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K-AR DATING OF THE SAMOTHRAKI VOLCANIC ROCKS, THRACE, NORTH-EASTERN AEGEAN (GREECE)

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ABSTRACT

K-Ar measurements were carried out on volcanic rocks of Samothraki Island, north-eastern Aegean Sea. The ages obtained, ranging from 27.5 to 18.9 Ma, are in agreement with stratigraphic evidence and petrologic data, according to which the volcanic rocks are divided into an old volcanic rock series (OVRS) and a young volcanic rock series (YVRS). The OVRS is of Late Oligocene-earliest Miocene age (27.5-22.7 Ma) whereas the YVRS, erupted in a relative narrower interval is of Early Miocene (22.3-18.9 Ma). The available radiometric ages confirm the suggestion that the Tertiary magmatic activity, which manifested in the Rhodope massif and the Aegean Sea, shifted successively southwards.

ΣΥΝΟΨΗ

Στην εργασία αυτή δίνονται ραδιοχρονολογήσεις ηφαιστειακών πετρωμάτων της νήσου Σαμοθράκης, οι οποίες έγιναν με τη μέθοδο K-Ar. Οι ηλικίες των ηφαιστειακών πετρωμάτων, που κυμαίνονται από 27.5 έως 18.9 εκ. έτη, είναι σε συμφωνία με στρωματογραφικά και πετρολογικά δεδομένα, βάσει των οποίων τα ηφαιστειακά πετρώματα διαιρούνται σε μία παλιά ηφαιστειακή σειρά πετρωμάτων και σε μία νέα ηφαιστειακή σειρά. Τα πετρώματα της παλιάς σειράς είναι ηλικίας Ολιγοκαίνου-κατώτατου Μειοκαίνου (27.5-22.7 εκ. έτη), ενώ εκείνα της νέας σειράς είναι κάτω μειοκαινικά. Οι υπάρχουσες ραδιοχρονολογήσεις επιβεβαιώνουν την άποψη ότι η Τριτογενής μαγματική δραστηριότητα, που εκδηλώθηκε στη μάζα της Ροδόπης και στο Αιγαίο πέλαγος, μετατοπίστηκε βαθμιαία από βορρά προς νότο.

INTRODUCTION

The volcanic rocks of Samothraki Island belong to the widespread Tertiary volcanism that affected the Rhodope massif and its southern margins, including the north and central Aegean area.

Based on stratigraphic evidence and geochronological data the volcanic activity started in the northern parts of the Rhodope massif during the Late Eocene (Pal'schin et al., 1974; Lilov et al., 1987; Dabovski et al., 1991) and successively migrated southwards to the central Aegean and western Anatolia,

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where it died out in the Middle Miocene (Fytikas et al., 1984).

The volcanic products, mainly of intermediate and acid composition belong to the calc-alkaline, high-K calc-alkaline and shoshonitic rock series. They are considered as the result of extension following the collision between the African and Eurasian plates (Dabovski et al., 1991 and references therein).

The volcanic activity in Samothraki Island started in the Late Eocene and ended before the Pliocene, as indicated by the presence of andesitic tuffs on Upper Eocene nummulitic limestones and the occurrence of volcanic pebbles underlying Pliocene marine deposits (Hoernes, 1874; Davis, 1963; Kopp 1964). Based on nummulitic fossils found in calcareous intercalations of a volcano-sedimentary sequence including andesitic tuffs, Christodoulou (1957) suggested, although with reserve, an Oligocene age for the above andesitic tuffs. Finally, on the geological map of Samothraki (Heimann et al., 1972) the above tuffs and generally the andesitic rocks are quoted as Upper Eocene and the acid rocks as Oligocene-Lower Miocene.

The purpose of this paper is to define more precisely the age of the Samothraki volcanic rocks by using the K-Ar method and thus to contribute to a better understanding of the Tertiary volcanism evolution in the broader area of the Rhodope massif.

GEOLOGICAL DATA

The Samothraki Island is located in the north-eastern Aegean Sea (Fig. 1) and is a constituent of the Circum-Rhodope Belt of Kauffmann et al. (1976).

Lithologically, five units have been distinguished in Samothraki; the basement, the ophiolites, the granites, the volcanic rocks and the Neogene to

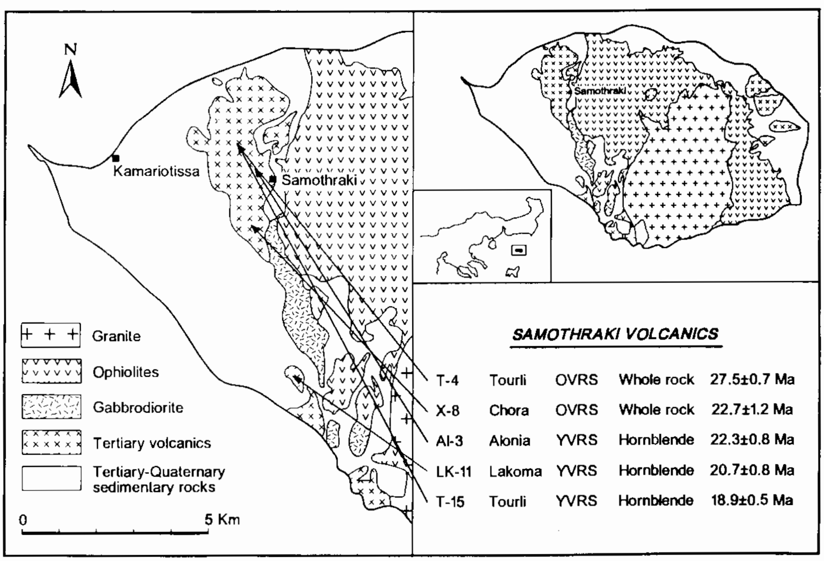

Fig. 1: Simplified geological map of Samothraki island after Heimann et al., (1972) and K-Ar age data from selected samples of the Samothraki volcanic rocks.

Σχ. 1: Απλοποιημένος γεωλογικός χάρτης της νήσου Σαμοθράκης κατά Heimann et al., (1972) και ηλικίες K-Ar από επιλεγμένα δείγματα ηφαιστειακών πετρωμάτων.

Quaternary formations.

The basement is a sequence consisting of an Upper Jurassic to Lower Cretaceous low grade metamorphic rock series comprising argillaceous and quartzose slates, schistose greywackes and marbles (Davis, 1963; Kopp, 1964; Heimann, 1967; Heimann et al., 1972; Tsikouras et al., 1990).

The basement is intruded by the ophiolites which in some cases are in tectonic contact with it and which are more or less epizonally metamorphosed. No ultrabasic members have been found. From the lower to the upper part this unit consists of cumulitic gabbros passing upwards into non-cumulitic ones, pillow basalts and diabases, and dolerite dykes cutting the previous rocks. In some cases above the gabbros hornblende diorites comprise a complicated unit (the "gabbrodiorites" of Heimann et al., 1972 or the "dioritic veins network" of Tsikouras et al., 1990). The age of these diorites is 155 Ma (Tsikouras et al., 1990).

The granite occupies the central eastern part of the island. It intrudes the ophiolites and the basement rocks causing thermal metamorphism. It is a normally zoned metaluminous calc-alkaline intrusion of Miocene age (Kyriakopoulos, 1987) with a porphyritic quartz-monzonitic marginal zone and a granitic core. The origin of his granite was subduction related and its evolution was controlled by fractional crystallization (Christofides et al., 1990).

The lower north-east, west and south-west slopes of the island are covered by Tertiary volcanic rocks in the form of domes, dykes, lava flows and abundant pyroclastic formations mainly of andesitic composition.

Finally, the stratigraphy of Samothraki Island is completed by Neogene and Quaternary formations that occupy the west and south-west parts of the island.

PETROGRAPHY

The Samothraki volcanic rocks show a wide spectrum of petrographic types ranging from basalts to dacites through basaltic andesites, andesites, latites and trachytes.

Based on stratigraphic and geochronological data, Eleftheriadis et al. (1989) discriminated two cycles of volcanic activity and consequently two rock series, i.e., an old volcanic rock series (OVRS), with a calc-alkaline and high-K calc-alkaline trend and a young volcanic rock series (YVRS), with a high-K calc-alkaline and shoshonitic trend.

The OVRS consists of basalts, high-K basaltic andesites, andesites, high-K andesites and latites as well as abundant pyroclastic materials, some of which interbed with Upper Eocene sedimentary rocks. Texturally the lavas are slightly porphyritic to subaphyric, consisting mainly of plagioclase and clinopyroxenes. Pseudomorph phenocrysts of serpentine after olivine in the more mafic rocks occur whereas in the acid ones biotite and hornblende. Generally, the rocks of the old series are variably altered, containing significant amounts of kaolinite, sericite, iron oxides and carbonates.

The YVRS, which intrudes Upper Eocene sediments and volcanoclastic materials of the old series and/or include pieces of the latter rocks, consist of latites, trachytes and high-K dacites. All these rocks show porphyritic texture and prismatic megaphenocrysts of sanidine (up to 10cm in length) and idiomorphic phenocrysts of quartz. Besides, there are phenocrysts of plagioclase, biotite and hornblende, as well as subordinate amounts of clinopyroxenes, set in a partly or entirely glassy groundmass.

GEOCHEMISTRY

Between the two volcanic rock series of the Samothraki Island there are small but distinct geochemical differences (see Eleftheriadis et al., 1993).

Table 1: Chemical composition of selected volcanic rocks from Samothraki island dated with the K-Ar method.

Πιν. 1: Χημική σύσταση επιλεγμένων ηφαιστειακών πετρωμάτων της νήσου Σαμοθράκης τα οποία χρονολογήθηκαν με τη μέθοδο K-Ar.

	OVRS		YVRS		
	X-8	T-4	T-15	LK-11	AL-3
SiO2 (wt%)	48.90	57.10	61.00	64.30	65.10
TiO2	1.17	0.65	0.72	0.49	0.36
Al2O3	17.70	17.50	14.70	15.20	15.10
Fe2O3	10.30	5.33	5.17	3.95	3.39
FeO	0.00	0.00	0.00	0.00	0.00
MnO	0.45	0.15	0.11	0.10	0.08
MgO	2.83	1.43	2.73	1.75	1.97
CaO	10.00	6.47	4.42	3.74	3.81
Na2O	4.05	4.20	3.21	3.75	3.76
K2O	0.51	4.01	4.87	4.31	3.88
P2O5	0.28	0.28	0.70	0.42	0.20
L.O.I.	3.90	2.45	2.10	1.85	2.50
Total	100.09	99.57	99.73	99.86	100.15
Ba (ppm)	366	773	2872	2081	1271
Rb	12	123	168	175	175
Sr	802	471	941	1370	641
Y	34	27	24	25	15
Zr	139	205	445	356	198
Nb	0	7	20	22	12
Th	0	16	29	47	25
Pb	15	29	64	84	61
Ga	18	17	18	19	18
Zn	81	87	61	62	47
Cu	49	90	21	19	15
Ni	7	6	11	6	9
V	274	146	100	101	72
Cr	0	0	12	11	14

OVRS: old volcanic rock series; YVRS: young volcanic rock series

Thus, the silica content of the OVRS ranges from 50.2 to 63.0 wt% while that of the YVRS from 57.0 to 70.8 wt%. The P_2O_5 and the K_2O content are clearly higher in the YVRS than the OVRS, reflecting, according to Green & Watson (1982), the more high-K calc-alkaline character of the former rocks.

Significant differences between the old and the young volcanic series occur also in the abundances of some trace elements such as Ba, Rb, Zr, Nb, Y and LREE, which are comparatively higher in the younger series.

The volcanic rocks studied belong, generally, to the calc- alkaline rocks series of continental margins as is shown by their geochemical characteristics [($FeO+Fe_2O_3$)/MgO, K_2O/Na_2O, K/Rb, Ba/Sr and LILE/HFSE ratios, Pearce's (1982) spider diagrams] (cf. Eleftheriadis et al., 1989; 1993)

The parental magmas of both volcanic rock series were generated by partial melting of an "enriched" upper mantle source region, with the YVRS being derived by lower degrees of partial melting (Eleftheriadis et al., 1993). The two series evolved mainly through fractional crystallization, although disequilibrium mineral phases shown in the YVRS (Esson et al., 1990) could alternatively be explained by magma mixing processes.

activity in Samothraki started earlier than 27.5 Ma. This suggestion is in good agreement with the presence of tuffs on Upper Eocene nummulitic limestones (Hoernes, 1874; Kopp, 1964; Heimann et al., 1972) and the aspect of Christodoulou (1957) for a probable Oligocene age of these tuffs.

Table 2: K-Ar ages of selected volcanic rocks from Samothraki island.
Πιν. 2: Ηλικίες K-Ar επιλεγμένων ηφαιστειακών πετρωμάτων της νήσου Σαμοθράκης.

Sample	Rock type	Material	K%	^{40}K ppm	^{40}Ar ppm	$^{40}Ar/^{40}K$	Age Ma (±1σ)
OVRS							
X-8	Basalt	WR	0.368	0.439	0.000582	0.001326	22.7±0.7
T-4	Latite	WR	3.319	3.959	0.006367	0.001608	27.5±0.7
YVRS							
T-15	Latite	HB	7.447	8.884	0.009811	0.001104	18.9±0.5
LK-11	Trachyte	HB	0.722	0.861	0.001044	0.001212	20.7±0.8
AL-3	High-K dacite	HB	0.803	0.957	0.00125	0.001306	22.3±0.8

WR: Whole rock; HB: Hornblende

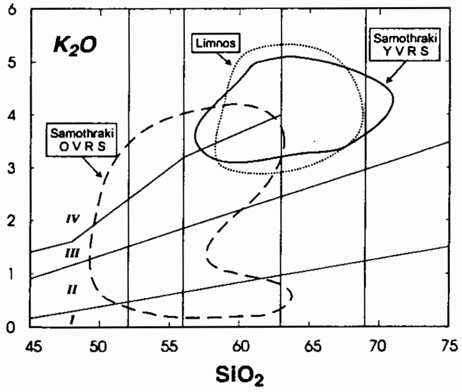

Fig. 2: K_2O vs. SiO_2 variation diagram (after Peccerillo and Taylor, 1976) for the Samothraki (Eleftheriadis et al., 1993) and Limnos (Innocenti et al., 1993) volcanic rocks.
(I) arc tholeiite, (II) calc-alkaline, (III) high-K calc-alkaline, (IV) shoshonite series.

Σχ. 2: Διάγραμμα K_2O-SiO_2 (κατά Peccerillo and Taylor, 1976) για τα ηφαιστειακά πετρώματα της Σαμοθράκης (Eleftheriadis et al., 1993) και της Λήμνου (Innocenti et al., 1993).
(I) θολεϊτική σειρά, (II) ασβεσταλκαλική σειρά, (III) πλούσια σε K ασβεσταλκαλική σειρά, (IV) σωσονιτική σειρά.

The chemical composition of the samples analysed by the K-Ar method are given in Table 1.

DISCUSSION

The radiometric ages of the Samothraki volcanic rocks, obtained by the K-Ar method on representative samples, range from 27.5 to 18.9 Ma (Table 2).

The oldest and the youngest ages were determined on samples T-4 and T-15, of latitic composition, belonging to the old and the young volcanic rock series respectively. Both samples have been collected from the hill Tourli, NW of Samothraki (Chora), (Fig. 1). The Tourli hill consists in its basement of unsorted to well sorted volcanoclastic materials of the OVRS into which the lavas T-4 are interbedded. This formation is overlain by the young lavas T-15. The above relations show that the radiometric dating is in agreement with the stratigraphic evidences.

On the basis of the relative thickness of the volcanoclastic materials, underlying the lavas of the sample T-4 we can suppose that the volcanic

A Late Eocene (?)-Early Oligocene age has been also suggested (Innocenti et al., 1993) for a tuff layer 1-6m thick found in Limnos Island, south-south-west of Samothraki, overlying an Upper Eocene sedimentary sequence (sandstones and siltstones). According to the above authors, the age of the tuffs corresponds with the onset of the calc-alkaline volcanic activity in the Rhodope massif.

On account of the 22.7 Ma age, obtained on the sample X-8, that is considered to belong to the OVRS, results that the volcanic activity of the first cycle must have continued until the latest Oligocene-earliest Miocene. The emitted products during the last phases of this cycle are volumetrically very limited.

As regards the volcanic activity of the second cycle it started and died out in Lower Miocene; that is it took place in a relative short interval (between 22 and 19 Ma; Table 2). This cycle coincides approximately with the volcanic activity manifested in Limnos between 21 and 18 Ma (Innocenti et al., 1993) which gave volcanic products similar with those of Samothraki, being mainly of a high-K dacitic nature (Fig. 2).

During the early Miocene, Samothraki was also affected by a plutonic activity resulted in the creation of intrusive rocks (Davis, 1963; Kyriakopoulos, 1987; Christofides et al., 1990).

The age of the Tertiary magmatic activity of Samothraki is younger than that of Thrace (southern Rhodope massif), which ranges from 35 to 23.6 Ma (Eleftheriadis & Lippolt, 1984; Innocenti et al., 1984) and older than that of the islands of Limnos, Ag. Efstratios and Lesvos (central north-eastern Aegean), which varies between 23.2 and 17.3 Ma (Borsi et al., 1972; Fytikas et al., 1979, 1984; Pe-Piper, 1980; Pe-Piper & Piper, 1993).

Summarising, we can say that the geochronological data obtained on the Samothraki volcanic (this paper) and the plutonic rocks (Kyriakopoulos, 1987) are consistent with the general aspect that the Tertiary magmatism manifested in the Rhodope massif and the Aegean area shifted successively southwards.

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