The geochemistry and tectonic setting of the Demirköy pluton of the Srednogorie–Istranca granitoid chain, NW Turkey

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Abstract

The chain of Late Subhercynian granitoids can be traced along the Srednogorie–Istranca–Pontid belt. The Demirköy pluton outcrops in the Istranca segment. The rocks of the pluton range from diorite through grandiorite to perthite granite with granodiorite predominating. On the basis of 25 chemical analyses, the intrusive setting of the granitoid has been investigated. Calcic to calc-alkaline and peraluminous to metaluminous character indicate a subduction-related origin. Low to moderate concentrations of the large-ion lithophiles (LIL), high field strength elements (HFS), light rare earth elements (La, Ce) and low HFS/LIL ratios indicate a mantle-derived magma with subduction-related enrichment. Trace element discrimination diagrams such as Rb/Zr–Nb, Rb/Zr–Y, Rb–SiO_2 and Rb–(Nb + Y), are particularly indicative of normal arc-setting for the samples.

The Demirköy granitoid is chemically indistinguishable from the Upper Cretaceous granitoids of Strednogorie to the west and the Pontids to the east. This extensive maximum of plutonism can be considered as a time marker in the northern Tethys subduction system.

KEYWORDS: geochemistry, granitoid, plate tectonics, Turkey.

Introduction

THE innermost zone of the Balkan chain is called the Srednogorie–Istranca region. In many respects this area represents an independent structural unit of anticlinorium type. It can be traced from eastern Serbia, and crosses the entire southern Bulgarian region of Srednogorie, and the Istranca mountains of European Turkey. Intensive magmatism of Upper Cretaceous age is one of the most outstanding traits of this unit, being represented by numerous granitoid outcrops ranging in size from a few square kilometres to hundreds of square kilometres. A chain of Late Subhercynian magmatic arc granitoids can also be traced in a continuous zone from southern Bulgaria–Istranca through western and eastern and Lesser Caucasus (Fig. 1). K/Ar radiometric data identify the Istranca granitoids (Demirköy and Şükrüpaşa) as a Late Subhercynian (*c.* 80 Ma) formation (Moore *et al.*, 1980). A similar K/Ar date of *c.* 75 Ma has been obtained for the Srednogorie granitoids (Boyadjiev, 1981).

The Late Cretaceous Carpathian-Pontid strike direction has been reconstructed on the basis of paleomagnetic data by Burtman (1986). According to these data the Srednogorie–Istranca area is a segment of the Carpathian–Balkan–Pontid belt which was an active margin of northern Tethys throughout the entire Mesozoic and Cenozoic.

Although the general tectonic divisions of the eastern Mediterranean part of the Alpine–Tethys system were established long ago and numereous geological data have been presented in many synthetic works (e.g. Dewey *et al.*, 1973; Şengör and Yilmaz, 1981; Dercourt *et al.*, 1986; Ricou *et al.*, 1986), geochemical studies on the magmatic complexes as a marker of the Eurasian active margin are limited.

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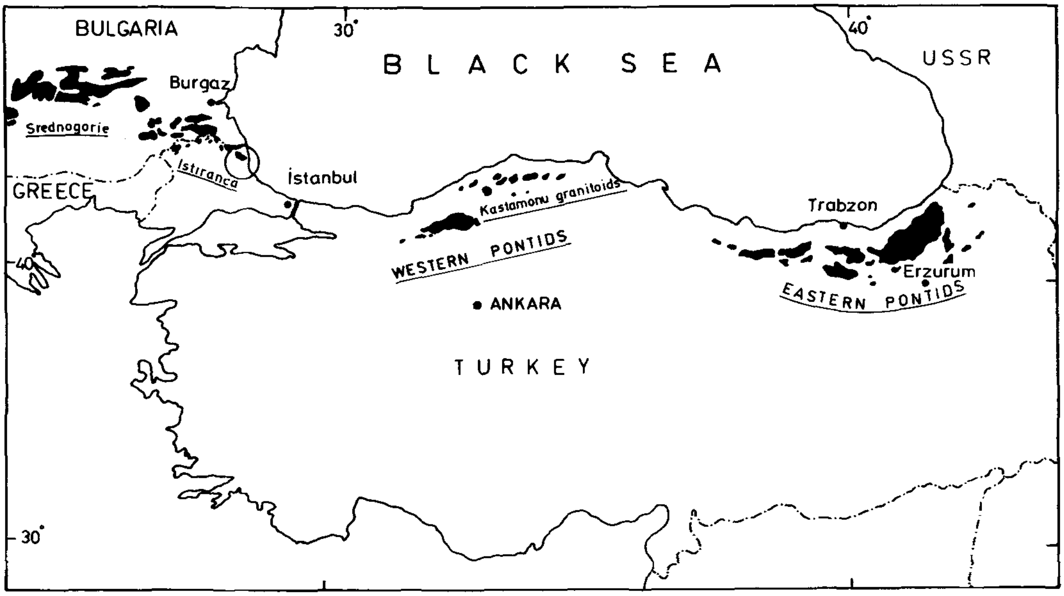

FIG. 1. Distribution of subduction-related Subhercynian granitoids along Balkans and Anatolian Peninsula. The Demirköy Pluton (circle) is located in the Istranca area.

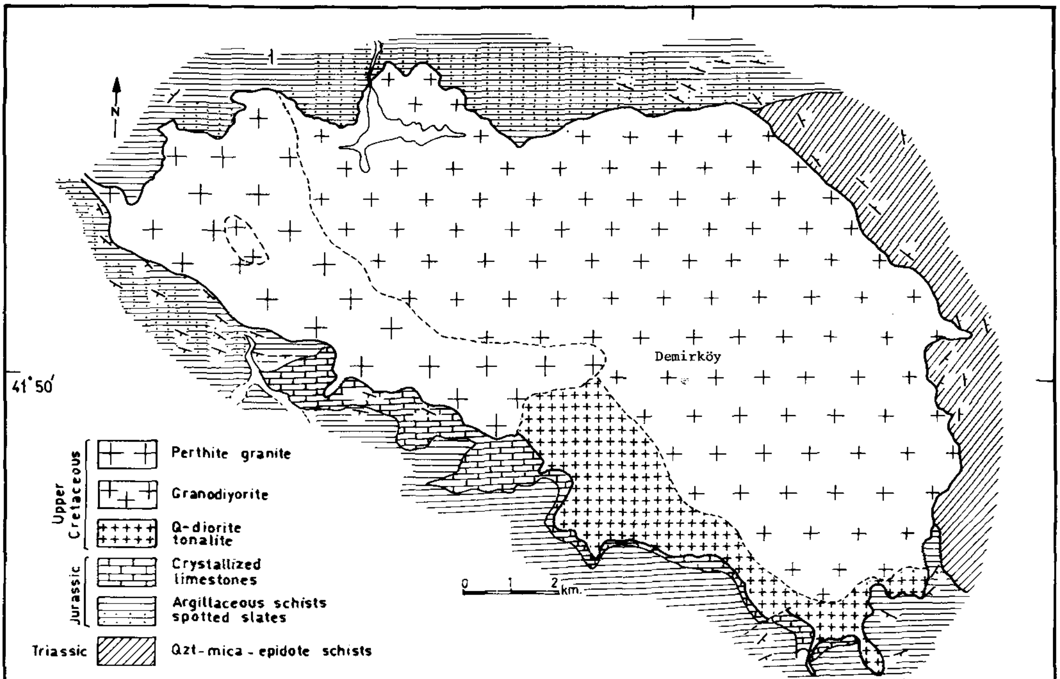

FIG. 2. Simplified geological map of the Demirköy pluton and the surrounding rocks.

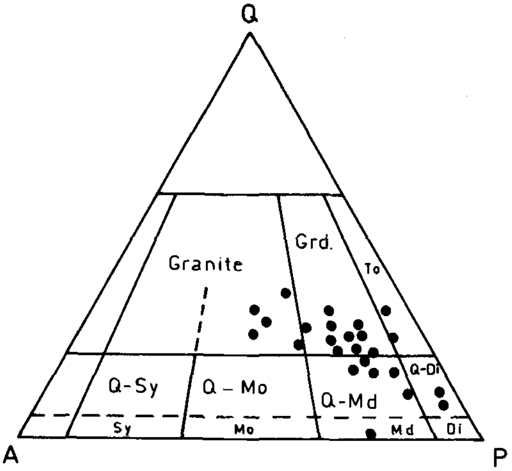

FIG. 3. Modal analyses of 25 samples plotted on the classification diagram recommended by Streckeisen (1976).

The object of this paper is to present new geochemical data on the Demirköy granitoid and compare the data with those of contemporaneous granitoids in the eastern Pontids. Comparison between the two provinces may prove useful in constraining models for the evaluation of the Eurasian active margin.

Geological setting

The Istranca massif and the Pontids are the northern branch of the Alpine–Himalayan belt of Turkey (Fig. 1), and they include calc-alkaline volcanics as well as plutonic rocks.

In broad terms the Istranca Massif is an eroded anticline with a NW–SE axis. The oldest rocks in the anticline are high grade metamorphics of Paleozoic age, which are mostly veined gneisses of migmatite origin. A metagranite sample collected from this formation yielded a Permian Rb/Sr whole-rock isochron age of 245 Ma (Aydin, 1974). This basement is overlain by intermediate grade metamorphics characterised by quartz–mica–epidote–actinolite schists of Triassic age. Metamorphosed limestones and argillaceous schists of Jurassic age follow conformably. After a further period of uplift and erosion unmetamorphosed cover rocks of Cretaceous age were deposited. These consist of a basal conglomerate overlain by a sequence of limestones, shales, sandstones, tuffs and basaltic lavas, suggesting a shallow water inter-arc depositional environment.

The Demirköy pluton is elliptical in shape with maximum dimensions 16 and 20 km, elongated in NW–SE direction (Fig. 2). The Tertiary cover has been extensively removed due to uplift in the Quaternary, and the metamorphic basement exposed over a wide area.

Petrography

The main rock types range from diorite, or more commonly tonalite, to granodiorite and perthite granite (Aykol, 1979). Modal analyses of 25 samples plotted in the classification diagram recommended by Streckeisen (1976) are shown in Fig. 3. The dominant lithologies are biotite, granodiorite or biotite–hornblende granodiorite, which constitute 60% of the outcrop; with subordinate diorites in the south, ranging from diorite, through quartz diorite to tonalite, with quartz diorite most abundant. Modes and mineral compositions are given in Table 1. The plagioclases are frequently zoned (ranges listed in Table 2). The whole pluton is cut by numerous NW–SE trending aplite dykes.

A steeply inclined foliation is developed near the contacts of the pluton. The periphery of

TABLE 1. Average modes of the rock types found in Demirköy granitoid

	Perthite granite (n=5)	Ademelite (n=5)	Granodiorite (n=7)	Tonalite (n=3)	Q-Diorite (n=5)
Quartz	28	28	23	25	4
Orthoclase	15	24	15	-	-
Plagioclase	13	32	46	56	45
Perthite	33	3	-	-	-
Biotite	8	10	8	7	15
Hornblende	2	2	7	8	18
Pyroxenes	-	-	-	2	13
Accessories	1	1	1	2	5

TABLE 2. Electron probe microanalyses of the two zoned plagioclases

	Plagioclase from granodiorite			Plagioclase from diorite		
	core	inner rim	outer rim	core	inner rim	outer rim
SiO_2	54.41	53.12	57.12	52.42	53.39	53.41
Al_2O_3	26.62	26.35	25.05	26.46	26.97	26.57
CaO	11.08	10.36	8.45	11.64	11.74	11.65
Na_2O	5.57	5.55	6.77	5.29	4.39	4.04
K_2O	0.23	0.20	0.28	0.24	0.18	0.14
Total	97.90	95.58	97.67	96.05	96.66	95.81
An	52	50	40	54	59	61
Ab	47	49	58	45	40	38
Or	1	1	2	1	1	1

granite has been converted to mortar gneiss and mylonite-schist. Country-rocks of pelitic composition have been transformed into foliated hornfelses containing cordierite and andalusite (Çağlayan *et al.*, 1987). Xenoliths are common and some of these occur locally as large blocks or screens of country rocks.

Geochemistry

A representative selection of whole-rock major and trace element analyses, together with CIPW norms are presented in Table 3. Chemical analyses were performed in the Geological Department, Black Sea Technical University. Major elements were analysed by XRF analyses of glass disc prepared with lithium tetraborate flux, except for Na and Mg which were analysed by atomic absorbtion. FeO concentrations were determined by titration. Trace element were analysed directly on pressed powder pellets by XRF using Rh and W excitation. Results were corrected for interference and matrix variation. U.S.G.S. and CANMET standards were used for calibration.

The typical I-type granitoid features, in field setting and petrography (Chappell and White 1974; Pitcher, 1983) are reflected in the major element geochemistry, for example in the alkali-lime relationship which is best displayed in the alkali-lime diagram (Fig. 4). The alkali-lime index is approximately 63, thus falling in the calcic subdivision of Peacock's (1931) classification. Calc-alkaline affinities displayed in the AFM diagram (Fig. 5), by the large range of SiO_2 content and of alumina saturation (peraluminous to metaluminous). Na_2O content always exceeds that of K_2O with a ratio >2. K_2O *vs.* Na_2O plots (Fig. 6) based on the criteria of Chappell and White (1974) lie predominantly in the I-type field.

Multi-element chondrite-normalized spectra for the 25 samples are shown in Fig. 7, yielding a pattern similar to those of normal subduction-related granites reported by Brown *et al.* (1984). The LIL elements K, R and Ba all increase while Sr decreases with fractionation. Rb, Rb/Sr, Ba and *LREE*s (La, Ce) values are generally moderate and span the compositional spectrum of I-types (Pitcher *et al.*, 1985; Atherton and Plant, 1985) and volcanic arc granites (Pearce *et al.*, 1984). Some of the Sr concentrations are probably slightly enhanced, due to the calcic nature of these rocks rather than calc-alkaline. The HFS elements Zr, Y and particularly Nb are generally depleted, consequently the LIL/HFS ratios are low and similar to those of subduction related I-type granitoids. The low Nb and Y contents clearly indicate the volcanic arc origin on the Rb–(Y + Nb) plot (Fig. 9).

Chemical discrimination of tectonic setting

The most characteristic feature of subduction-related magmatism is an enrichment in LIL elements in contrast to a depletion in HFS elements, so that low HFS/LIL ratios are typical of this magmatic setting (Pearce, 1983; Brown *et al.*, 1984; Saunders and Tarney, 1984). These trace element characteristics of granitoids formed in contrasting tectonic settings have been illustrated on the discrimination diagrams of Pearce *et al.* (1984). The analysed samples, together with unpublished analyses from the author's (S. T.) collection from the granitoids of the eastern Pontids, are plotted on the Rb–SiO_2, Rb–(Y + Nb), Rb/Zr–Nb and Rb/Zr–Y discrimination diagrams (Figs. 8–10). The VAG character of the samples is clearly defined on all the diagrams. Fig. 10 (Brown *et al.*, 1984) shows trends of

TABLE 3. Representative analyses from the Demirköy intrusion.

Oxides wt.%	G-105	G-109	G-6	G-19	G-95	G-106	G-33	G-10	G-104	G-36	G-28	G-81	G-14	G-78	G-71	G-22	G-96	G-39	G-56	G-108	G-18	G-57	G-20	G-93	G-30
SiO_2	46.52	50.58	52.29	52.52	56.66	57.73	59.78	60.46	62.94	63.55	63.67	63.76	64.36	64.45	64.51	65.07	65.07	66.71	68.58	69.20	69.27	70.19	70.44	72.28	72.41
TO_2	0.82	0.82	0.93	0.69	0.65	0.62	0.60	0.65	0.54	0.47	0.45	0.73	0.45	0.71	0.43	0.41	0.42	0.35	0.46	0.44	0.45	0.33	0.43	0.11	0.26
Al_2O_3	21.88	18.77	17.40	16.28	19.31	17.48	17.41	17.33	15.97	16.99	17.35	16.68	16.52	16.74	17.07	16.99	16.66	16.25	15.82	15.52	15.70	15.33	15.28	15.26	14.52
Fe_2O_3	8.99	2.31	2.38	2.00	1.99	1.98	2.10	2.07	2.01	1.79	1.83	1.60	1.80	2.84	1.67	1.51	1.74	1.40	1.16	0.96	0.92	0.95	0.91	0.58	0.67
FeO	2.25	10.04	9.54	6.66	4.99	5.66	4.67	4.14	3.64	3.25	3.33	2.90	3.28	1.56	3.03	2.75	3.16	2.54	1.94	1.60	1.66	1.58	1.51	0.96	1.12
MnO	0.21	0.28	0.23	0.15	0.14	0.18	0.15	0.09	0.11	0.12	0.11	0.08	0.10	0.08	0.11	0.10	0.11	0.09	0.06	0.07	0.07	0.07	0.06	0.05	0.06
MgO	1.69	0.82	0.95	2.58	2.60	2.57	2.43	2.56	2.47	2.11	2.04	2.07	2.04	1.91	1.87	1.87	2.17	1.70	1.43	1.54	1.52	1.21	0.97	0.72	0.84
CaO	14.79	14.92	12.30	11.27	9.19	8.35	6.94	7.29	6.45	5.91	6.23	4.10	5.74	3.86	5.33	5.74	6.74	5.12	2.94	2.55	3.18	1.60	1.73	3.81	1.47
Na_2O	1.45	1.79	2.22	4.91	2.72	2.78	3.29	3.30	2.88	3.17	3.71	4.87	3.12	4.45	3.49	3.27	3.19	3.22	4.02	4.27	4.28	3.54	3.93	2.78	3.65
K_2O	0.07	0.21	0.86	1.96	1.04	1.73	1.93	1.49	2.47	2.12	0.75	2.63	2.11	2.80	1.99	1.85	0.27	2.20	3.21	3.60	2.61	4.96	4.48	3.39	4.82
P_2O_5	0.24	0.19	0.09	0.20	0.10	0.26	0.15	0.14	0.10	0.11	0.12	0.26	0.09	0.27	0.13	0.10	0.13	0.90	0.16	0.10	0.18	0.10	0.12	0.02	0.02
Sum	98.91	100.73	99.19	99.27	99.39	99.34	99.45	99.52	99.58	99.59	99.59	99.68	99.59	99.67	99.63	99.66	99.66	100.48	99.78	99.85	99.84	99.86	99.86	99.96	99.84
CIPW norms																									
Q	8.36	6.10	7.51	-	12.16	12.37	13.80	15.82	19.28	20.32	21.69	13.51	21.90	17.61	21.22	23.02	26.94	27.20	24.06	22.43	25.07	24.92	24.99	33.43	27.87
Or	0.41	1.24	5.08	11.58	6.14	10.22	11.40	8.80	14.59	12.53	4.43	15.54	12.47	16.54	11.76	10.93	1.60	13.00	18.97	21.27	15.42	29.30	26.47	20.03	28.48
Ab	12.26	15.24	18.78	25.97	23.01	23.51	27.83	27.91	24.36	26.81	31.38	41.19	26.39	37.63	29.52	17.66	26.98	27.23	34.00	36.11	36.20	29.94	33.24	23.51	30.87
An	52.99	42.55	34.96	16.60	37.41	30.11	27.04	28.08	23.36	25.87	28.48	15.89	24.85	17.38	25.04	26.22	30.35	19.52	13.54	12.00	14.60	7.28	7.80	18.77	7.16
Ne	-	-	-	8.43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cr	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	-	-	1.42	0.77	0.21	0.48	1.47	1.11	0.14	0.68
Wo	2.98	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Di	9.08	26.43	22.18	31.88	6.23	8.01	5.30	5.88	6.53	2.23	1.35	2.23	2.49	-	0.45	1.31	1.71	-	-	-	-	-	-	-	-
Hy	-	3.91	5.25	-	10.09	10.47	9.55	8.47	7.30	8.10	8.48	7.02	7.83	4.76	8.11	7.33	8.44	7.33	5.52	5.38	5.46	4.71	3.84	2.99	3.23
Mt	5.56	3.35	3.45	2.90	2.89	2.87	3.05	3.00	2.91	2.60	2.65	2.32	2.61	3.23	2.42	2.19	2.52	2.03	1.68	1.39	1.33	1.38	1.32	0.84	0.97
Hm	5.16	-	-	-	-	-	-	-	-	-	-	-	-	0.61	-	-	-	-	-	-	-	-	-	-	-
Tl	1.56	1.56	1.77	1.31	1.23	1.18	1.14	1.23	1.03	0.89	0.86	1.39	0.86	1.35	0.82	0.78	0.80	0.67	0.87	0.34	0.86	0.63	0.21	0.21	0.49
Ap	0.57	0.45	0.21	0.47	0.24	0.62	0.36	0.33	0.24	0.26	0.29	0.62	0.21	0.64	0.31	0.24	0.31	2.13	0.38	0.23	0.43	0.24	0.29	0.05	0.05
Sum	98.93	100.73	99.19	99.14	99.40	99.36	99.47	99.52	99.60	99.61	99.61	99.71	99.61	99.78	99.65	99.68	99.65	100.53	99.79	99.36	99.85	99.87	99.88	99.97	99.80
Trace elements																									
Rb ppm	97	6	30	43	28	39	56	55	72	45	25	80	65	81	66	44	14	60	104	117	78	87	126	60	162
Sr	587	455	321	343	369	515	328	382	390	334	497	759	392	642	488	228	533	320	38	304	299	261	183	406	349
Y	8	16	14	16	9	20	18	16	21	16	7	24	25	38	7	12	12	15	19	25	18	28	22	11	26
Zr	22	30	42	60	31	38	61	74	45	90	57	204	92	72	44	138	37	77	64	111	52	100	168	30	81
Nb	2	2	6	9	3	3	4	6	14	8	2	12	1	4	35	2	2	2	4	6	1	7	2	4	14
Ba	36	58	193	231	257	376	353	330	555	456	242	1057	369	926	455	291	103	467	678	628	568	1042	584	980	927
La	18	5	25	40	7	18	18	18	18	15	17	5	19	42	14	16	36	18	12	19	13	14	15	16	32
Ce	43	54	73	28	20	49	23	30	74	64	42	32	45	66	30	46	44	30	86	36	78	42	74	62	40

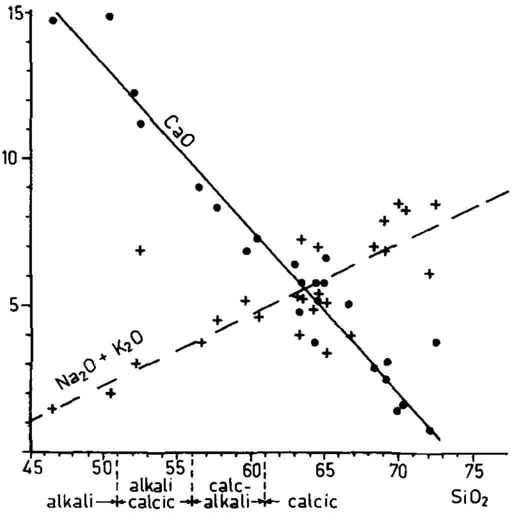

FIG. 4. Alkali-lime relation of the Demirköy pluton based on the diagram from Peacock (1931).

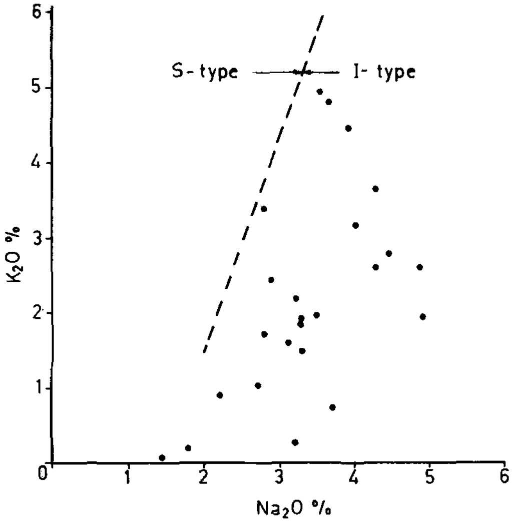

FIG. 6. K_2O *vs*. Na_2O plots of the samples. Dashed line based on the criteria of Chappell and White (1974).

increasing Rb/Zr, Nb and Y, and increasing Nb at a given Rb/Zr, with increasing arc maturity. The plot of the Demirköy samples demonstrate that the pluton was probably generated in a primitive to normal stage of the subduction.

Conclusions

Petrographic and geochemical characterisation and tectonic environment discrimination indicate that the Demirköy pluton is a granodiorite-dominated I-type granitoid which displays calc–alkaline geochemical characteristics similar to the less evolved Jamaican arc-related granites (Pearce *et al.*, 1984). The pluton is spatially and temporally related to the other granitoid outcrops

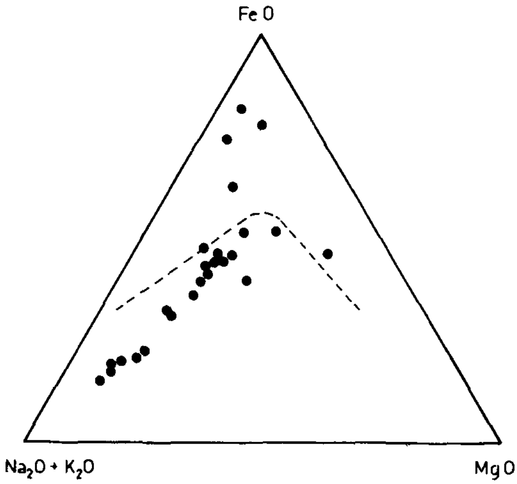

FIG. 5. AFM plots of the samples. Dashed line (after Irvine and Baragar, 1971) serves to separate tholeiitic and calc–alkaline compositions.

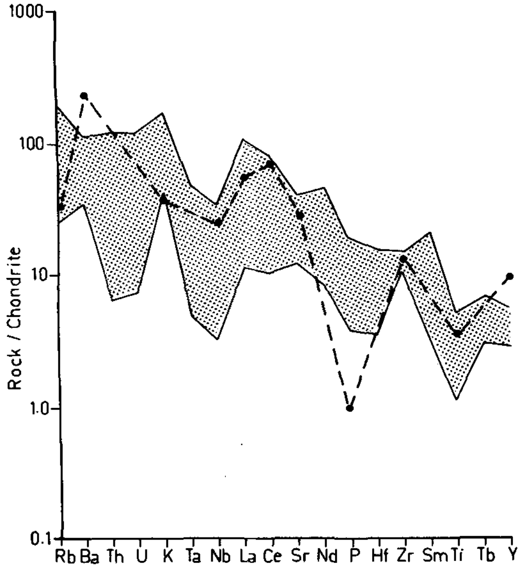

FIG. 7. Chondrite-normalized trace elements pattern for Demirköy pluton. SiO_2 = 66–75%, n = 8. Normalizing values from Wedephol (1975). Stippled area represents the range of primitive and normal arcs (mature continental arcs excluded) after Brown *et al.* (1984).

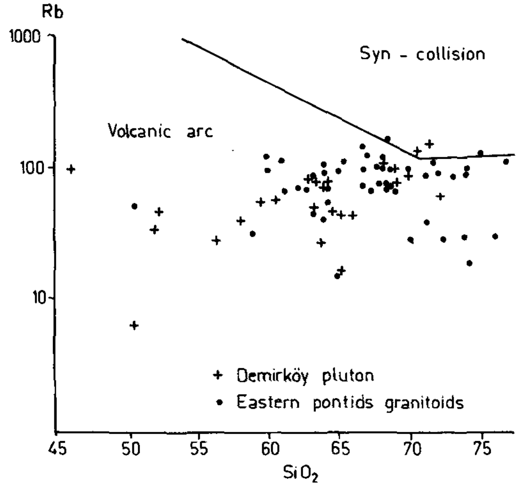

FIG. 8. Rb *vs.* SiO_2 discriminant plots for the granitoids of Demirköy and eastern Pontids showing tectonic classification suggested by Pearce *et al.* (1984).

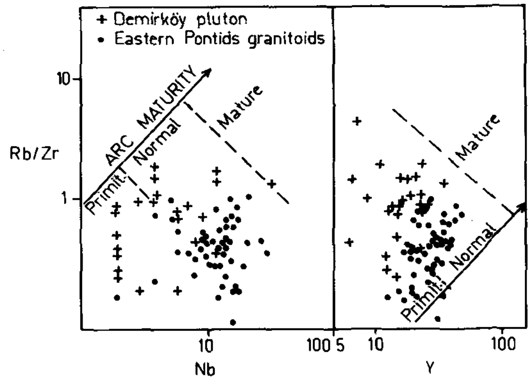

FIG. 10. Rb/Zr against Nb and Y plots for the granitoids of Demirköy and eastern Pontids indicating arc maturity suggested by Brown *et al.* (1984).

which are placed in the southern Bulgaria–European-Turkey Late Subhercynian granitoid chain. The Upper Cretaceous granitoids within the Srednogorie area have been first discussed by Boyadjiev (1979) who identified the island-arc type plutonism. The same feature for the southern Bulgarian granitoids was also recognised by Ivanov and Arnaudova (1980) and Ivanov *et al.* (1981). In these studies it is reported that the granitic rocks occurring in Srednogorie, Rila-Rhodope, Pirin and Osogovo are characterised by low Nb and Ta content.

The eastward extension of the Srednogorie–Istranca granitoid chain can be traced to the western and eastern Pontids. In the western Pontids, these granitoids are called the Kastamonu granitoid belt, and have been interpreted as subduction-related calc-alkaline intrusions by Boztuğ *et al.* (1985). In the eastern Pontids a chain of granite–granodiorite plutons of Late Subhercynian age occurs along the belt axis. These granitoids are similar in petrographic, chemical and temporal features to the Demirköy granitoid.

In conclusion we may remark that Srednogorie–Istranca granitoid belt actually existed as an island-arc of Upper Cretaceous age formed on a Hercynian basement. This granitoid chain, which extends as a broad band along the entire Black Sea coast, can be considered as a marker of the northern Tethys subduction system.

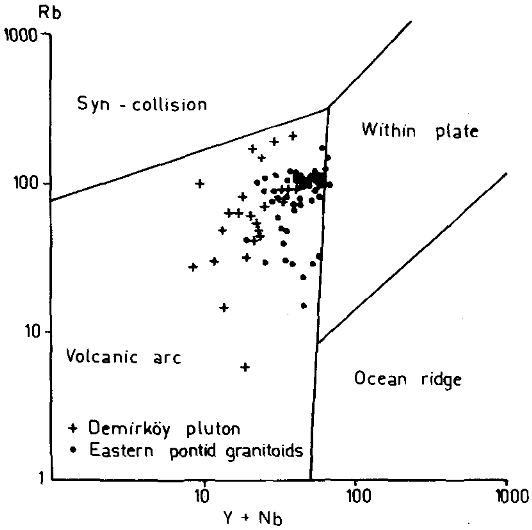

FIG. 9. Rb *vs.* (Y + Nb) discriminant plots for the granitoids of Demirköy and eastern Pontids showing tectonic classification suggesting by Pearce *et al.* (1984).

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