustal contamination due to the varying crustal thickness in the different volcanic centres. Mixing of various proportions of three components give rise to the characteristic compositions of the different volcanic centres in the Aegean Arc. The three end-member components are: a)a LILE enriched lithosphere component b) a depleted-mantle asthenosphere component and c) a crustal component.

According to their $^{87}Sr/^{86}Sr$ ratio the volcanics of the western part of the arc contain higher proportions of crust component than those of the central and western sectors, while the involvement of the enriched mantle component is higher in the eastern part of the arc. It is shown that the variation of the $^{87}Sr/^{86}Sr$ ratio in the calc-alkaline volcanic rocks of the Aegean arc is not time depended. It is suggested here that the isotopic variation is associated to a rather specific tectonic setting in the broad eastern Aegean area. The extensive and deep faulting in the broad eastern Aegean lithosphere section would have facilitated the ascent of more mafic and isotopically depleted mantle-derived magmas.

KEY WORDS: Sr isotopic ratios, magma genesis, calc-alkaline volcanics, Aegean arc, Greece.

1. INTRODUCTION - GEOLOGICAL SETTING

The active volcanic arc of the south Aegean Sea is one of the structural elements of the Hellenic arc which is formed in response to the northeastward subduction of the Mediterranean seafloor of the African plate beneath Crete and the Southern Aegean. The main volcanic centres of the arc (Fig. 1), Aegina, Methana, Poros, Milos, Santorini, Kos and Nisyros, have their base on continental crust. The erupted lavas show a total range in composition from basalts to rhyolites.

The mineralogy, mineral chemistry and whole-rock geochemistry of lavas from the main volcanic centres of the arc have been studied in detail (MITROPOULOS et al., 1987; MITROPOULOS & TARNEY, 1992). According to those studies it is suggested that whereas the magma source for most of the lavas of the arc was rather refractory hornblende-bearing lithosphere, the magma source for Santorini lavas involved more fertile asthenosphere, uprising beneath the central part of the arc as a consequence of the greater degree of lithosphere extension in this part of the arc.

Just to the north of the Aegean volcanic arc mid-late Miocene granitoids, both of S- and I-type form a broad belt running northeasternwards 200 Km from Serifos. The majority of the Cyclades I-type granitoids

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consists of granodiorites and granites (Lavrium, Serifos, Naxos, Mykonos, Tinos, Ikaria) while monzonites and quartz diorites are the main rock types at the Eastern end of the arc (Samos, Kos). STOURAITI et al., (1997) have studied the petrogenesis of the Cyclades granitoids mainly on the basis of their isotope geochemistry.

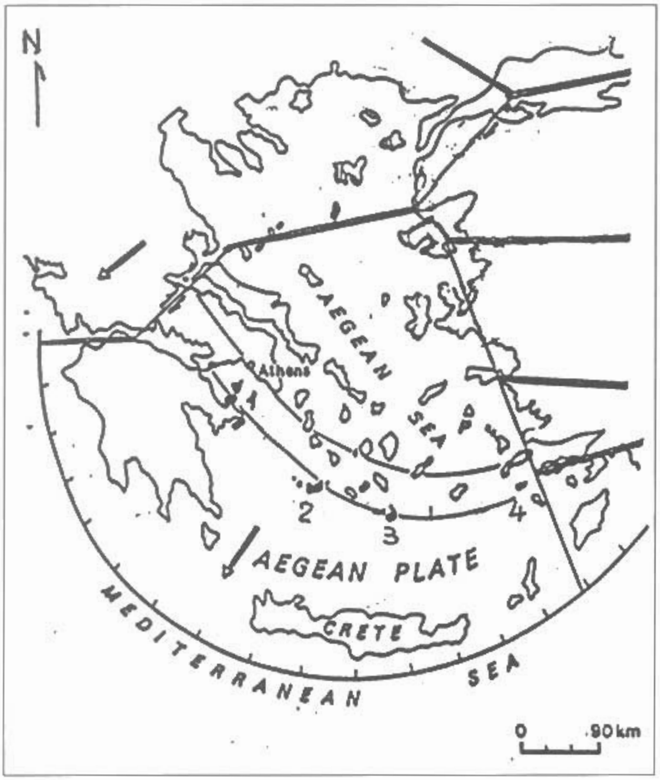

Fig. 1: Sketch structural map of the Aegean area (from BRIQUEU et al., 1986) also showing the main volcanic centres of the Aegean volcanic arc. (1: Aegina, Methana, Poros 2: Milos 3: Santorini 4: Kos, Nisyros)

A number of isotopic studies on the Aegean arc volcanics have been done by various researchers (BRIQUEU et al., 1986; GULEN, 1989) in order to define the magmatic processes at the various volcanic centres of the arc. On the basis of the new Sr isotope data for rocks from all the volcanic centres of the arc, presented in this paper, as well as the new isotope data of the Cyclades granitoids (STOURAITI et al., 1997)an attempt is made to define the along arc variations of the magma formation processes.

2. RESULTS

Strontium isotopic determinations were performed on a number of volcanic rocks from the main volcanic centres of the Aegean arc, namely Aegina, Methana, Poros, Milos, Santorini, Nisyros and Kos. The analysed rock samples (Table 1) are the same used for the study of the geochemistry and mineral chemistry of the arc lavas (MITROPOULOS et al., 1987; MITROPOULOS & TARNEY, 1992).

Strontium in the rock samples was separated by a conventional cation exchange technique. Strontium isotope ratios were determined using a MAT 262 mass spectrometer at Ocean Research Institute of University of Tokyo. Details on the analytical method used as well as on its precision and accuracy are given in NOTSU (1983).

3. DISCUSSION - CONCLUSIONS

New $^{87}Sr/^{86}Sr$ ratios of rocks from all the main volcanic centres of the Aegean Arc are given in Table 1. It is clear that there is a variation of the $^{87}Sr/^{86}Sr$ ratio along the arc. That variation is better shown as a plot of distance along the arc versus isotopic ratio in Fig. 2, where the new data are plotted along with those of BRIQUEU et al. (1986) and GULEN (1989). In the same plot the late Tertiary Cyclades granitoids $^{87}Sr/^{86}Sr$ which lie just to the north of the arc are presented (ALTHER, 1988; STOURATI et al., 1987), translated to their respective positions within the arc.

Table 1. $^{87}Sr/^{86}Sr$ ratios of rocks from all the main volcanic centres of the Aegean Arc. The sample location, the rock type and the K/Ar ages of the analysed samles are also given.

Sample No	Location	Rock type	K/Ar age (Ma)	$^{87}Sr/^{86}Sr$	Sr (ppm)
	SANTORINI				
SA-4	Megalo Vouno	Basaltic andesite	0.073	0.70403	183
SA-5	Megalo Vouno	Basaltic andesite	0.109	0.70493	188
SA-6	Megalo Vouno	Andesite	0.194	0.70488	195
SA-7	Megalo Vouno	Andesite	0.074	0.70491	193
SA-10	Akrotiri	Basaltic andesite	0.210	0.70471	184
SA-13	Mikros Profitis Ilias	Andesite	0.517	0.70633	231
	AEGINA				
AG-2	Marathon	Andesite	2.490	0.70567	598
AG-5	Profitis Ilias	Andesite	3.569	0.70601	309
AG-6	Perdika	Andesite	2.239	0.70573	414
	KOS				
KO-6	Vigla (Kephalos)	Dacite	2.542	0.70416	786
KO-7	Vigla (Kephalos)	Dacite	2.990	0.70422	780
	METHANA				
ME-3	Kammeno Vouno	Andesite	0.222	0.70632	256
ME-5	Megalo Chorio	Andesite	0.378	0.70671	331
	MILOS				
MI-1	Plaka Village	Dacite	0.980	0.70556	326
MI-3	Plaka Village	Dacite	1.141	0.70573	276
	NISYROS				
NI-1	South of Mandraki Village	Andesite	0.133	0.70477	396
NI-2	South of Mandraki Village	Andesite		0.70373	928
	POROS				
PO-1	Poros Village	Andesite	2.588	0.70576	353
PO-3	Poros Village	Andesite	2.603	0.7074	381

* K/Ar ages are from MITROPOULOS et al. (1997)

It is clear (Fig. 2) that the $^{87}Sr/^{86}Sr$ ratio of the volcanic rocks increases along the arc from east (0.704) to west (0.706). As the crustal thickness is lower in the central sector of the arc (Santorini) than in both the western and eastern sectors, it is apparent that the Sr isotopic ratio along the arc is not simply a function of the different crustal thicknesses manifest as crustal contamination in the different volcanic centres.

The $^{87}Sr/^{86}Sr$ ratio of the Cyclades granitoids also varies, but instead increases from west to east (Fig. 2). There is an increase from 0.710 at Lavrium to ~0.7135 at Ikaria, while Samos and Kos in the far east of the arc show low ratios (0.706 - 0.7075), completely departing from the trend. That variation of the $^{87}Sr/^{86}Sr$ ratio of the Cyclades granitoids is due to the different proportions of at least 3 source components which have been mobilised to form the bodies (STOURAITI et al., 1977) These end-member components are (1) a greywacke type metasediment, (2) a mafic enclave component and (3) a marble component. The increasing $^{87}Sr/^{86}Sr$ ratio from Lavrium to Ikaria is the result of the increasing involvement of metasediments. However the low $^{87}Sr/^{86}Sr$ ratios of Samos and Kos granitoids must be due to an enhanced lithosphere component, that may result from mantle enrichment processes. It is clear that that this component is dominant in the eastern Aegean with respect to the volcanics too.

The extensional regime in the southern Aegean has resulted in a thinning of the lithosphere as well as simultaneous upwelling of the asthenosphere. Decompression following the thinning of the lithosphere

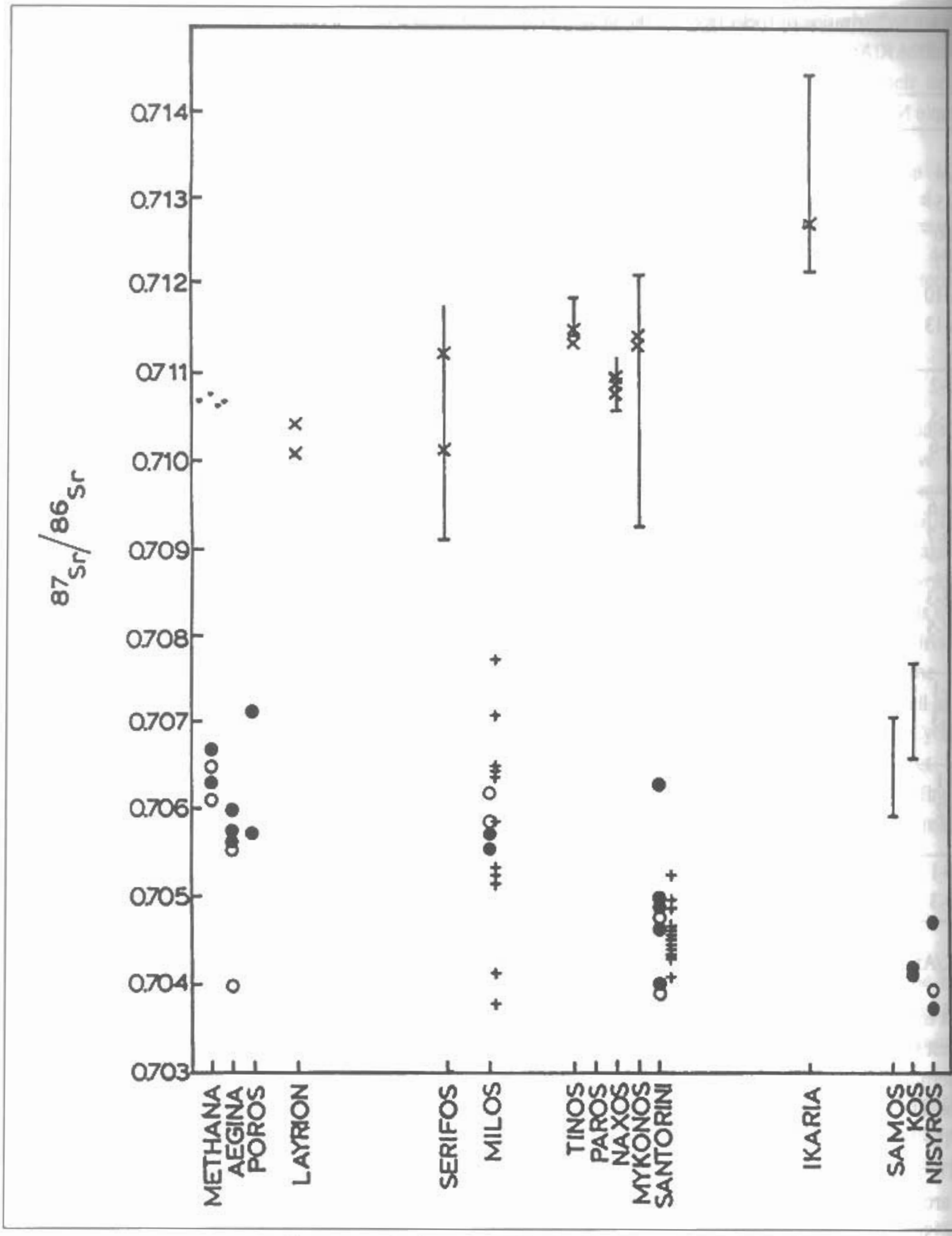

Fig. 2: Plot of relative position of the main volcanic centres along the arc versus strontium isotopic ratio. The new da ● are plotted along with those of BRIQUEU et al. (1986)(+) and GULEN (1989) (o). In the same plot the stronti isotopic ratios of the late Tertiary Cyclades granitoids which lie just to the north of the arc are also plotted (ALTHE 1988 (I); STOURATI et al., 1987 (x)), according to their respective positions within the arc.

leads to the melting of a LILE enriched lithosphere component. That is the first of the three end-memb components of the magma sources of the Aegean Arc volcanics. The second component is a deplete mantle asthenosphere component, and the third is a crustal component which might be equivalent to t high crustal components which dominates the compositions of the Cyclades granites. Mixing of various proportions of the three components could give rise to the characteristic compositions of the different volcanic centres in the Aegean Arc.

According to the $^{87}Sr/^{86}Sr$ ratio (as well as the Rb and Sr contents; MITROPOULOS et al., 1987), the volcanics of the western part of the arc contain higher proportions of crust component than those of the central and eastern sectors, while the involvement of the enriched mantle component is higher in the eastern part of the arc and the Turkish mainland, Minor Asia (ROBERT et al., 1992; GULEC, 1991).

ROBERT et al. (1992), working on the Upper Miocene potassic volcanics of Bodrum and Samos, suggest that the proportion of asthenophere (depleted-mantle) increases with time, in the eastern Aegean Plio-Quaternary volcanics. However, as shown from the K/Ar ages given in Table 1, the $^{87}Sr/^{86}Sr$ ratios do not vary with age at the eastern sector of the arc where Nisyros (0.133 Ma) and Kos (2.542-2.990 Ma) calc- alkaline volcanic rocks show similar $^{87}Sr/^{86}Sr$ ratios (Table 1). $^{87}Sr/^{86}Sr$ ratios also do not vary with age at the western sector of the arc where Methana (0.222-0.378 Ma) and Aegina (2.239-3.569 Ma) calc-alkaline volcanic rocks also show similar $^{87}Sr/^{86}Sr$ ratios (Table 1). Additionally, initial $^{87}Sr/^{86}Sr$ ratios of the youngest volcanics of the arc (Nea-Kameni; Briqueu et al., 1986) do not show any significant differences from the older Santorini volcanics, although the contribution of the depleted asthenospheric mantle is higher in Santorini than in the eastern and western sectors of the arc. It is consequently clear that the variation of the $^{87}Sr/^{86}Sr$ ratio in the calc-alkaline volcanic rocks of the Aegean arc do not seem to be time depended.

It has been shown (STOURAITI et al., 1997; ALTHERR et al., 1988: SATIR et al., 1986) that the granitoids of the eastern Aegean have a higher proportion of enriched mantle component relative to the western Arc magmatic rocks, as a result of the different tectonic regime of the areas. It is suggested here that the isotopic variation is associated to a rather specific tectonic setting in the broad eastern Aegean area, including Kos-Samos-Patmos and Bodrum, in a zone extending broadly in a N-S orientation, that is across the modern volcanic arc. It is well known, that the Aegean sea is one of the most rapidly extending areas of continental crust in the world (ANGELIER et al., 1982). On the one hand, most calc-alkaline volcanic centers of the south Aegean arc form stratovolcanoes, the location of which is controlled by extensional faulting (PAPAZACHOS & PANAGIOTOPOULOS, 1992). On the other hand eastern Aegean-western Turkey late Miocene-Pliocene age volcanic centers are spatially associated with graben systems of E-W orientation, as a result of N-S directed extension(ANGELIER et al., 1981; JACKSON et al., 1982). These grabens extend, with the same orientation, to the west in the Aegean sea and are bounded to the north by the North Anatolian Fault. Additionally, the chemistry of the eastern Aegean volcanic centers, which consist of high K-to ultrapotassic volcanics (e.g. Samos, Patmos) resemble other K-rich volcanoes associated with extensional collapse of orogens due to convective thinning of the underlying lithospheric mantle (PE-PIPER 1994; TURNER et al., 1993). The extensive and deep faulting in the broad eastern Aegean lithosphere section would have facilitated the ascent of more mafic and isotopically depleted mantle-derived magmas.

REFERENCES

ALTHERR, R., HENJES-KUNST, F.J., MATTHEWS, A., FRIEDRICHSEN, H. & HANSEN, B.T. 1988. *O-Sr isotopic variations in Miocene granitoids from the Aegean: evidence for an origin by combined assimilation and fractional crystallisation.* Contributions to Mineralogy and Petrology 100, 528-541.

ANGELIER, J., LYBERIS, N., LE PICHON, X., BARRIER, E. & HUCHON, P., 1982. The tectonic development of the Hellenic arc and the sea of Crete: a synthesis. Tectonophysics, 86: 159-196.

ANGELIER, J., DUMONT, J.F., KARAMADERESI, H., POISSON, A., SIMSEK, S. UYSAL, S. 1981. Analyses of fault mechanisms and expansion of southwestern Anatolia since the Late Miocene. Tectonophysics 75, T1

BRIQUEU, L., JAVOY, M., LANCELOT, J.R. & TATSUMOTO, M. 1986. Isotope geochemistry of recent magmatism in the Aegean arc: Sr, Nd, Hf, and O isotopic ratios in the lavas of Milos and Santorini - geodynamic implications. Earth and Planetary Science Letters 80, 41-54.

GULEC, N. 1991. Crust-mantle interaction in western Turkey; implications from Sr and Nd isotope geochemistry of Tertiary and Quaternary volcanics. Geological Magazine 128, 417-435.

GULEN, L. 1989. Isotopic characterization of Aegean magmatism and geodynamic evolution of Aegean subduction. In: Hart, S.R. & Glen, L. (eds) Crust/mantle recycling at convergence zones. NATO-ASI Series C258, 143-166.

JACKSON, J.A., KING, G. & VITA-FINZI, C. 1982. The neotectonics of the Aegean: and alternative view. Earth and Planetary Science Letters 61, 303-18.

MITROPOULOS, P., TARNEY, J., SAUNDERS, A.D. & MARSH, N.G. 1987. Petrogenesis of Cenozoic volcanic rocks from the Aegean Island Arc. Journal of Volcanology and Geothermal Research 32, 177-193.

MITROPOULOS, P. & TARNEY, J. 1992. Significance of mineralogical composition variations in the Aegean Island Arc. Journal of Volcanology and Geothermal Research 51, 283-303.

MITROPOULOS, P., MATSUDA, J., SENOH, K. & MARUOKA, T. (1997). Contribution to the study of the volcanic activity evolution in the Aegean arc, on the basis of new K/Ar age determinations of calc-alkaline lavas from the main volcanic centres. Anal. Geol. Pays Hellen.(In press).

NOTSU, K.(1983). Strontium isotope composition in volcanic rocks from the Northeast Japan arc. Journal of Volcanology and Geothermal Research 18, 531-548.

PAPAZACHOS, B.C. and PANAGIOTOPOULOS, D.G., 1992. Normal faults associated with volcanic activity and deep rupture zones in the southern Aegean volcanic arc. 6th Congr. Geol. Soc. Greece, Athens, May 25-27, 1992, p.89 (abstract).

PE-PIPER, G. 1994. Lead isotopic compositions of Neogene volcanic rocks from the Aegean extensional area. Chemical Geology 118: 27-41.

ROBERT, U., FODEN, J. & VARNE, R. 1992. The Dodecanese Province, SE Aegean: A model for tectonic control on potassic magmatism. Lithos 28, 241-260.

SATIR, M. & FRIEDRICHSEN, H. 1986. The origin and evolution of the Menderes Massif, W-Turkey: a rubidium/strontium and oxygen isotope study. Geologische Rundschau 75/3, 703-714.

STOURAITI, C., TARNEY, J., MITROPOULOS, P., BARREIRO, B. & BALTATZIS, E. 1997. Geochemistry and petrogenesis of late Miocene granitoids, Cyclades, southern Aegean: nature of source components. (submitted for publication).

TURNER, S., HAWKESWORTH, S., LIU, J., ROGERS, N., KELLEY, S. & VAN CALSTEREN, P., 1993. Timing of Tibetan uplift constrained by analysis of volcanic rocks. Nature, 364: 50-54.