Granitic intrusions in western Anatolia : a contribution to the geodynamic study of this area

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Granitic intrusions in western Anatolia: a contribution to the geodynamic study of this area

By Ergüzer Bingöl[1]), Michel Delaloye[2]) and Gürol Ataman[3])

SUMMARY

33 new K–Ar ages have been measured on minerals from various granitic bodies of western Anatolia. In addition to previously published data, our results lead to the following conclusions. Granitic intrusions located north of the North Anatolian Fault show Paleozoic to Upper Mesozoic ages. The granites between the Fault and a line passing through Eskişehir, Bursa and Edremit are pre-Lower Jurassic while the granites lying south of this line have post-Upper Cretaceous to pre-Miocene ages. The intrusions are generally monzonitic and plot in the calcalkaline field, near to the alkaline area. K_2O concentrations for a fixed SiO_2 value increase from north to south. This observation is important for a geodynamic interpretation of our results.

RÉSUMÉ

33 nouvelles données géochronologiques K–Ar ont été mesurées sur des minéraux provenant de corps granitiques d'Anatolie occidentale. Joints aux données déjà existantes, ces résultats permettent de tirer quelques conclusions intéressantes. Les intrusions granitiques situées au nord de la Faille Nord-Anatolienne ont des âges compris entre le Paléozoïque et le Mésozoïque supérieur. Les intrusions affleurant entre la Faille Nord-Anatolienne et une ligne passant par Eskişehir, Bursa et Edremit sont anté-Jurassique inférieur alors que celles situées au sud de cette ligne datent du post-Crétacé supérieur à anté-Miocène. Ces intrusions sont généralement de type monzonitique avec une tendance alcaline. Pour une valeur constante de SiO_2, les concentrations en K_2O augmentent du nord vers le sud. Cette constatation est importante pour notre interprétation géodynamique de cette région.

Introduction

The granitic intrusions of western Anatolia are one of the major features of the geology of this region but, with a few exceptions, they have not been studied in detail. The various models describing the geodynamic evolution of this area tend to be incomplete because insufficient attention has been paid to the tectonic significance of the granite bodies.

This paper is a contribution to the geochronology of these granitic intrusions and to the geodynamic evolution of western Anatolia.

[1]) Maden Tetkik ve Arama Enstitüsü, Ankara, Turkey.
[2]) Department of Mineralogy, University of Geneva, Switzerland.
[3]) Hacettepe University, Ankara, Turkey.

Geology

The granites of western Anatolia are numerous, their outcrops ranging in size from a few square kilometers to hundreds of square kilometers. They are geographically situated along two main directions: roughly east–west in the north of the region and northeast–southwest in the northwest (Fig. 1).

North of the North Anatolian Fault the granitic intrusions are isotopically dated as Paleozoic in age (Bürküt 1966; Yılmaz 1975; Abdüsselamoglu 1959). In the northern part of the Istranca Massif, Aydın (1974) has described and also dated pre-Triassic metamorphic granites (the Kırklareli metagranites) together with Upper Cretaceous granitic, gabbroic, monzonitic and syenitic intrusions.

Ages of granitic intrusions south of the North Anatolian Fault are spread between the Paleozoic and the Tertiary. The purpose of the present study is to subdivide the area lying south of the North Anatolian Fault by two lines. These lines

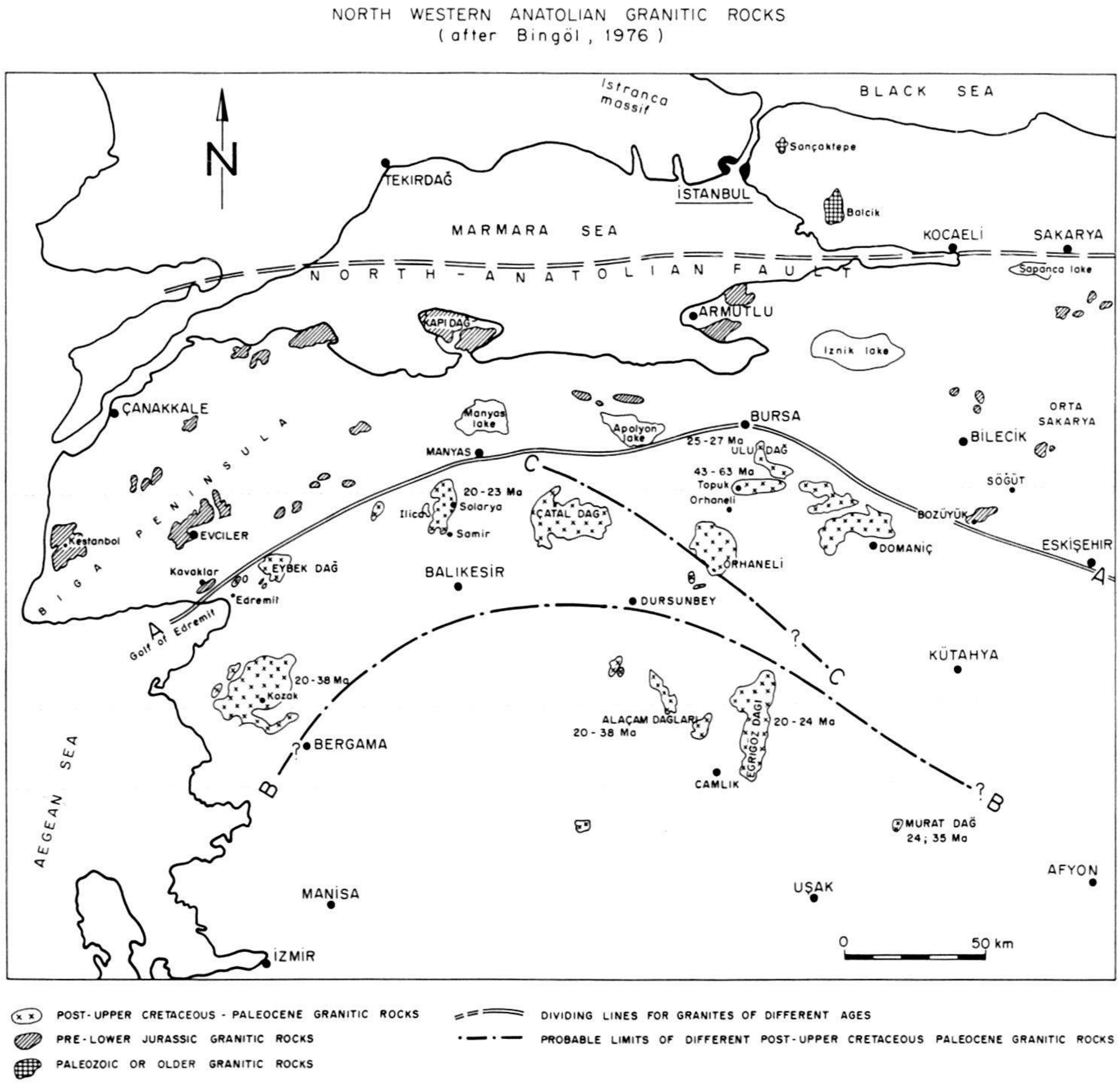

Fig. 1. Situation map of northwestern Anatolia.

are boundaries between domains where the granitic bodies are similar in character. The first boundary is a line A–A joining Ankara, Eskişehir, Bozüyük, Bursa, Manyas and the Gulf of Edremit (BINGÖL 1976).

A second line, B–B, is nearly parallel to the previous one and situated south of it. It joins the localities of Afyon, Dursunbey, Balıkesır and Bergama.

The granitic bodies outcropping between the North Anatolian Fault and the line A–A have pre-Liassic ages (BINGÖL 1976; YILMAZ 1977). YILMAZ has described "en écailles" structures dipping north–south in those granites. They could be of Paleozoic age (BRINKMANN 1971).

The granitic bodies lying south of the line A–A seem to be post-Lower Trias but their lower age limit is not so well defined (IZDAR 1968; BINGÖL 1968, 1974, 1978; ATAMAN 1972, 1973, 1975a, b; BINGÖL et al. 1973). Many of these granites developed metamorphic aureoles in Late-Cretaceous to Paleocene sediments. Most of the published ages on these rocks are younger than Late Cretaceous (BÜRKÜT 1966; VACHETTE et al. 1968; ÖZKOÇAK 1969; LISENBEE 1972; ATAMAN 1972, 1973, 1975; BINGÖL 1977) apart from two (ÖZTUNALI 1973; YILMAZ 1973).

In order to narrow down the stratigraphic age of these granites, we can say that Eocene conglomerates do not contain granitic elements but Miocene conglomerates do. The emplacement age of these granites is therefore limited by the ages of these two conglomerates.

The various massifs seem not to belong to the same large granitic body. The massifs are completely independent and are situated in anticlines and antiforms. The elongations of the granitic bodies correspond to the axes of the anticlines (HEDLEY et al. 1974; BINGÖL 1976).

Petrography

The granitic bodies situated north of the North Anatolian Fault have not been extensively studied. For example the Sancaktepe intrusion has been named a quartz–biotite leucogranite by YILMAZ (1975) and a biotite bearing quartz monzonite by BÜRKÜT (1976).

The Çavusbası intrusion is a quartz diorite. The Kırklareli metagranite, near Istranca has a composition between a monzogranite and a syenogranite (AYDIN 1974). According to this author, the post-Jurassic magmatic sequence of Dereköy shows gabbros, diorites, monzonites and syenites. Continuous variations can be seen between the three first members but the syenites are different.

The granitic massifs situated between the North Anatolian Fault and line A (Eskişehir–Bursa–Edremit) have varying petrographic compositions: the Orta-Sakarya intrusions are intermediate between granodiorite and true granites with cataclastic and sometimes mylonitic textures (YILMAZ 1977); southwest from Armutlu and Kapıdağ, the intrusions are normally granitic (BÜRKÜT 1966) the Biga Peninsula, the Kavlaklar intrusion and the Evciler massif (Çavuşlu-Katlandağ) are granodioritic (BÜRKÜT 1966; BINGÖL 1968) while the Kestanbol massif is a quartz monzonite (BÜRKÜT 1966).

South of the line A–A, the granites have fine grained margins. Many and often large xenoliths are present in these granites. The Topuk intrusion, for example

Table 1: *Summary of the petrographic characters of the analyzed rocks.*

Sample Nb and Massif	Rock name	% quartz	Mafic minerals	% Feldspar	Feldspar assemblage	Accessory minerals	Structure
Y 22 Muratdağ	Monzogranite	20	bi+ho	60	ol+or	ap,sp,op	hydiomorph
Y 1 Egrigöz	Syenomonzogran.	25	bi	65	ol+or		porphyritic
Y 2 "	"	20	bi	70	ol+or		porphyritic
Y 9 Uludağ	Syenogranite	40	bi	50	ol+mi+or	mu	hypid+porphyr.
Y 12 "	Granite	30	bi+ho	25	ol+and+or	ap,ep,sp,op,zr	hypidiomorph
Y 6 Topuk	Monzogranite	20-25	bi±ho	65	ol+or	ap,sp,op,zr	hypidiomorph
Y 7 "	"	25-30	bi±ho	60	ol+or		granular
Y 23 Alaçam	Syenogranite	20-25	bi	65-70	ol+or	zr,op	hypidiomorph
Y 24 "	Syenomonzogr.	20	bi±ho	65-70	ol+or	sp,op	hypidiomorph
Y 25 "	Syenogranite	30	bi	65	ol+or	zr	hypidiomorph
Y 26 "	Syenomonzogr.	25-30	chl	65-70	ol+or	ep,sp,op	porphyritic
Y 27 "	Monzogranite	20	bi±ho	70	ol+or	ap,zr,op	hypidiomorph
Y 28 "	Syenogranite	30	bi	60	ol+or	ap,op,zr	hypidiomorph
Y 4 "	Granodiorite	20-25	bi±ho	60	ol-and	ap,ep,op	porphyritic
Y 16 Solarya	Granodiorite	20	ho±bi	55-60	ol-and±or	ap,sp,op,zr	hypidiomorph
Y 18 Kozak	Monzogranodior.	25	bi±ho	55-60	ol-and+or	ap,sp±op±zr	hypidiomorph
Y 19 "	Monzogranite	20	ho±bi	65	ol+or	ap,op	hypidiomorph

bi=biotite; ho=hornblende; ol=oligoclase; or=orthoclase; and=andesine; ap=apatite; sp=sphene; mu=muscovite; ep=epidote; zr=zircon; op=opaque minerals.

Table 2: *Previous geochronological studies.*

Massif	Sample	Sr^{87}/Sr^{86} mes.	$Sr.^{87}/Sr^{86}$ isochr.	Rb^{87}/Sr^{86}	Rb/Sr age	K/Ar Age	References
Muratdağ	whole rock	0.7124	0.71118±0.00014	1.6278	52±7		Bingöl (1975)
		0.7117		0.8140			
		0.7122		1.2008			
		0.7119		0.9405			
Eğrigöz	whole rock				167±14	217±33	Öztunali (1973)
	orthoclase				31± 5	60± 6	
	biotite				29± 3	52±12,5	
Uludağ	whole rock				245±37	269±39	Öztunali (1973)
	orthoclase				235±35	58±25	
	biotite				30± 3	78±10,5	
Uludağ	biotite					23,8	Börküt (1966)
Solarya (Ilica-Şamli)	biotite	0.7163	0.7064	28.10	23.5±1.5		Ataman (1974)
	whole rock	0.7069		0.72			
	biotite	0.7128		17.58			
	whole rock	0.7066		0.57			
	biotite	0.7096		9.06			
Kozak	whole rock	0.7104		8.73			Ataman (1975)
	whole rock	0.7075		0.70	13		
	biotite	0.7092		8.81			
	whole rock	0.7087		0.49	23		
	biotite	0.7114		8.43			
	whole rock	0.7092		0.60	16		
	biotite	0.7129		16.40			

contains mafic and ultramafic xenoliths. The petrography of these granites are summarized in Table 1. We can conclude that syenogranitic and monzogranitic compositions are more common than granodioritic compositions.

Geochronology

a) Analytical procedure

All age measurements were made on mineral concentrates such as biotite, orthoclase and hornblende. With one exception, two different minerals were dated from each sample. The isotopic ratios were measured on an AEI-MS-10-S mass spectrometer equiped with a digital output and the data were then processed by computer (DELALOYE & WAGNER 1974).

The results are presented in Table 3. The error given for each measurement represents the absolute error (95% confidence level) according to the definition and calculation of FONTIGNIE (1980). The isochron age error was calculated using errors

Table 3: *K-Ar data and age results.*

Sample no Locality	Coordinates	Mineral	% K	Ar^{40}rad 10^{-9}moles/g	% Ar^{40}rad	Ar^{40}/Ar^{36}	K^{40}/Ar^{36}	Age m. y.
γ22 Muratdağ	-	mica	2.09	0.088	37.4	$0.468 \cdot 10^3$	$0.123 \cdot 10^6$	23.9±2.4
		orthoclase	10.33	0.642	34.4	$0.449 \cdot 10^3$	$0.135 \cdot 10^6$	35.5±3.0
γ 1 Eğrigöz	35 SPD 795643	biotite	7.01	0.251	72.7	$0.108 \cdot 10^4$	$0.657 \cdot 10^6$	20.0±0.7
		orthoclase	9.28	0.398	55.8	$0.663 \cdot 10^3$	$0.257 \cdot 10^6$	24.6±1.4
γ 2 "	35 SPD 808404	biotite	6.60	0.241	76.0	$0.122 \cdot 10^4$	$0.752 \cdot 10^6$	20.4±0.6
		orthoclase	9.79	0.362	84.5	$0.448 \cdot 10^3$	$0.124 \cdot 10^6$	21.2±1.8
γ 9 Uludağ	35 TPE 798384	biotite	6.30	0.279	71.1	$0.101 \cdot 10^4$	$0.487 \cdot 10^6$	24.7±0.7
		orthoclase	11.17	0.651	38.9	$0.432 \cdot 10^3$	$0.906 \cdot 10^5$	26.0±2.9
γ12 "	35 TPE 848416	biotite	6.06	0.292	81.1	$0.155 \cdot 10^4$	$0.779 \cdot 10^6$	26.8±0.8
		orthoclase	11.61	0.529	97.5	$0.329 \cdot 10^4$	$0.222 \cdot 10^7$	26.1±1.7
γ 6 Topuk	35 SPE 875296	biotite	6.14	0.479	86.1	$0.212 \cdot 10^4$	$0.698 \cdot 10^6$	43.0±2.7
		orthoclase	11.19	0.980	98.9	$0.438 \cdot 10^4$	$0.163 \cdot 10^7$	49.8±2.7
γ 7 "	35 SPE 746288	orthoclase	10.92	1.220	83.1	$0.175 \cdot 10^4$	$0.388 \cdot 10^6$	63.5±2.8
γ23 Alaçam	35 SPD 611472	biotite	6.76	0.246	73.2	$0.108 \cdot 10^4$	$0.652 \cdot 10^6$	20.3±0.6
		orthoclase	6.71	1.170	22.1	$0.376 \cdot 10^3$	$0.142 \cdot 10^5$	95.7±8.1
γ24 "	35 SPD 552568	biotite	3.57	0.128	51.0	$0.601 \cdot 10^3$	$0.255 \cdot 10^6$	20.0±0.8
		orthoclase	10.53	0.499	96.4	$0.931 \cdot 10^3$	$0.568 \cdot 10^6$	27.1±1.0
γ25 "	35 SPD 677526	biotite	6.47	0.231	73.4	$0.111 \cdot 10^4$	$0.679 \cdot 10^6$	19.9±0.7
		orthoclase	8.37	0.457	95.0	$0.620 \cdot 10^4$	$0.323 \cdot 10^7$	31.2±1.2
γ26 "	35 SPD 426558	mica	1.78	0.059	65.2	$0.838 \cdot 10^3$	$0.489 \cdot 10^6$	18.6±0.7
		orthoclase	4.60	0.282	91.8	$0.906 \cdot 10^3$	$0.476 \cdot 10^6$	35.0±1.6
γ27 "	35 SPD 445604	biotite	5.60	0.206	67.3	$0.915 \cdot 10^3$	$0.499 \cdot 10^6$	20.6±0.8
		orthoclase	9.80	0.661	92.1	$0.266 \cdot 10^4$	$0.199 \cdot 10^7$	38.5±1.8
γ28 "	35 SPD 482568	biotite	6.16	0.830	79.5	$0.144 \cdot 10^4$	$0.916 \cdot 10^6$	20.9±0.5
		orthoclase	9.63	0.365	47.8	$0.562 \cdot 10^3$	$0.212 \cdot 10^6$	21.7±2.2
γ 4 "	35 SPD 310570	biotite	4.73	0.236	85.0	$0.156 \cdot 10^4$	$0.781 \cdot 10^6$	27.9±1.9
		orthoclase	9.37	0.411	52.5	$0.619 \cdot 10^3$	$0.222 \cdot 10^6$	25.1±3.1
γ16 Solarya	35 SNE 754207	hornblende	1.60	0.058	69.7	$0.972 \cdot 10^3$	$0.556 \cdot 10^6$	20.3±1.1
		orthoclase	10.76	0.434	82.4	$0.166 \cdot 10^4$	$0.102 \cdot 10^7$	23.1±1.2
γ18 Kozak	35 SMD 995450	biotite	3.80	0.168	46.5	$0.547 \cdot 10^3$	$0.172 \cdot 10^6$	24.6±1.5
		orthoclase	10.97	0.723	33.6	$0.158 \cdot 10^4$	$0.979 \cdot 10^6$	37.6±3.3
γ19 "	35 SND 118490	biotite	3.16	0.115	74.5	$0.115 \cdot 10^4$	$0.703 \cdot 10^6$	20.3±0.9
		orthoclase	10.06	0.425	97.3	$0.181 \cdot 10^4$	$0.139 \cdot 10^7$	24.2±1.1

± represent the 95% confidence level (see text).

on both $^{40}Ar/^{36}Ar$ and $^{40}K/^{36}Ar$ coordinates (FONTIGNIE 1980). The constants used are those recommended by the Commission on Geochronology (STEIGER & JÄGER 1977).

b) Discussion of the results

Two distinct isochron ages were calculated: 22.5 ± 0.5 and 38.5 ± 4.7 my. A large majority of individual dates plot on the 22.5-my isochron. This isochron has an initial ratio $^{40}Ar/^{36}Ar$ of 300 indicating the absence of excess argon.

Samples from Eğrigöz, Uludağ, Solarya and micas from Muratdağ and Kozak, belong to this isochron. All these granitic bodies are situated south of a line joining Eskişehir, Bursa, Manyas and Edremit. The normal $^{40}Ar/^{36}Ar$ ratio suggest that these granites had a simple cooling history since the system closed during Late Oligocene to Early Miocene.

Orthoclase from Muratdağ, Alaçam and Kozak plot on the 38.5-my isochron. The initial ratio of this isochron is close to 500 so that the presence of inherited argon cannot be eliminated. It must be pointed out that all these granites are from the southern part of the granitic belt, close to the metamorphic Menderes massif. Samples from Topuk give ages between 43 and 63 my. This granitic body is petrographically very different in that it has assimilated older rocks (large and abundant xenoliths have been described).

The orthoclase from Alaçam number 23 give a Mid-Cretaceous age. No reason can be envoked to explain this particular result.

A good agreement between mica ages occurs in the same granitic body and also between various massifs (except Topuk as stated above). On the other hand discrepancies appear with orthoclase ages for some samples. This mineral is not well adapted for potassium-argon dating because it does not retain argon well even at room temperature.

K-Ar ages published by ÖZTUNALI (1973) are very different from ours. They must suffer from a systematic error. It is not often that Rb-Sr ages are younger than K-Ar ages and the biotite age published by BÜRKÜT (1966) on Uludağ massif is in good accordance with our results.

K_2O-SiO_2 plot

A general petrochemical study of the granites of western Anatolia has been made by ATAMAN & BINGÖL (1978).

In the present paper only the K_2O-SiO_2 relationship is discussed. It is possible to show a correlation between the SiO_2/K_2O ratio and the geographic position of the intrusions (Fig. 2).

Correlation coefficients for the straight lines in Figure 2:

Group	No. of analyses	Correlation coefficient
1	16	0.4648
2	13	0.5902
3	30	0.7588

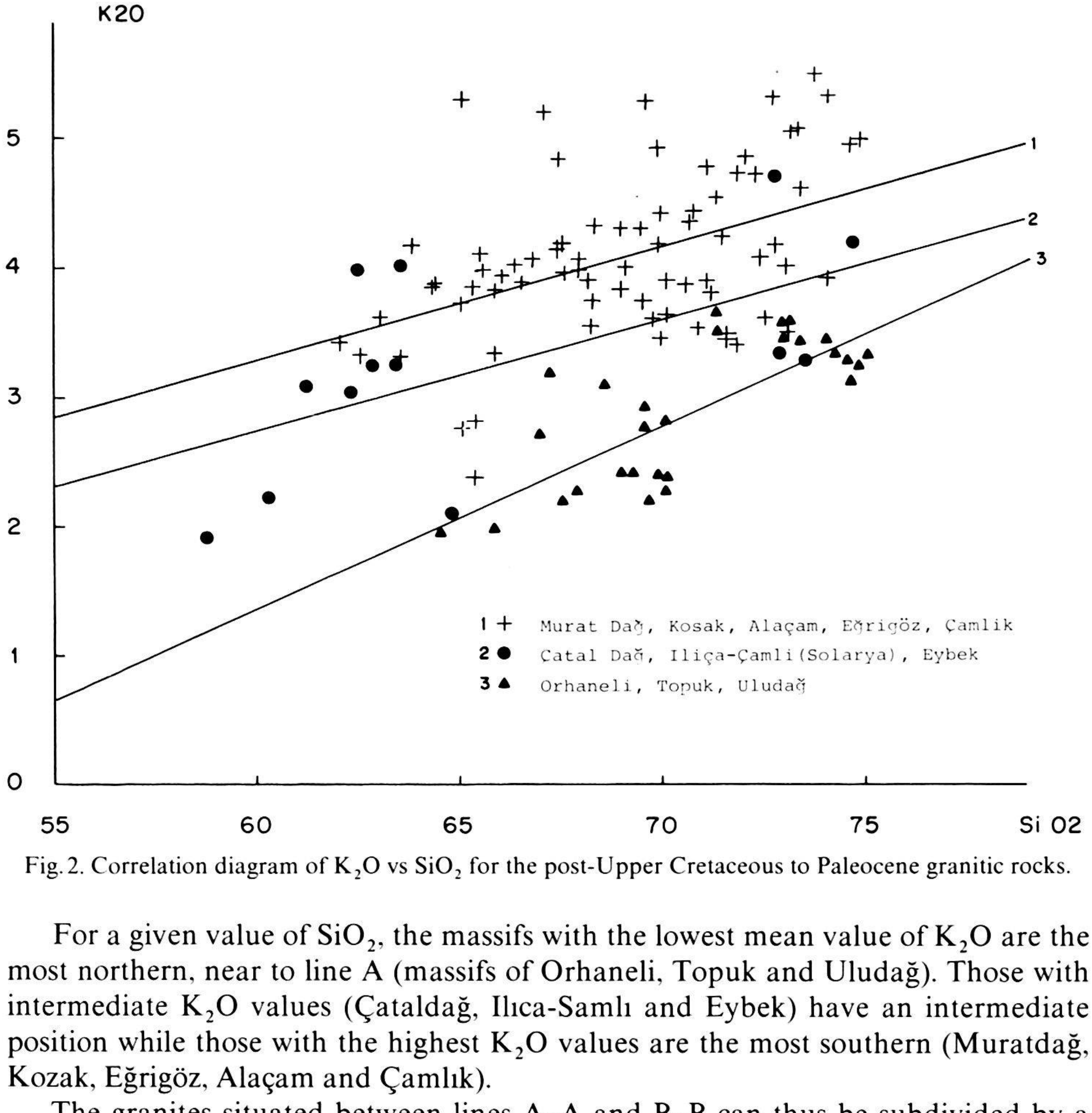

Fig. 2. Correlation diagram of K_2O vs SiO_2 for the post-Upper Cretaceous to Paleocene granitic rocks.

For a given value of SiO_2, the massifs with the lowest mean value of K_2O are the most northern, near to line A (massifs of Orhaneli, Topuk and Uludağ). Those with intermediate K_2O values (Çataldağ, Ilıca-Samlı and Eybek) have an intermediate position while those with the highest K_2O values are the most southern (Muratdağ, Kozak, Eğrigöz, Alaçam and Çamlık).

The granites situated between lines A–A and B–B can thus be subdivided by a line C–C which is nearly parallel to the Eskişehir–Bursa part of line A–A.

According to the Chappell & White (1974) classification of granites in S- and I-types, the granitic outcrops under investigation in the present paper are likely to belong to the I-type. The petrology and the geological environment of western Anatolia show that these granites belong to a spectrum of basic to acid differentiation. They present relatively high sodium contents in respect to potassium. The minerals hornblende and sphene are always present but muscovite, monazite, cordierite and garnet are rare or totally absent. The ratios FeO/Fe_2O_3 are high, magnetite is common in the opaque minerals. Unfortunately no isotopic oxygen measurements have been made; the $^{87}Sr/^{86}Sr$ ratios published in the literature (Bingöl 1977; Ataman 1974, 1975) are not numerous enough and are above and below the limit of 0.708. Isotopic strontium measurements are currently being made.

Our conclusion is that for a fixed value of SiO_2 there is a progressive increase in K_2O between the northeastern and the southwestern massifs.

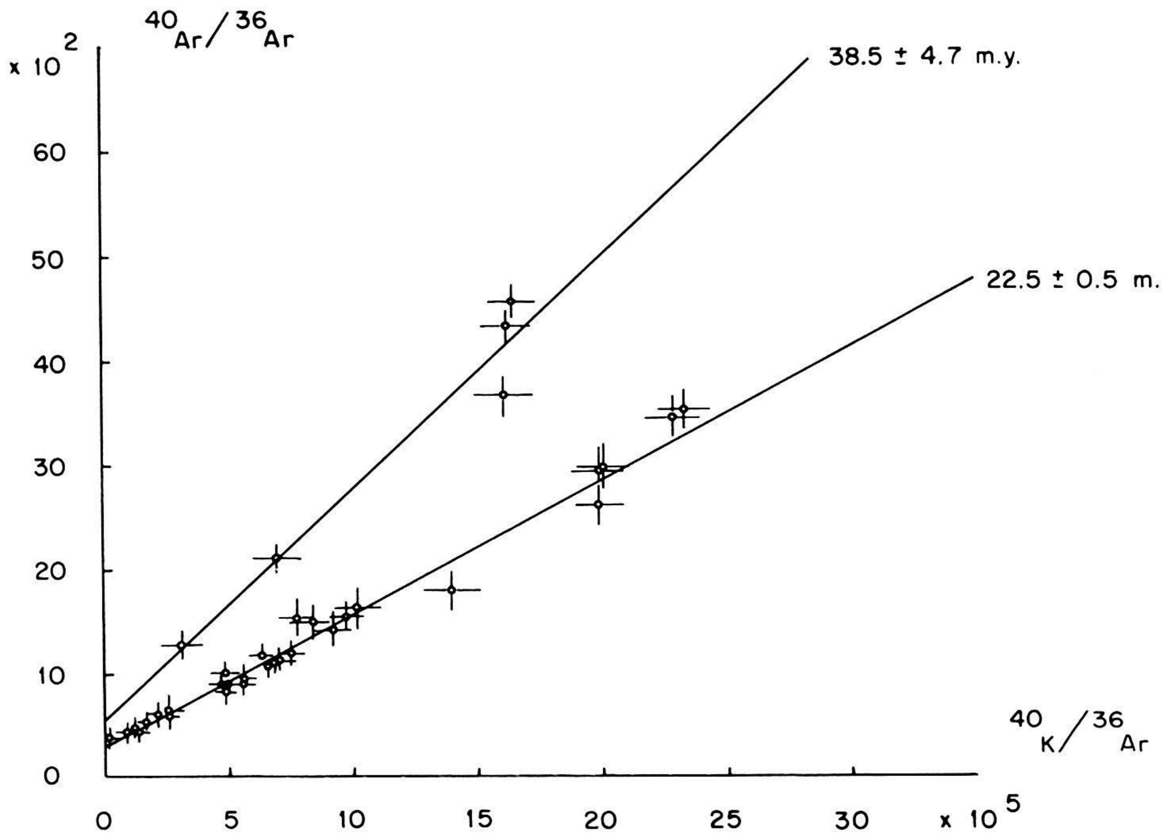

Fig. 3. $^{40}Ar/^{36}Ar$ vs $^{40}K/^{36}Ar$ isochrone plot of dated samples.

This gradient in K_2O may be an indication of the subduction direction in this area. BINGÖL (1976) proposed a subduction toward the north. According to the K_2O-SiO_2 plot and to the K–Ar age determinations presented here a possibility of one or several subduction zones inclined toward the south must be proposed. This has several important implications for the geodynamics of western Anatolia.

Most notably the thickening of the Menderes massif towards the south might have been caused by the reverse faults dipping north as a result of collision or down plunging of the southern continental crust under itself following the subduction northwards.

Conclusions

The granitic massifs of northwestern Anatolia can be classified into three families on the basis of age and petrology:

a) North of the North Anatolian Fault Paleozoic to Late Cretaceous granite are found.
b) Between the North Anatolian Fault and the Eskişehir–Bursa–Edremit line the granites are of pre-Liassic age.
c) South of the Eskişehir–Bursa–Edremit line the granites give Miocene radiometric ages. Moreover, it is possible to subdivide the latter family into three groups on the basis of K_2O content: for a fixed SiO_2 content the amount of K_2O in these granites increases from north to south.

On a regional scale the relations between the domains separated by line A-A (Eskişehir-Bursa-Edremit) have been reconsidered: the southern domain is thickened by the reverse faults dipping north as a result of collision or by down plunging under itself following the subduction northwards.

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