PETROLOGY AND INTERPRETATION OF THE ORIGIN OF QUATERNARY VOLCANICS IN THE DATÇA PENINSULA

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ABSTRACT. — Volcanic materials such as tuffs, pumice and lava fragments are observed in the Late Quaternary sediments occurring in the Datça Peninsula, SW Turkey. The petrological characteristics and regional extents of these volcanic rocks lead to the conclusion that they are aerially transported deposits of powerful volcanic eruptions that took place in the Nysiros island, situated some 18 km. W of the peninsula, probably 40 000-50 000 years ago. The volcanic island of Nysiros forms the easternmost end of an active Plio-Quaternary island arc in the Aegean sea. The volcanic products of the Dat9a Peninsula and the Nysiros volcanic island exhibit identical petrological and geochemical properties and typical calc-alkaline characteristics.

INTRODUCTION

The Dat9a peninsula covers an area of 500 km^2 in SW Anatolia, being 70 km in length and at the most 15 km in width. The first detailed geological work on the peninsula is that of Phillipson (1915). Chaput (1936, 1955) carried out detailed palaeontological work while Kaaden and Metz (1954) were more concerned with the Palaeozoic and Mesozoic basement rocks of the peninsula. Tintant (1954) investigated the abundant Pliocene fauna and Kaaden (1960) studied the ultrabasic rocks. More recent works are those of Rossi (1966) and Orombelli et al. (1967) who prepared detailed geological maps and shed light on the stratigraphic succession and of Ercan et al. (1980, 1982) who made detailed studies on the stratigraphy of the Plio-Quaternary sediments of the peninsula.

GENERAL GEOLOGY

Dolomitic limestones, roughly 1700 m. thick, form the lowermost units of the studied area. Rossi (1966) and Orombelli et al. (1967) term the formation as the «Yelimlik limestone» and determine the age as Upper Triassic-Lias. The formation is overlain by the «Şarıabat radiolarite» which is of 40-50 m. thickness and composed of interbeded radiolarite, marl and chert. The next formation up in the succession is the «Kurudağ Marl», 70 m. thick and made up of marls and marly limestones. The «Mandalya Formation» overlies the Kurudağ Marl and is constituted by the Tithonian-Lower Maastrichtian age cherty limestones of approximately 500 m. thickness. This formation is followed by the upper Maastrichtian-Eocene «Datça Flysch». The sediments of the f lysch contain older blocks of limestones and ultrabasic rocks. The succession in the peninsula continues with continental sediments.

Conglomerates which are entirely formed of pebbles of peridotite and serpentinised peridotite and deposited in an alluvial fan environment are found to the south of Kızıldağ in the studied area (Fig. 1) and to the east, outside the studied area, at the flanks of the hills formed of ultrabasic rocks around the bay of Hisarönü. They are at the most 100 m. thick and devoid of fossils and probably of Upper Oligocene or Lower Miocene age. The later deposits in the peninsula are the Pliocene continental and marine sediments (Ercan et al., 1980, 1982) on top of which the Quaternary river terrace deposits, cemented or loose slope scree, alluvials and aerially transported volcanic products present outcrops.

VOLCANISM

The volcanic rocks of the Dat9a peninsula have drawn the attentions of many workers for a long time. Deposits of the volcanic products (tuffaceous beds comprising lava 2nd pumice fragments) are observed around the antique city of Knidos at the western end of the peninsula and to the east in the area defined by the villages of Çeşmeköy-Belemköy, Yazıköy and Cumalı. They are immediately below the recent alluviums and up to 30 m. thick. These deposits probably accumulated in depressions on the peninsula, being aerially transported from volcanic centres on the islands of Nysiros and Yelli in the west of the peninsula during forceful explosions.

The volcanism on the Nysiros and Yelli islands have been studied for a long time. These volcanic islands are situated 18 km. from the antique city of Knidos which is at the western extreme of the peninsula. Figure 2 shows the Aegean islands around the peninsula where the volcanic outcrops are marked with dark colours. The islands of Nysiros and Yelli and the western end of the Kos island are the centres of volcanic explosions and form the easternmost sector of the island arc in the Aegean Sea (Fig. 3). The volcanism is a product of the subduction of the African plate under the Aegean-Anatolian plate at thesouthern side of the island of Crete. The subduction probably started in the Middle Miocene and has been causing a calc-alkaline island-arc volcanism for approximately the last three million years. Various geological and geophysical works related to the subduction and the associated volcanism in the Aegean Sea and the islands carried out by different workers have recently been compiled by Ercan (1979, 1980, 1981).

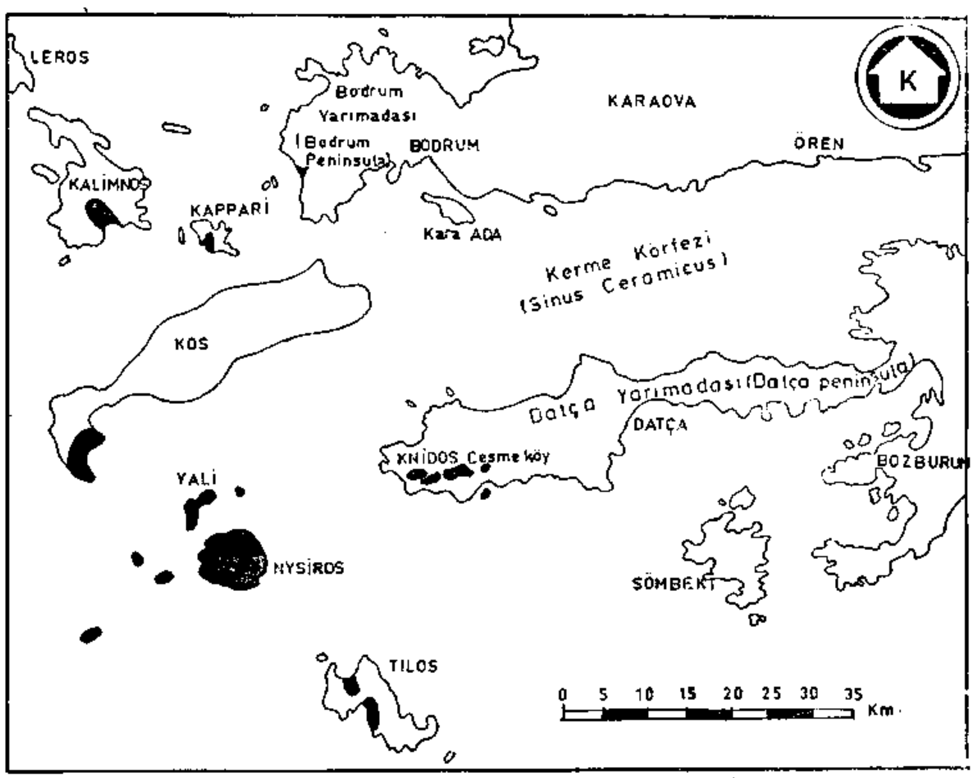

Fig. 2 - Quaternary island arc volcanism at and around the Nysiros island.

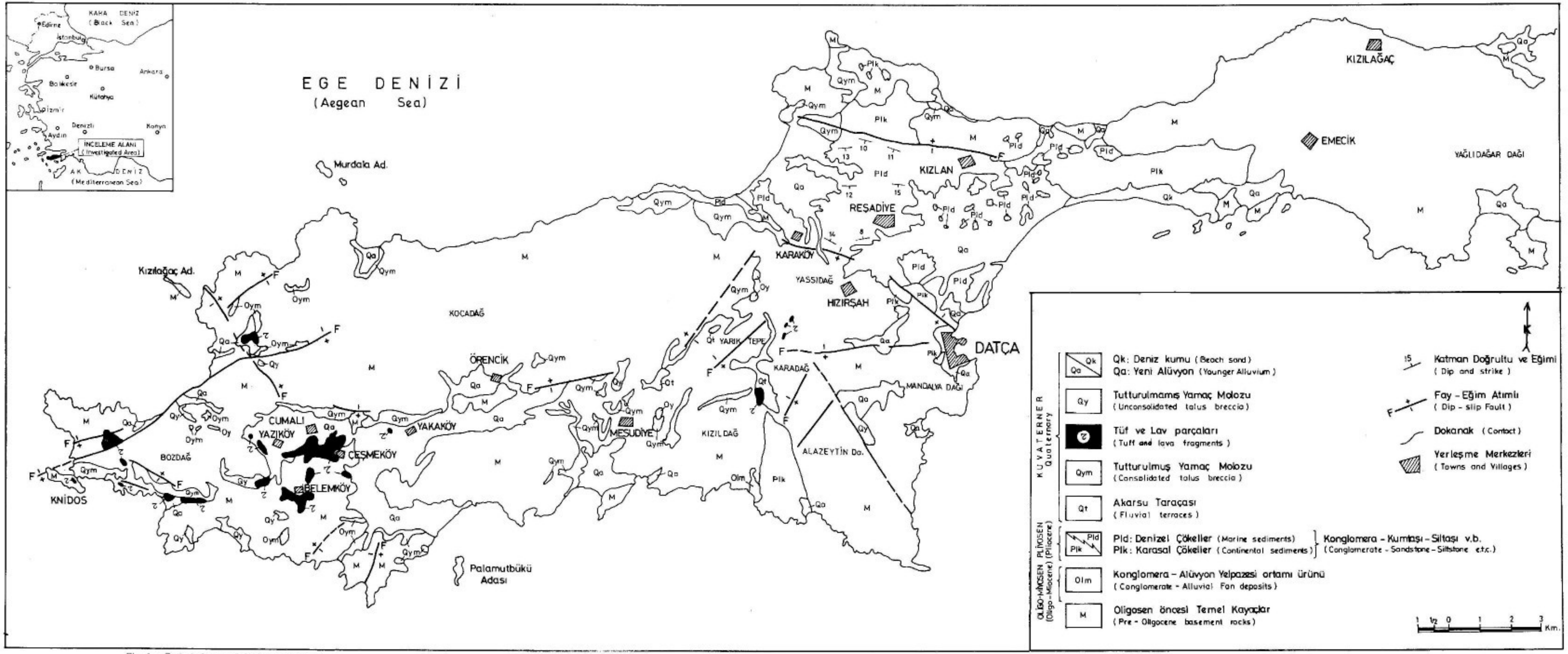

Fig. 1 - Geological map of the Datça peninsula.

Fig. 3 - The active subduction zone and the resulting system of island arc volcanism in the Mediterranean.

The volcanics originating from the active subduction zone in the Aegean Sea demonstrate a double volcanic arc. The southern external arc is formed by the volcanic islands of Crommyonia, Aegina, Methana, Porbs, Milos, Santorini, Khristiana, Anidhros, Nysiros and Yelli and the northern internal arc by the islands of Porphyrion, Thebes, Zileria, Achilleion, H. loannis, Antiporos and Kos (Fig. 3). The subduction zone which staftefl forming around 12 m.y. ago produced its first volcanic material probably 3 m.y. ago (the Milos islands). The volcanism is still active today (the Santorini islands). Petrochemically, the lavas from all the islands present a typical calc-alkaline trend of evolution with basalts, andesites, dacites and rhyolites. The only active volcano in the Aegean island arc system is in the Santorini islands and the most recent activity was recorded in 1950. The other recent and known volcanic activities on the islands are those of Methana (250 B.C.) and Nysiros (1888). The volcanism in the Nysiros and Yelli islands was initially submarine and gradually built up the islands with volcanic products such as lava, tuff, ash, pumice, perlite and obsidian. The Nysiros and Yelli islands are made up totally of volcanic material and the age of the oldest lavas on the.Nysiros island has been determined as 200 000 years (Di Paola, 1974).

The volcanism on the Nysiros island has gone through a few stages but on the whole two main stages. The first stage is identified by submarine pre-caldera volcanic activities which generated pillow lavas and lavas with low to intermediate silica contents and generally basaltic andesite and andesitic compositions. In places, tuffs and scoria are observed. The second main stage is recognised as the post-caldera activities (Davis, 1968) and produced mainly more acidic lavas (dacite, rhyodacite and rhyolite), pumice, perlite, obsidian and tuffs. The post-volcanic activities on the Nysiros island still continues with fumaroles, H_2S fumes and hot springs with much sulphur precipitation. Petrochemically all the volcanic products in the Nysiros and Yelli islands are of calc-alkaline nature.

It is likely that, there were powerful enough volcanic explosions on the Nysiros island about 40 000-50 000 years ago, during the second main stage of volcanism i.e. the post-caldera stage to bring about the scatter and transportation of abundant volcanic material such as fragments of lava and pumice, volcanic bomb, lapilli, tuff and ash by aerial means for many kilometers. Such volcanic materials also reached and fell upon the Dat9a peninsula, some 18 km. to the east of the island, and formed tuff deposits up to 30-40 m. thick. Initially, a major portion of the west of the peninsula was covered with these deposits. However, in time they were largely eroded away by the action of running water and only those which originally filled the topographic depressions have survived till today. The remains of the deposits are now covered with thin recent alluvium. They are basically tuffs and in places comprise fragments of lava and pumice. The deposits are hardened by the action of rain and running water particularly around the villages of Çeşmeköy and Belemköy (Fig. 1) and at the sides of the banks of the stream Tavas Dere that runs in between the villages where the thickness of the deposits is around 30-40 m. In this region where the deposits demonstrate their maximum thickness they exhibit horizontal beds of different colours and grain sizes and this may provide evidence to suggest that they did not come to being due to a single explosion on the Nysiros island but a series of different outbreaks of volcanic explosions. They are so young as fossil soil has been observed at lower levels around the Tavas Dere stream. The fact that the content of the deposits gradually changes from fine ash to coarse ash then to lapilli and volcanic blocks i.e. increasing grain size and as well as the increase in the volume of the volcanic material from the centre of the peninsula towards the ancient city of Knidos in the west strongly suggests that they came from the Nysiros island. There is no volcanic centre on the Datça peninsula and the largest lava fragments are around Knidos where they may be upto 50 cm. across.

THE PETROLOGY OF THE DATÇA VOLCANICS

Thin section studies of the lava samples taken from within the tuff deposits revealed that they are mostly andesitic and dacitic and show hyalopilitic textures with phenocrysts of plagioclase, hornblende, augite and biotite in a matrix composed of microliths of plagioclase, hornblende and pyroxene and of volcanic glass. The plagioclase phenocrysts are predominantly of labradorite and rarely of andesine composition. The biotites show traces of opaque minerals along the cleavage planes.

The samples contain very little quartz. Zeolites as the secondary mineral formations are found in some of the samples. The pumice is composed of crystals of biotite, plagioclase, quartz and sanidine embedded in a matrix of volcanic glass. Biotites are sometimes bent. The size of the quartz grains may reach up to 1 cm. The tuffs exhibit the same properties.

Chemical analyses of 11 lava samples and 4 tuff and pumice samples were carried out in the Faculty of Earth Sciences, the Aegean University and are presented in Table 1.

The Rittmann parameters (Al, Alk, Fm, K, an, P) are calculated and the appropriate nomenclature for the samples are determined following Rittmann (1952). Accordingly, the samples are termed as Nepheline Phonolite-Trachyte-Latite-Trachyandesite-Dacite-Rhyodacite and Rhyolite. The first 11 samples are of lava and volcanic bombs and the last 4 samples (TM-79-218, TM-79-219, TM-79-220 and TM-79-229) are of pumice and tuffs.

The samples contain widely varying SiO_2 contents, from 54.5 % to 75.17 %. All the members of the calc-alkaline rock series are present. $A1_2O_3$ content varies a great deal from 11.75 % to 21.49 %. Total Fe-oxides range from 1.03 % to 8.7 %. CaO content is in the range 0.04-4.53 %. The K_2O content which varies from 2.12 % to 3.87 % is slightly higher in the basaltic andesite and andesitic lava samples with lower SiO_2 content (the first 4 samples). Sim larly the Na_2O content which ranges from 3.92 % to 9.26 % and is relatively very high in the first 4 samples (TM-79-232/A, TM-79-225, TM-79-223 and TM-79-232/B). The reason why the first 4 samples contain high concentrations of the alkalis (Na_2O and K_2O) is the zeolite crystals that they contain since zeolites are hydrothermally formed minerals rich in alkalis. Although these samples in fact are of basaltic andesite and andesitic nature (as determined by Di Paola (1974) for all the lower silica lavas from the Nysiros and Yelli islands) they are given the apparent names such as nepheline phonolite, latite and trachyte according to the Rittmann norms due to their high K_2O and Na_2O contents (Fig. 1). The chemical analyses plot into the alkaline field in the appropriate diagrams. In reality, all the volcanics are calc-alkaline.

The volcanics generally plot into the delimited calc-alkaline fields of the alkali (Na_2O+K_2O) and SiO_2 discriminant diagrams designed by Irvine and Baragar (1971), Macdonald and Katsura (1964) and Kuno (1960). In these diagrams the first 4 samples, which are altered and in which the alkali contents are high due to secondary clay mineral formations, plot into the alkaline fields (Fig.4).

The samples mostly fall into the calc-alkaline and some into the alkaline region in the An-SiO_2 diagram of Rittmann (1953).

When the Rittmann indices (s) of the samples [$s = (Na_2O+K_2O)^2 / (SiO_2-43)$] are calculated, it becomes apparent that the zeolite-containing first 4 samples exhibit alkaline characteristics since the index values are rather high (5.36-10,6-11,52 and 11.58). The other samples present normal Rittmann index values for the calc-alkaline rock types. In fact, the same observation is made in the Rittmann (1962) diagram.

A chemical classification of the analysed samples is also attempted by the diagram proposed by Barberi et al. (1974) based on K_2O and SiO_2.contents in which the samples are given the names Andesite-Dacite and Rhyolite. The zeolite-containing first 4 samples again occupy the Latite and Trachyte fields (Fig. 5).

Similarly, the chemical analyses of the samples plot into the Andesite-Trachyandesitc-Rhyolite fields in the alkali-SiO_2 diagram suggested by Cox et al. (1979), while the samples with zeolites fall into the phonolite field due to their high alkali content (Fig. 6).

Sample no. and location	*TM-79 232/A Tavasdere*	*TM-79 225 Knidos*	*TM-79 223 Knidos*	*TM-79 232/B Tavasdere*	*TM-79 224 Knidos*	*TM-79 221/A Tavasdere*	*TM-79 231/A Tavasdere*	*TM-79 221/B Tavasdere*	*TM-79 226 Bozdağ*	*TM-79 227 Bozdağ*	*TM-79 231/B Tavasdere*	*TM-79 220 Tavasdere*	*TM-79 229 Belemköy*	*TM-79 218 Çeşmeköy*	*TM-79 219 Tavasdere*
SiO_2	54.40	54.96	57.43	58.60	60.57	60.76	60.78	61.89	62.09	63.19	64.18	71.83	72.85	73.32	75.17
Al_2O_3	17.35	16.51	17.47	16.64	14.91	17.15	20.37	19.98	17.87	21.49	19.91	15.38	14.65	14.60	11.75
Σ Fe_2O_3	5.66	6.47	7.63	4.90	8.70	5.14	5.35	4.42	5.02	4.72	3.24	1.29	1.03	1.06	1.10
MgO	4.14	4.33	3.28	2.10	2.59	2.85	1.59	2.54	2.36	0.36	1.65	0.45	0.45	0.30	0.17
CaO	4.53	4.53	3.96	3.29	2.79	3.46	3.39	4.16	4.51	1.54	3.31	0.39	0.04	0.09	0.43
Na_2O	7.86	8.14	5.23	9.26	4.96	5.42	4.60	3.90	3.42	3.78	4.24	3.99	3.61	3.78	5.28
K_2O	3.63	3.60	3.57	3.60	2.72	2.46	2.55	2.18	2.12	2.55	2.21	3.87	3.82	3.78	2.72
TiO_2	1.15	0.92	1.11	0.59	1.40	1.14	0.63	0.60	0.73	0.52	0.73	0.27	0.12	0.33	0.16
P_2O_5	0.32	E	E	0.11	0.19	0.17	0.21	E	0.14	E	0.26	E	0.16	E	E
Loss of ignition	1.04	0.58	0.42	0.59	1.01	1.24	0.95	0.55	0.98	0.90	0.60	2.82	2.18	2.06	2.83
Total	**100.08**	**100.09**	**100.10**	**99.69**	**99.84**	99.79	100.42	**100.22**	**99.24**	**99.05**	**100.33**	**100.29**	**98.91**	**99.32**	**99.61**
Al	15.61	14.85	15.72	14.97	13.41	15.43	18.33	17.98	16.08	19.34	17.91	13.84	13.18	13.14	10.57
Alk	15.42	15.81	11.41	17.49	10.16	10.59	9.45	8.43	7.05	8.22	8.57	9.85	9.23	9.45	10.64
FM	13.94	15.13	14.19	9.10	13.88	10.84	8.53	9.50	9.74	5.44	6.54	2.19	1.93	1.66	1.44
K	0.23	0.22	0.31	0.20	0.26	0.23	0.26	0.27	0.29	0.31	0.25	0.39	0.41	0.40	0.25
An	0.006	-0.03	0.15	-0.07	0.13	0.18	0.31	0.38	0.37	0.40	0.35	0.16	0.17	0.16	0.003
P	38.08	36.82	48.81	36.91	50.27	53.46	61.38	66.84	66.43	69.50	67.38	61.77	63.37	63.05	52.61
Rock name accord to Ritman	**Nepheline phonolite**	**Nepheline phonolite**	**Latite**	**Alcaline trachyte**	**Trachy-andesite**	**Trachy-andesite**	**Dacite**	**Dacite**	**Rhyo-dacite**	**Labra-dorite rhyodacite**	**Rhyo-dacite**	**Rhyo-lite**	**Rhyo-lite**	**Rhyo-lite**	**Sodre rhyolite**
σ	11.58	11.52	5.36	10.60	3.35	3.49	2.87	1.95	1.60	1.98	1.96	2.14	1.84	1.88	1.98
τ	8.25	9.09	11.02	12.50	7.10	10.28	25.03	26.80	19.79	34.05	21.46	42.18	92.00	32.78	40.43
Log σ	1.06	1.06	0.72	1.02	0.52	0.54	0.45	0.29	0.20	0.29	0.29	0.33	0.26	0.27	0.29
Log τ	0.91	0.95	1.04	1.09	0.85	1.01	1.39	1.42	1.29	1.53	1.33	1.62	1.96	1.51	1.60
K_2O/Na_2O	0.46	0.44	0.68	0.38	0.54	0.45	0.55	0.55	0.61	0.67	0.52	0.96	1.05	1.00	0.51
K_2O/SiO_2	0.066	0.065	0.062	0.061	0.044	0.040	0.041	0.035	0.034	0.040	0.034	0.053	0.052	0.051	0.036
Rock name accord to Barberi et al.	**Latite**	**Latite**	**Latite**	**Trachyte**	**Andesite**	**Andesite**	**Andesite**	**Andesite**	**Andesite**	**Dacite**	**Dacite**	**Rhyolite**	**Rhyolite**	**Rhyolite**	**Rhyolite**

Table 1 - Chemical analyses, Rittmann norms and various parameters of the Datça volcanics.

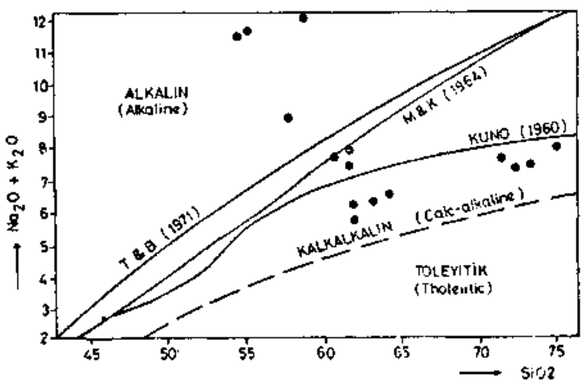

Fig. 4 - Classification of the volcanics based on their Na_2O+K_2O and SiO_2 contents.

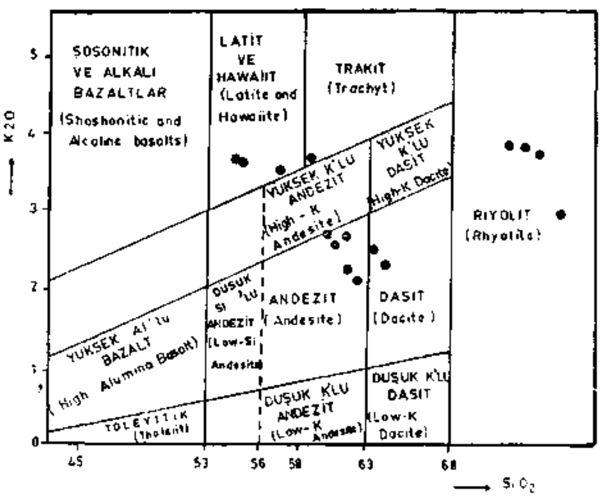

Fig. 5 - Nomenclature of the volcanics according to Barberi et al. (1974).

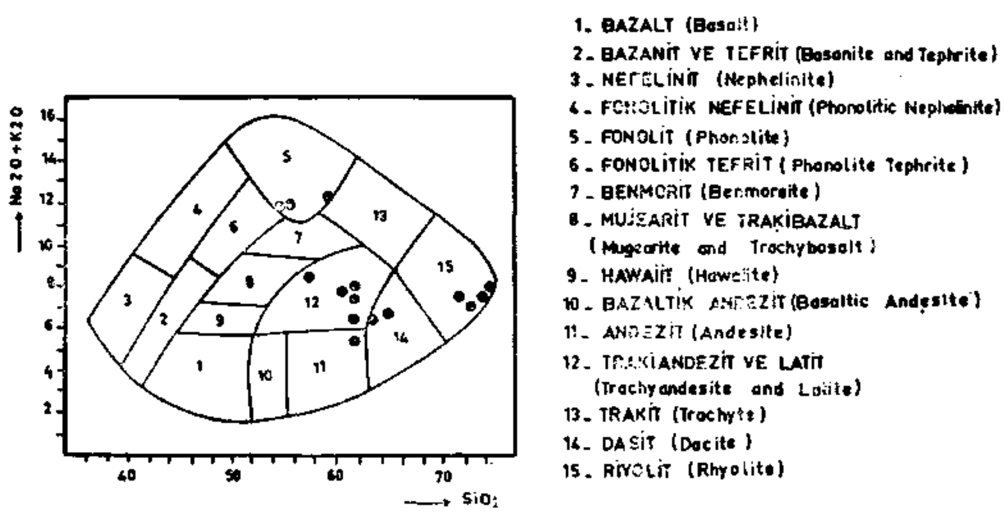

Fig. 6 - Nomenclature of the volcanics according to their alkali and silica contents.

The K_2O/Na_2O ratio of the samples is approximately in the range 0.40-1.00. The Di Paola (1974) diagram based on K_2O/Na_2O ratios and SiO_2 contents define the samples by the names low silica-andesite, dacite and rhyolite (Fig. 7).

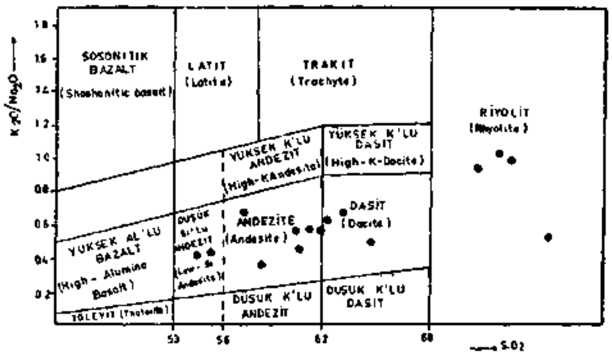

Fig. 7 - Nomenclature of the volcanics based on K_2O/Na_2O ratios and SiO_2 contents.

The total iron and magnesium contents of the samples are typical of calc-alkaline rocks and conformable with the known calc-alkaline trends in other parts of the world (Fig. 8).

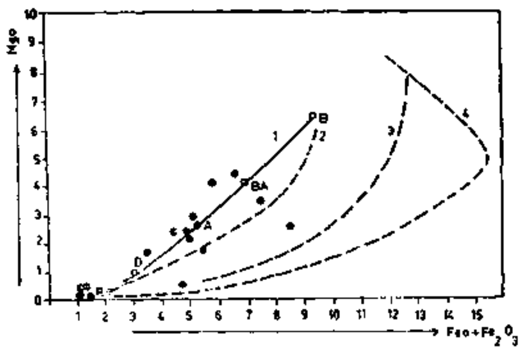

Fig. 8 - Variation of total Fe and MgO in the volcanics. 1 - The Cascade calc-alkaline trend (Carmichael et al., 1974); 2 - Calc-alkaline series (Nockolds, 1954); 3 - The Hawaiian alkali series trend (MacDonald and Katsura, 1964); 4 - The Thingmuli tholeiitic series trend (Tilley and Muir, 1967).

The variation of SiO_2 with t = (Al_2O_3-Na_2O) / (TiO_2) values is investigated in order to search into the origin of the magma following the method developed by Gottini (1968 and 1969). The t value (the Gottini index) is in general greater than 10 and rises with the increase in SiO_2 content. The index is less than 10 in the lava samples containing zeolites. According to Gottini (1969), lavas with sialic origin have t values greater than 10 and the value increases with rising silica content. This suggests that the volcanics of the Datça peninsula have a sialic origin. In addition, Gottini (op. cit.) established a relationship between log t and log s (the Rittmann index) and delimited fields for rocks of sialic and simatic origins in a diagram. The investigated volcanics plot into the sialic field, however the samples with zeolites occupy the simatic field (Fig. 9). When the volcanic rocks of the Nysiros and Yelli islands (Davis, 1968) and the detailed petrochemical results of Di Paola (1974) are considered, it is apparent they are totally conformable with the Datça volcanics and their chemical characteristics.

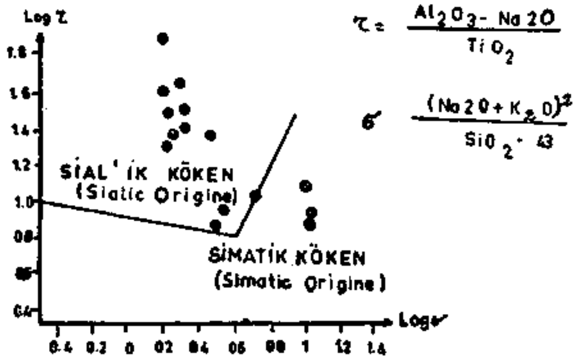

Fig. 9 - Variation diagram of log σ and log τ in the volcanics.

DISCUSSION AND CONCLUSIONS

Geological and petrochemical findings lead to the conclusion that the volcanic rocks of the Datça peninsula are basaltic andesite, andesite, dacite and rhyolite, containing all the rock types of a calc-alkaline series, and composed of lava fragments, ash, tuff, lapilli and pumice. They are aerially transported deposits formed by numerous powerful explosions taking place at the Nysiros island about 40 000-50 000 years ago (or even earlier) during the final periods of the second stage of the volcanism.

The products of the active island arc volcanism in the Aegean sea are also observed in other parts of Western Anatolia and some of the Aegean islands. From time to time, very forceful explosions in the volcanic centres that form the island arc have taken place and the volcanic products are scattered aerially for very long distances. For instance, the dacitic and rhyolitic lavas, pumice and tuffs of the Quaternary island arc volcanism at the island of Kos have formed tuff and ignimbrite plateaus by aerial transport on the surrounding islands of Kalimnos and Kappari (Keller, 1970) (Fig. 2). Studies of samples from the mentioned islands reveal that the rocks fragments and the phenocrysts are of the same composition and origin. The ignimbrites originate from a now submerged caldera at the western end of the Kos island (Wright, 1977). The tuffs and pumice fragments that originate from this explosive centre are aerially dispursed over long distances and some of them even reached the Bodrum peninsula (Ercan, 1982) now underlying the recent alluvials.

There are also volcanic products of the island arc volcanism in the Aegean sea which have reached Western Anatolia through the sea by floating. Pumice fragments which are round and upto 10-15 cm. in diameter are found in Western Anatolia on small sand hills, beach crests and along the coast between Kuşadası and Bodrum. There is not any acidic volcanic centre where the pumice fragments are found. In any case, the beach crests are contemporary formations whose consolidation is not even completed. These pumice fragments are those which fell into the sea following forceful explosions on the island of Santorini, one of the volcanic centres of the active island arc, and carried away by wave action to the Western Anatolian coasts (Ercan and Günay, 1981). Furthermore, some workers (e.g. Eisma, 1977) claim that they reached the coast after the explosion in the Santorini island in 726 A.C.. As a matter of fact, in ancient-Greek history, it is recorded that there were powerful explosions in the Santorini island in 726 A.C. after which the Aegean sea was covered with floating pumice fragments, the extent being measured in terms of kms (Eisma, 1977).

The work currently carried out and that in the future will further clarify the issue.

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