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Comparative petrogenetic investigation of Composite Kaçkar Batholith granitoids in Eastern Pontide magmatic arc—Northern Turkey

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The Pontides are an east-west trending orogenic belt which is subdivided into west, middle and eastern sectors according to their different tectonostratigraphy. The Eastern Pontides are represented by west-east-trending tectonic zones resulted from a common Mesozoic-Tertiary history, comprises dominantly of magmatic rocks. The magmatic belt in the Eastern Pontides includes a large batholith, termed the Composite Kaçkar Batholith (CKB) in which there are various granitic facies. The emplacement of CKB occurred in pulses between the Early Cretaceous and Eocene period during the development of the eastern Pontide magmatic arc and following collisional events. The members of the CKB are Dereli-Şebinkarahisar (Giresun) in the west, southern Araklı (Trabzon) in the middle and Kaçkar Mountain and its surrounding area (Rize) in the east. The plutons ranging from syenite through monzonite to granite are typically medium-high K calc-alkaline rarely tholeiitic and metaluminous I-type. The studied members of the CKB intrudes into the Late Cretaceous arc volcanics and are determined to be Late Cretaceous-Eocene (75.7 ± 1.55; 41.2 ± 0.89) in K-Ar age. The tectono-magmatic setting of the granitoids has been interpreted as an arc-related granitic suite, a post-collisional granitic suite and a post-orogenic granitic suite. Some plutons including mafic magmatic enclaves (MME) and K-feldspar megacrystals suggest magma mixing/mingling. HFS and LIL element geochemistry of the granitic intrusions also suggest that fractional crystallization, magma mixing/mingling and crustal contamination played an important role in the evolution of the CKB. All the data mentioned above show that the granitoids in the three different regions may have been derived from an arc, developed in response to the northward subduction of the northern branch of neo-Tethyan oceanic crust beneath the Eurasian plate in Late Cretaceous and a collision between the Pontide arc and the Anatolide-Tauride platform in Paleocene.
Key words: Granite, Turkey, arc magmatism, collision; Eastern Pontides.

1. Introduction

The Pontide tectonic belt of N Turkey is divided into three segments: the western, central and eastern Pontides, based on differences on pre-Jurassic basement units (Şengör and Yılmaz, 1981; Yılmaz *et al.*, 1997; Ustaömer and Robertson, 1997; Okay and Şahintürk, 1997). The Eastern Pontides is characterized by the Late Mesozoic-Early Tertiary magmatic belt (Fig. 1), interpreted as a west-east trending continental margin arc developed in response to the northward subduction of northern branch of neo-Tethyan oceanic crust beneath the Eurasian plate in Senonian, while the formation of an Atlantic-type active continental margin (Yılmaz *et al.*, 1997; Okay and Şahintürk, 1997; Ustaömer and Robertson, 1997). In this region, The Eastern Black Sea Basin opened during the Campanian-Maastrichtian through the rifting of a magmatic arc axis (Yılmaz *et al.*, 1997; Okay and Şahintürk, 1997). Closure of the Neo-Tethyan Ocean caused a collision between the Pontide arc and the Touride-Anatolide platform in the Paleocene-Early Eocene. The effect of this collision continued until the middle Eocene (Elmas, 1995; Yılmaz and Boztuğ, 1996; Yılmaz *et al.*, 1997; Okay and Şahintürk, 1997).

In the Pontide arc, calc-alkaline magmatic activity began in the Turonian and continued intermittently till the end of the Paleocene. During the same period, granitic intrusions were emplaced into the shallow levels of the crust and formed the first components of a composite pluton called the Rize granite (Çoğulu, 1975; Taner, 1977; Tokel, 1995; Yılmaz *et al.*, 1997). Emplacement of the pluton occurred in pulses and lasted until the late Eocene.

Magmatic rocks of different ages with various magmatic histories and different emplacement levels within the crust are exposed throughout the Pontide Belt. Granitic rocks in the Eastern Pontides were described as "Kaçkar Batholith" by Pelin (1977) first and "Composite Kaçkar Batholith" by Boztuğ *et al.* (2001) subsequently. Either the various types of granitoids from granite to gabbro or the assorted magmatic evaluation terms like arc to collision, post collision and even extensional regime magmatism derived from the direct mantle material uplifting which aroused interest in the region.

According to some of the former studies it is put forward that the granitic rocks are composed of hornblende-biotite granite, granodiorite and quartz diorite, intruding into basic volcanic rocks, and generally show a calc-alkaline trend and have 65–95 Ma, of isotopic age (Çoğulu, 1975; Taner, 1977; Gedikoğlu, 1978; Moore *et al.*, 1980; Okay

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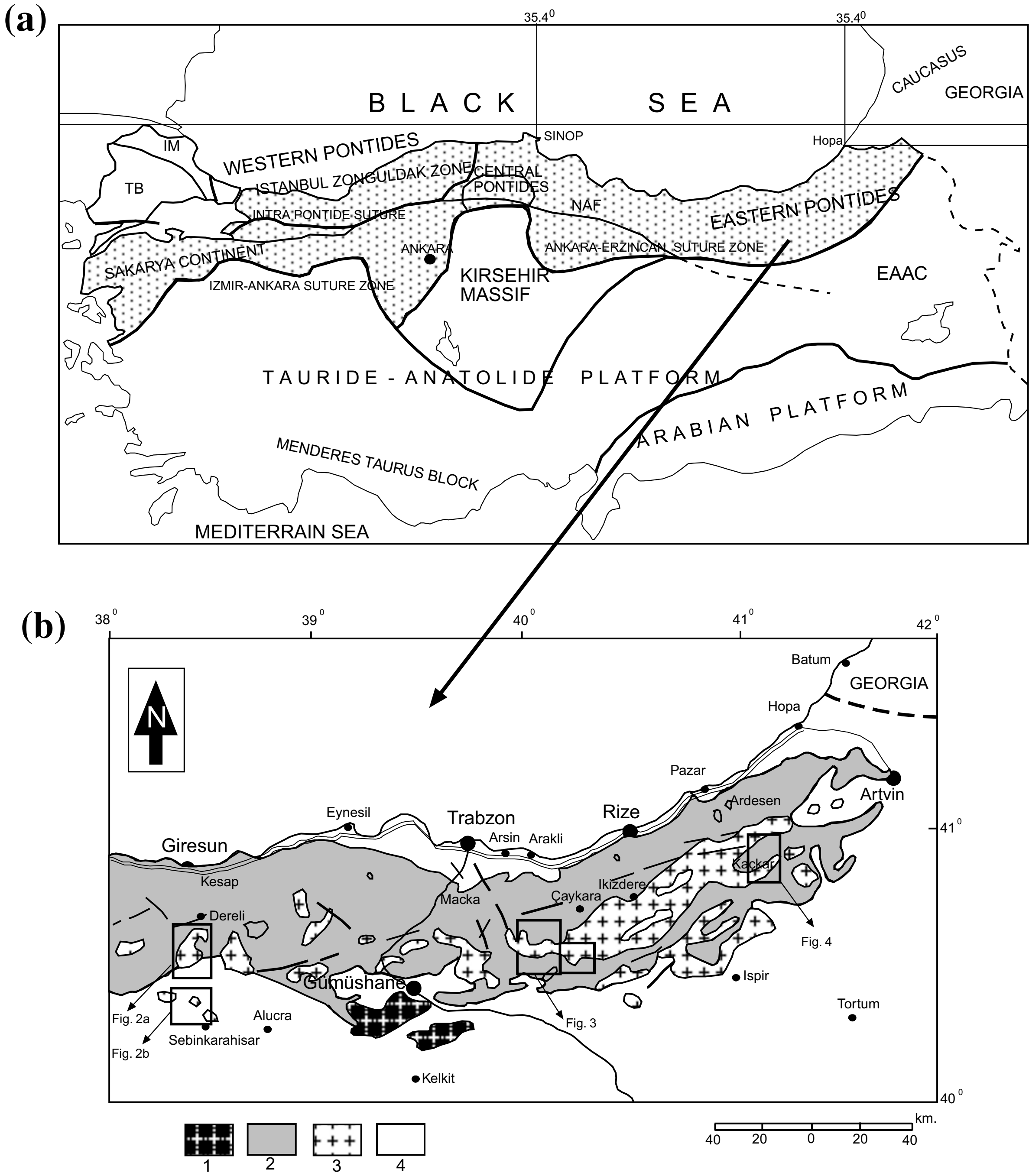

Fig. 1. (a) Major tectonic divisions of the Pontides and tectonic units of Turkey; IM, Istranca massive; TB, Thrace basin; AAZ, Armutlu-Almacık zone; KM, Kargı Massif; NAF, North Anatolian transform fault zone; EAAC, Eastern Anatolian accretionary complex (Yılmaz *et al.*, 1997). (b) Location map of the studied area include three different area as the Dereli-Şebinkarahisar, Araklı and Kaçkar regions. 1. Paleozoic granitoids, 2. Late Cretaceous volcanic-volcano-sedimentary rocks, 3. Late Cretaceous-Eocene granitoids, 4. Studied area.

and Şahintürk, 1997). The collision between the Anatolide and Pontide basements is suggested to have occurred sometime between Palaeocene (Yılmaz and Boztuğ, 1996) and early Eocene (Şengör and Yılmaz, 1981; Yılmaz *et al.*, 1997; Okay and Şahintürk, 1997), or the uppermost Cretaceous to early Palaeocene (Yılmaz *et al.*, 2000). Following this collision, an early to middle Eocene extensional regime took place in the Eastern Black Sea region. It has been explained that the extensional regime and associated magmatism in the Eocene is related to the opening of the oceanic Eastern Black Sea Basin (Okay and Şahintürk, 1997; Kazmin *et al.*, 2000). Petrographical-geochemical and petrological properties of granitoids are explained in recent studies (Boztuğ *et al.*, 2001; Boztuğ *et al.*, 2002a, b; Yılmaz Şahin, 2002, 2004). Granitoids outcropping from west to east in the Dereli-Şebinkarahisar (Giresun) area, in the south of Araklı region and in Kaçkar region are appreciated as the products of CKB in the Eastern Pontides (Fig. 1) and have been investigated for their different properties by many researchers (Yılmaz and Boztuğ, 1996; Güngör *et al.*, 1997; Boztuğ *et al.*, 2001; Boztuğ *et al.*, 2002a, b; Yılmaz-Şahin, 2002).

The aim of this study is to evaluate the data of the previous

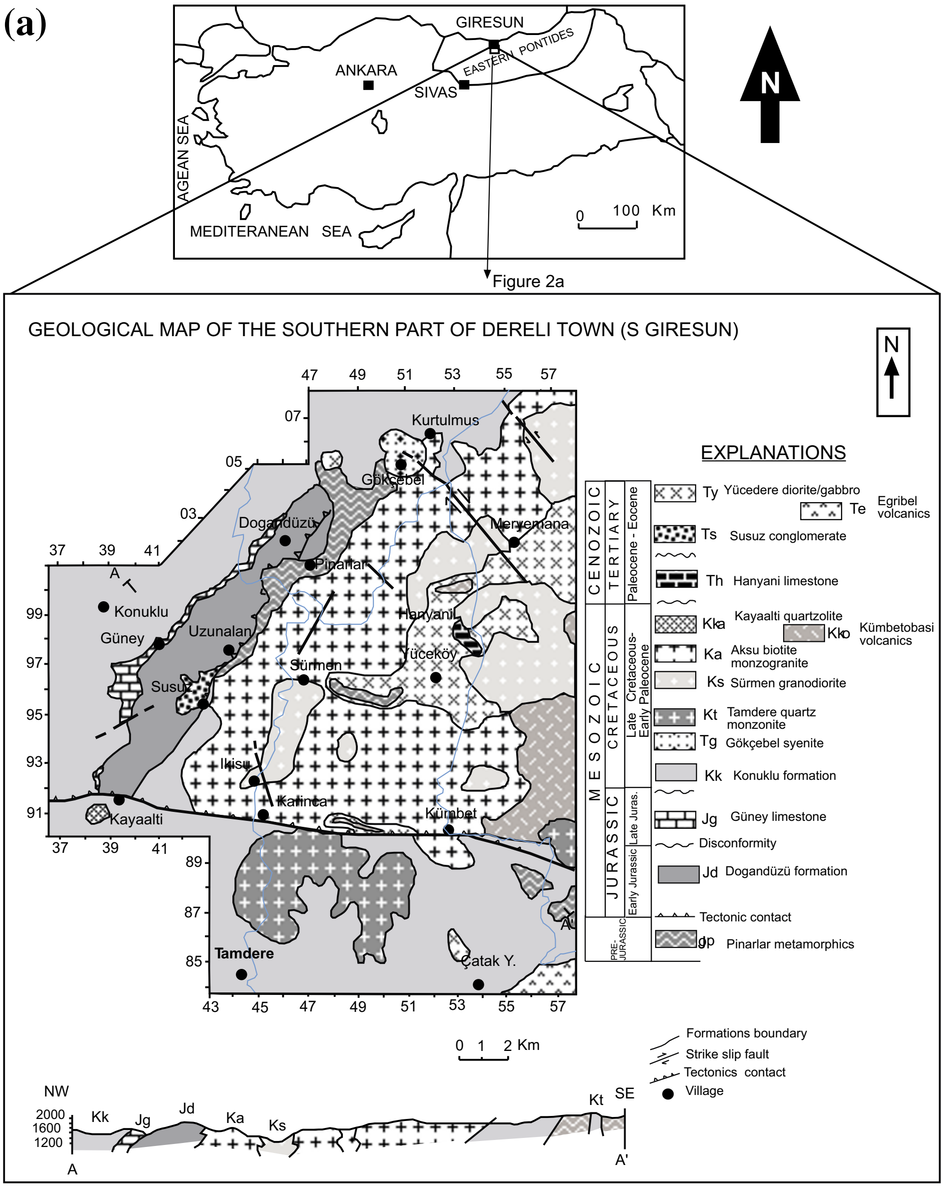

Fig. 2. Geological map of (a) The southern part of Dereli town (South Giresun); (b) The northern part of Şebinkarahisar town (South Giresun) (Yılmaz, 1995).

studies of the authors mentioned above, by explaining the similarities and differences of the plutonic rocks in terms of their age, magma types and geodynamic setting. Using the data from field mapping, petrography and whole rock geochemistry, we have attempted to determine the tectonomagmatic evolution of the Eastern Pontides and to provide better constraints of the geological evolution of Turkey.

2. Geological Setting

The granitoids of the Late Cretaceous to Eocene age are subclassed in three plutonic phases and are described in detail by Yılmaz and Boztuğ (1996) in the Dereli-Şebinkarahisar (DŞ) area (Figs. 2(a), (b)). The oldest unit of the DŞ region is the pre-Early Jurassic Pinarlar metamorphite which may be compared with the various types of regional metamorphic rocks (Topuz *et al.*, 2004) of Pulur massive in the Eastern Pontides (Okay and Şahintürk, 1997). The early Jurassic Doğandüzü formation, including volcanic-volcano-sedimentary rocks, tectonically overlays the metamorphic outcrops both in the Dereli and Şebinkarahisar areas. Uzunalan phyllonite is the third unit that was formed between Pinarlar metamorphic and Doğandüzü formation due to the NE-SW faulting system (Fig. 2(a)). The plutonics cut all these units. Previously, plutonic rocks were separated into three phases by Yılmaz and Boztuğ (1996), but later new radiometric ages (hornblende K-Ar) and cooling ages by apatite fission-track method (Boztuğ *et al.*, 2002a) required a revision. The first plutonic phase is Late Cretaceous in age, is syenitic-monzonitic in character and consists of Şebinkarahisar quartz syenite, Gökçebel quartz syenite and Tamdere quartz monzonite. Late Cretaceous Aksu biotite monzogranite and Sürmen granodiorite are defined as the second plutonic phase. These rocks intrude into the Late Cretaceous Konuklu and Kümbetobası formations of volcanic-volcano sedimentary rocks. Yücedere diorite/gabbro of the middle Eocene age is the third plutonic

(b)

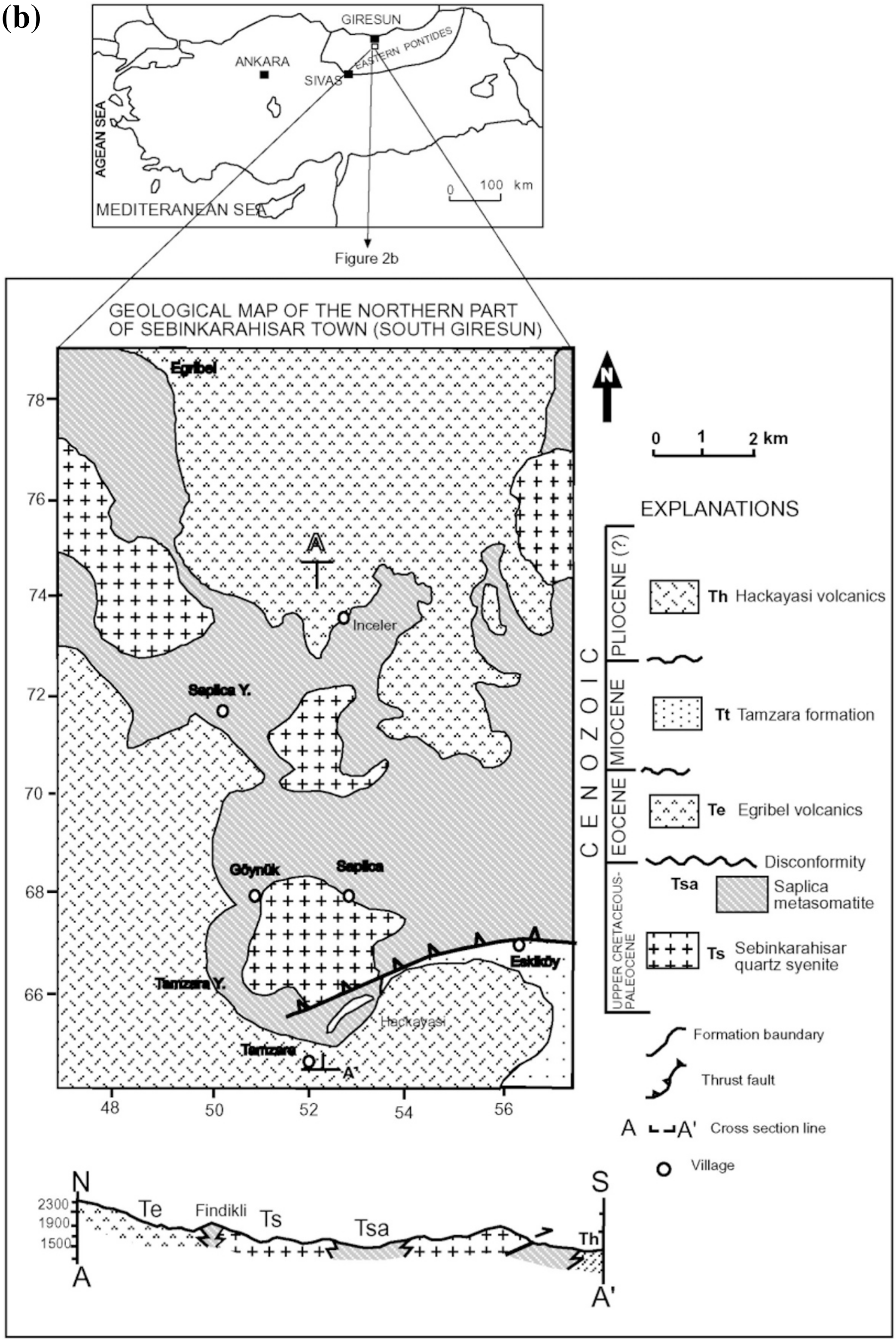

Fig. 2. (continued).

phase in the area. The youngest units of this region are the Miocene Tamzara formation and the Mio-Pliocene Hackayası volcanics (Fig. 2(b)).

The Araklı region (A) located in the westernmost part of the Kaçkar Batholith is evaluated within the magmatic association in the Eastern Pontide Magmatic Belt (Fig. 3; Yılmaz-Şahin, 2002). The oldest unit of this region is Early Jurassic basement metamorphic rocks, similar to the Pulur metamorphics and which is exposed in a very limited area. These rocks are disconformly covered by the Late Cretaceous volcanic-volcanosedimentary rocks called as the Taslıyayla volcanics including submarine basaltic-andesitic lavas, its pyroclastic products and carbonate-marl successions. Plutonic rocks of three different magma sources

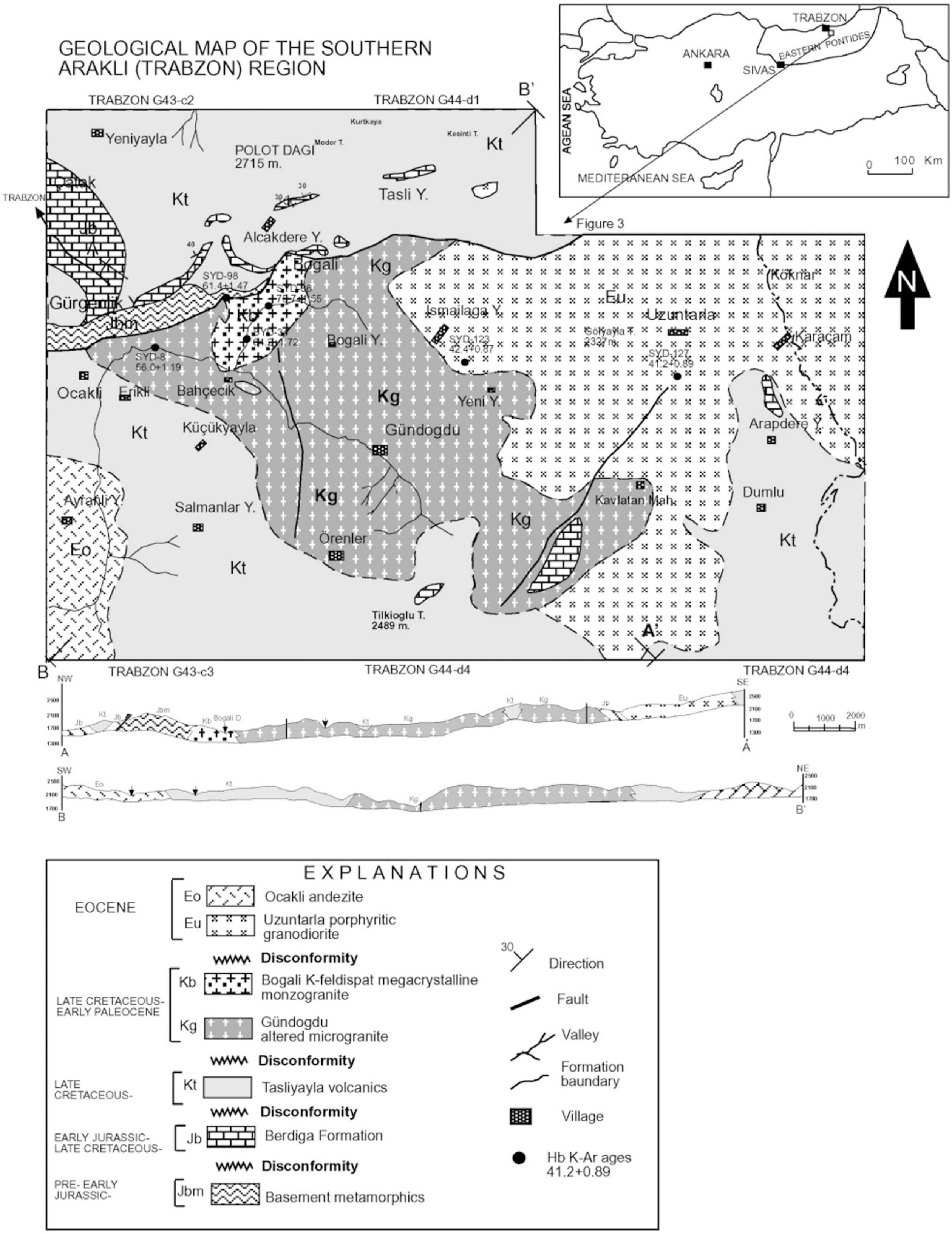

Fig. 3. Geological map of the south Araklı (Trabzon) region (Yılmaz-Şahin, 2004).

intrude into the Taslıyayla volcanics: Those are the Late Cretaceous-Early Paleocene Gündoğdu altered microgranite, Boğalı K-feldspar megacrystalline monzogranite and the Eocene Uzuntarla porphyritic granodiorite. The youngest unit of this region is the Ocaklı andesite (Yılmaz-Şahin, 2004; Fig. 3).

Three magmatic pulses comprising four plutonic units have been described at the main axis of the Kaçkar Batholith, in the most recent studies (Güngör, 1997; Fig. 4). These plutonics in the Kaçkar region called as Marselavat quartz

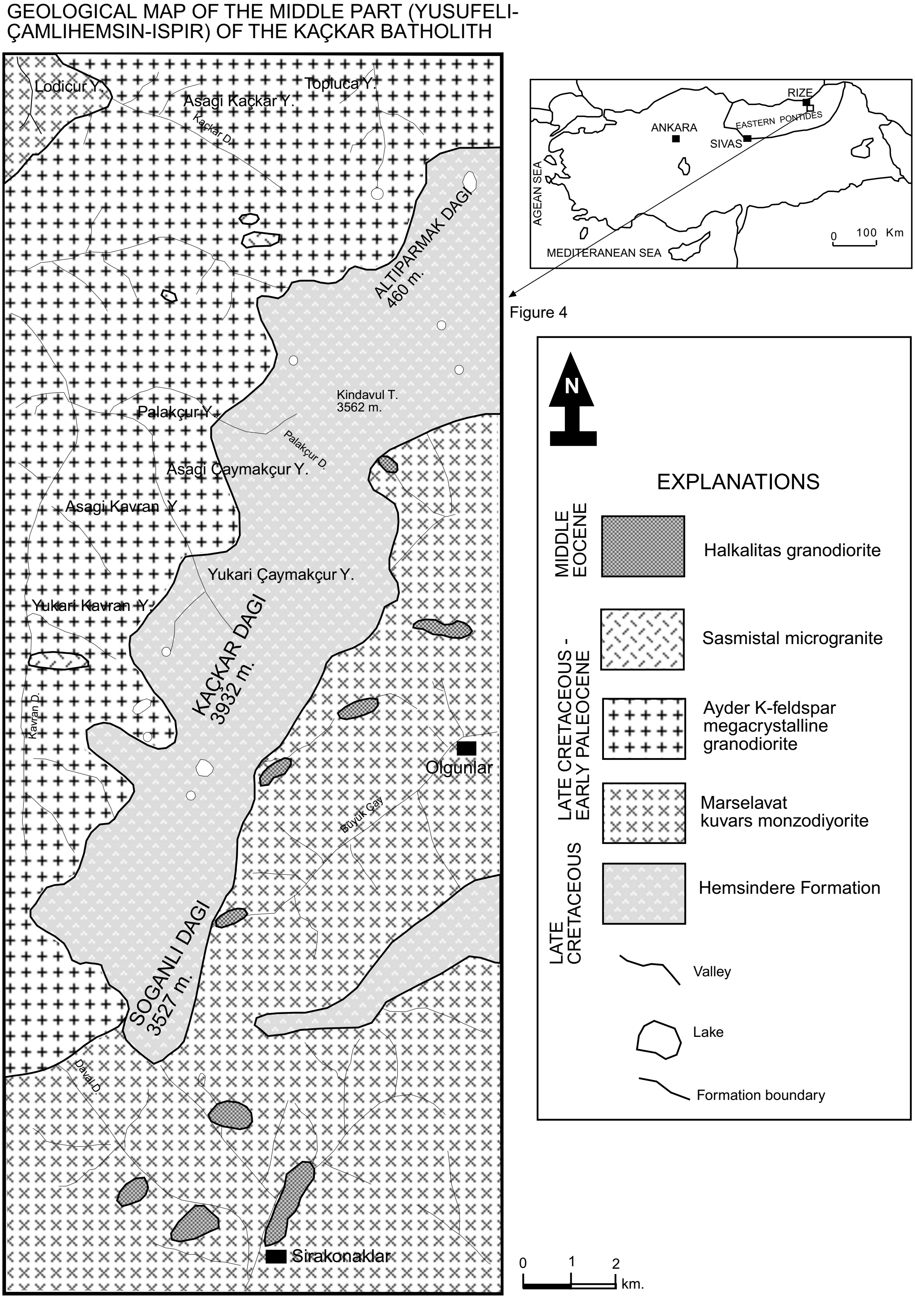

Fig. 4. Geological map of the middle part (Yusufeli-Artvin, Çamlıhemşin-Rize, İspir-Erzurum) of the CKB (Güngör, 1997).

monzodiorite, Ayder K-feldspar megacrystalline granodiorite, Sasmistal microgranite and Halkalıtaş granodiorite, intruding into the Hemşindere formation, aged from Late Cretaceous to Late Eocene.

The first magma pulse: Marselavat unit of the Late Cretaceous-Early Tertiary age is represented by the activity of monzonitic rocks.

The second magma pulse: Ayder unit of the Paleocene age and its highly fractionated product Sasmistal unit.

The third magma pulse: The youngest unit in the whole region; Halkalıtaş unit of the Late Eocene age (Fig. 4).

The plutons of CKB commonly intrude into Late Cretaceous volcanic rocks. They sometimes cause contact metamorphism in their wall rocks. Tectonically, E-W direction

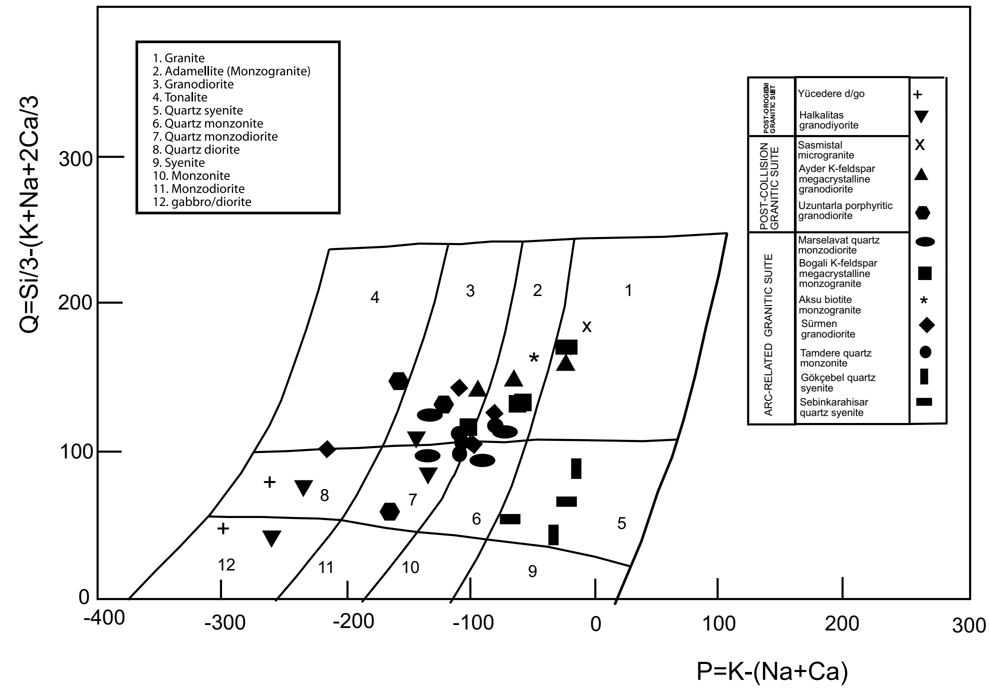

Fig. 5. Chemical nomenclature diagram (Debon and Le Fort, 1983) of the rock samples of some plutons of Dereli-Şebinkarahisar, Araklı and Kaçkar regions from the Kaçkar batholith.

thrusting faults and NE-SW direction diagonal faults formed under the effect of a N-S compression regime might have caused the intrusions of the plutons. According to geological properties; the pluton occurs in the three different areas of CKB may have different emplacement levels.

3. Intrusive Petrography

This study is supported by the previous major studies done (Yılmaz and Boztuğ, 1996; Güngör *et al.*, 1997; Boztuğ *et al.*, 2001; Yılmaz and Şahin, 2002) in the three different regions in order to compare the granitoids in terms of petrography.

3.1 Dereli-Şebinkarahisar region

The properties of the DŞ granitoids of the three plutonic phases are suggested to be valid for all the granitoids named as Composite Kaçkar Batholith (Yılmaz and Boztuğ, 1996). The first plutonic phase consists of Şebinkarahisar quartz syenite, Gökçebel quartz syenite and Tamdere quartz monzonite. According to the classification diagram (Debon and Le Fort, 1983); they are defined as syenite, quartz syenite and quartz monzonite (Fig. 5). The syenites are holocrystalline, medium to coarse grained, equigranular textured and mineralogically consist of alkaline feldspar (orthoclase and perthite), plagioclase, augite, hastingsite, arfvedsonite and quartz. Sphene, apatite, zircon and opaque minerals accompany the syenites as accessories. Tamdere quartz monzonite is medium-coarse grained and equigranular textured. According to the classification diagram (Debon and Le Fort, 1983) it is formed of quartz monzodiorite, quartz monzonite, granodiorite and adamellite (Fig. 5). Mineralogically, it consists of alkaline feldspar (orthoclase and microcline), plagioclase, quartz, hastingsite, augite and biotite; also apatite, epidote, zircon and opaque minerals as accessories. The second plutonic phase is constituted of granodiorite, monzogranite and adamellite of Aksu biotite monzogranite and Sürmen granodiorite (Fig. 5). Feldspars (commonly plagioclase (An_{25-40})) abundance in adamellite, occurrence of quartz and biotite, hornblende abundance in granodiorite and the presence of allanite makes out the mineralogical differences. The third plutonic phase is Yücedere diorite/gabbro and consists of diorite, quartz diorite and gabbro. Mineralogically it is composed of augite, hornblende and plagioclase (An_{35-50}).

3.2 Araklı region

Gündoğdu altered microgranite; the first unit of plutonic rocks (Fig. 3) in the South of Araklı differs from other rocks by its common aphanitic-porphyritic texture and graphic–myrmekitic texture. Alteration is mostly common in every rock such as rhyolite, porphyritic granite, aplite and granophyre dykes. Due to this common alteration, secondary minerals as carbonates, chlorites, epidotes and muscovites are formed. On account of this common alteration, whole rock geochemical analyses could not be done for the rocks of the unit except for the Boğalı and Uzuntarla rocks (Table 1). Boğalı K-feldspar megacrystalline monzogranite is situated in the adamellite area in the Q-P chemical nomenclature diagram (Fig. 5). These rocks are defined as porphyritic textured due to the presence of K-feldspar megacrystals and they contain mafic microgranular enclaves (MME) (Didier and Barbarin, 1991) and some special mixing textures (Hibbard, 1991, 1995) such as antirapakivi texture, spongy cellular dissolution/melting plagioclase and small lath-shaped plagioclase within large plagioclase. K-feldspar (orthoclase), plagioclase, hornblende, biotite and accessory apatite, titanite, zircon and opaque minerals are observed. Uzuntarla porphyritic granodiorite has a porphyritic texture with a fine grained matrix including plagioclase, quartz, orthoclase, hornblende, biotite and phenocrystals of plagio-

Table 1. Averages and standart deviations of the whole-rock major (wt %) and trace (ppm) chemical compositions of the various plutons of Dereli-Şebinkarahisar, Araklı and Kaçkar regions.

	DERELİ – ŞEBİNKARAHİSAR															
	Şebinkarahisar		Gökçebel		Tamdere				Aksu		Sürmen				Yücedere	
Sample	sq	mzq	sq	s	mzq	ad	mzdq	gd	ad	gr	ad	gd	mzq	dq	dq	d/go
	(n: 32)	(n: 03)	(n: 04)	(n: 01)	(n: 10)	(n: 09)	(n: 07)	(n: 01)	(n: 22)	(n: 05)	(n: 11)	(n: 06)	(n: 02)	(n: 01)	(n: 11)	(n: 04)
SiO_2	61.70	58.71	63.89	60.62	62.41	63.14	61.96	64.12	67.66	69.28	63.28	62.29	61.68	61.22	48.42	47.38
	(3.31)	(1.69)	(3.91)		(0.59)	(1.58)	(0.63)		(2.69)	(1.56)	(1.50)	(1.78)	(0.39)		(2.41)	(2.49)
TiO_2	0.45	0.57	0.27	0.36	0.37	0.36	0.34	0.35	0.41	0.41	0.47	0.50	0.51	0.58	0.74	0.57
	(0.08)	(0.06)	(0.08)		(0.04)	(0.05)	(0.16)		(0.06)	(0.09)	(0.05)	(0.10)	(0.01)		(0.30)	(0.06)
Al_2O_3	16.68	16.90	16.31	16.98	16.49	16.19	16.66	17.28	15.30	15.56	15.94	15.80	16.11	15.81	16.15	17.90
	(0.64)	(0.56)	(0.44)		(0.21)	(0.20)	(0.38)		(0.27)	(0.58)	(0.33)	(0.20)	(0.06)		(2.33)	(3.25)
Fe_2O_3	4.93	6.27	2.85	3.67	4.38	4.00	4.54	4.32	3.17	3.08	4.18	5.26	4.79	5.69	11.94	10.04
	(1.19)	(1.65)	(1.41)		(0.53)	(0.63)	(0.62)		(0.48)	(0.67)	(0.42)	(1.08)	(0.19)		(1.87)	(4.01)
MnO	0.26	0.16	0.08	0.09	0.12	0.12	0.13	0.10	0.06	0.06	0.08	0.10	0.10	011	0.24	0.17
	(0.71)	(0.02)	(0.04)		(0.01)	(0.03)	(0.08)		(0.01)	(0.01)	(0.01)	(0.02)	(0.01)		(0.12)	(0.07)
MgO	1.99	2.77	1.19	1.13	2.09	2.56	2.25	1.73	1.15	0.95	1.51	2.40	1.80	1.95	6.42	6.36
	(1.00)	(0.72)	(0.88)		(0.36)	(0.52)	(0.43)		(0.43)	(0.36)	(0.23)	(0.67)	(0.27)		(2.28)	(0.57)
CaO	2.98	4.62	2.97	4.45	4.38	3.89	4.59	4.36	2.65	2.23	4.35	4.84	4.78	5.55	10.80	12.78
	(1.24)	(0.76)	(1.42)		(0.21)	(0.66)	(0.09)		(0.32)	(0.40)	(0.56)	(0.45)	(0.49)		(1.51)	(2.86)
Na_2O	3.25	3.07	3.00	2.96	3.31	3.04	3.35	3.50	2.83	2.69	2.79	2.59	2.95	4.40	1.92	1.94
	(0.26)	(0.13)	(0.28)		(0.09)	(0.30)	(0.12)		(0.19)	(0.06)	(0.13)	(0.34)	(0.18)		(0.59)	(0.69)
K_2O	6.30	5.41	6.31	6.66	3.68	4.10	3.76	3.87	4.27	4.72	4.10	2.99	4.05	1.45	0.10	0.09
	(0.70)	(0.66)	(0.23)		(1.18)	(0.26)	(0.18)		(0.36)	(0.33)	(0.20)	(0.59)	(0.17)		(0.10)	(0.08)
P_2O_5	0.21	0.24	0.14	0.19	0.17	0.17	0.18	0.14	0.10	0.08	0.11	0.10	0.12	0.13	0.09	0.15
	(0.10)	(0.07)	(0.08)		(0.01)	(0.04)	(0.02)		(0.01)	(0.01)	(0.01)	(0.02)	(0.00)		(0.05)	(0.10)
LOI	1.09	0.93	1.61	1.20	0.77	1.25	1.04	0.17	1.08	1.23	1.56	1.54	1.57	1.29	1.72	1.04
	(0.51)	(0.09)	(0.20)		(0.45)	(0.27)	(0.44)		(0.36)	(0.23)	(0.35)	(0.43)	(0.01)		(0.90)	(0.12)
Total	99.72	99.67	98.64	98.31	98.51	98.52	98.82	99.84	99.08	100.54	98.40	98.41	98.45	98.18	98.51	98.67
	(1.13)	(1.40)	(0.31)		(0.53)	(0.27)	(0.75)		(0.74)	(0.32)	(0.35)	(0.53)	(0.24)		(0.31)	(0.30)
A/CNK	0.95	0.87	0.91	0.82	0.97	0.95	0.92	1.03	1.10	1.13	0.96	0.93	0.79	0.91	0.70	0.67
A/NK	1.37	1.55	1.33	1.34	1.83	1.63	1.69	1.95	1.69	1.60	1.83	1.95	1.38	2.15	4.94	5.44
Rb	235	154	196	173	109	120	96	107	155	175	118	104	114	56	39	34
	(83)	(43)	(33)		(17)	(19)	(07)		(22)	(32)	(17)	(24)	(02)		(9)	(15)
Sr	229	623	508	546	757	689	828	809	204	123	278	201	320	577	77	251
	(83)	(58)	(164)		(39)	(156)	(76)		(48)	(34)	(27)	(122)	(08)		(51)	(157)
Ba	675	773	780	659	954	997	963	886	716	647	807	601	859	660	182	195
	(192)	(46)	(171)		(54)	(86)	(82)		(83)	(35)	(145)	(171)	(56)		(27)	(34)
Y	58	44	46	46	28	30	27	29	36	41	31	26	30	24	11	11
	(20)	(13)	(02)		(02)	(03)	(01)		(04)	(06)	(03)	(04)	(0)		(5)	(5)
Zr	296	219	175	226	144	147	152	153	162	171	160	117	164	196	27	52
	(116)	(43)	(18)		(12)	(08)	(08)		(15)	(13)	(19)	(33)	(04)		(14)	(35)
Nb	21	14	12	09	03	03	03	03	10	11	9	5	9	11	0	3
	(16)	(08)	(4)		(01)	(02)	(02)		(04)	(02)	(02)	(04)	(0)		()	(4)
Th	70	50	36	19	13	15	12	16	17	22	16	16	12	12	3	5
	(48)	(29)	(17)		(03)	(05)	(03)		(05)	(05)	(05)	(03)	(04)		(3)	(5)
Pb	46	48	29	30	50	30	28	28	37	34	28	30	28	26	22	23
	(08)	(08)	(2)		(68)	(03)	(01)		(10)	(01)	(02)	(02)	(01)		(2)	(3)
Zn	93	90	78	78	83	81	81	82	83	83	88	85	91	90	92	82
	(10)	(4)	(7)		(12)	(14)	(04)		(07)	(06)	(02)	(08)	(01)		(6)	(13)
Co	76	237	54	60	100	62	76	99	132	150	84	91	84	42	48	42
	(27)	(281)	(10)		(17)	(20)	(33)		(26)	(25)	(14)	(15)	(05)		(10)	(2)
Cu	54	46	50	28	78	43	54	95	33	30	31	38	14	24	35	46
	(17)	(35)	(30)		(39)	(15)	(21)		(09)	(02)	(05)	(19)	(08)		(20)	(35)

Table 1. (continued).

	ARAKLI						KAÇKAR											
	Boğalı			Uzuntarla			Marselevat				Ayder		Sasmistal		Halkaltaş			
Sample	gr (n: 05)	ad (n: 04)	gd (n: 01)	gd (n: 07)	to (n: 02)	qmzd (n: 01)	mzdq (n: 11)	mzq (n: 8)	gd (n: 04)	ad (n: 03)	gd (n:17)	ad (n:08)	gr (n: 01)	gr (n: 05)	gd (n: 05)	d/go (n: 04)	dq (n: 03)	mzdq (n: 02)
SiO_2	68.57 (1.37)	67.96 (1.12)	66.31	63.85 (1.75)	65.32 (4.99)	56.39	60.95 (2.41)	68.18 (1.05)	63.47 (1.91)	63.86 (2.31)	68.22 (1.33)	69.69 (2.31)	71.55	75.14 (0.28)	60.50 (4.30)	52.70 (1.228)	55.27 (1.32)	60.05 (1.44)
TiO_2	0.28 (0.04)	0.28 (0.04)	0.33	0.41 (0.04)	0.42 (0.08)	0.53	0.65 (0.03)	0.58 (0.03)	0.54 (0.10)	0.60 (0.07)	0.38 (0.06)	0.41 (0.22)	0.31	0.11 (0.01)	0.60 (0.03)	0.74 (0.09)	0.70 (0.12)	0.69 (0.01)
Al_2O_3	15.59 (0.54)	15.77 (0.58)	17.24	16.07 (0.40)	15.96 (1.32)	15.70	16.21 (0.89)	16.13 (0.42)	16.11 (0.57)	15.30 (0.39)	15.04 (0.26)	15.00 (0.64)	14.55	13.98 (0.28)	16.00 (0.30)	18.45 (1.07)	17.45 (0.59)	16.46 (0.08)
Fe_2O_3	2.46 (0.41)	2.58 (0.51)	3.21	4.81 (0.58)	4.84 (0.31	6.67	5.22 (0.77)	3.90 (0.37)	4.31 (0.68)	4.07 (0.75)	2.44 (0.36)	2.16 (0.55)	1.78	0.27 (0.19)	5.30 (0.79)	7.74 (0.28)	7.39 (0.85)	5.30 (0.15)
MnO	0.09 (0.01)	0.10 (0.01)	0.12	0.12 (0.01)	0.12 (0.05)	0.14	0.12 (0.02)	0.09 (0.01)	0.11 (0.01)	0.08 (0.01)	0.06 (0.01)	0.06 (0.01)	0.04	0.01 (0.00)	0.14 (0.01)	0.17 (0.01)	0.16 (0.02)	0.13 (0.00)
MgO	1.32 (0.26)	1.31 (0.33)	1.45	2.60 (0.23)	2.35 (0.83)	5.80	3.61 (1.01)	3.02 (0.25)	2.84 (0.53)	3.36 (0.75)	1.42 (0.29)	1.24 (0.52)	0.86	0.01 (0.00)	3.33 (0.84)	4.87 (0.35)	4.43 (0.58)	3.33 (0.41)
CaO	2.76 (3.36)	2.67 (0.58)	3.41	3.90 (0.69)	4.32 (0.80)	5.22	5.03 (0.85)	4.28 (0.40)	4.30 (0.93)	3.93 (0.41)	2.79 (0.42)	2.37 (0.48)	1.85	0.78 (0.10)	4.31 (0.68)	8.56 (1.56)	7.63 (0.39)	5.28 (0.93)
Na_2O	3.51 (0.34)	3.54 (0.26)	3.92	3.64 (0.31)	3.78 (0.14)	4.01	3.50 (0.44)	3.37 (0.13)	3.56 (0.43)	3.04 (0.20)	3.85 (0.22)	3.61 (0.21)	3.18	3.36 (0.30)	3.73 (0.16)	3.89 (0.45)	3.64 (0.23)	3.44 (0.36)
K_2O	4.77 (0.43)	4.66 (0.22)	3.92	2.94 (0.46)	1.93 (0.21)	4.01	3.20 (0.60)	4.47 (0.30)	2.86 (0.95)	4.47 (0.48)	3.75 (0.43)	4.38 (0.41)	5.19	5.39 (0.27)	2.75 (0.43)	1.03 (0.66)	1.09 (0.53)	3.47 (0.22)
P_2O_5	0.14 (0.02)	0.13 (0.03)	0.17	0.14 (0.02)	0.12 (0.04)	0.15	0.22 (0.03)	0.24 (0.02)	0.20 (0.06)	0.23 (0.02)	0.17 (0.03)	0.14 (0.04)	0.12	0.03 (0.01)	0.18 (0.04)	0.26 (0.05)	0.23 (0.10)	0.21 (0.08)
LOI	0.87 (0.44)	1.22 (0.67)	0.64	1.79 (0.56)	1.66 (0.51)	3.00	1.00 (0.99)	0.55 (0.63)	0.88 (0.72)	0.98 (0.72)	1.00 (0.38)	0.48 (0.53)	0.15	0.29 (0.10)	1.35 (0.42)	1.17 (0.28)	1.43 (1.10)	1.05 (0.08)
Total	100.40 (1.20)	100.21 (0.38)	100.72	100.27 (0.31)	100.81 (0.72)	100.47	99.73 (0.63)	99.80 (0.63)	99.16 (0.65)	99.92 (0.85)	99.13 (0.31)	99.41 (0.69)	99.58	99.43 (0.41)	99.27 (0.59)	99.54 (1.01)	99.50 (0.77)	99.39 (0.00)
A/CNK	0.97	0.96	0.93	0.99	0.99	0.82	0.88	0.89	0.96	0.90	0.97	1.00	1.02	1.09	0.94	0.80	0.83	0.86
A/NK	1.42	1.37	1.39	1.75	1.92	1.62	1.76	1.55	1.80	1.55	1.45	1.40	1.34	1.23	1.75	2.45	2.43	1.75
Rb	149 (21)	149 (22)	144	85 (16)	51 (05)	68	68 (18)	130 (31)	67 (29)	118 (9)	126 (17)	162 (26)	216	215 (38)	50 (8)	15 (21)	21 (8)	77 (11)
Sr	442 (53)	455 (74)	410	607 (53)	626 (268)	792	396 (106)	445 (37)	420 (36)	474 (71)	627 (61)	469 (240)	494	40 (6)	409 (35)	473 (92)	494 (147)	419 (80)
Ba	1221 (238)	1285 (205)	463	1091 (193)	867 (261)	1072	569 (195)	6343 (99)	627 (162)	600 (133)	605 (92)	599 (168)	511	251 (42)	543 (200)	276 (157)	318 (155)	657 (105)
Y	31 (04)	31 (05)	32	16 (02)	12 (01)	14	212 (3)	27 (4)	20 (5)	34 (5)	31 (4)	37 (3)	45	47 (6)	21 (7)	10 (3)	12 (2)	20 (2)
Zr	149 (12)	148 (01)	153	136 (05)	126 (14)	133	160 (27)	174 (13)	187 (2)	187 (2)	168 (10)	162 (219)	147	92 (13)	173 (32)	90 (34)	105 (5)	164 (76)
Nb	16 (02)	16 (03)	22	11 (02)	11 (04)	7	9 (1)	12 (2)	14 (8)	18 (6)	30 (2)	31 (4)	30	31 (49	15 (7)	5 (2)	10 (8)	9 (1)
Th	27 (11)	26 (08)	35	07 (03)	04 (03)	16	9 (5)	19 (5)	11 (5)	24 (3)	33 (7)	34 (7)	40	49 (7)	7 (3)	1 (1)	1 (1)	7 (2)
Pb	25 (09)	25 (02)	25	23 (08)	16 (04)	23	20 (8)	35 (12)	25 (6)	26 (5)	28 (2)	29 (2)	31	28 (2)	17 (9)	12 (3)	17 (8)	16 (13)
Zn	40 (02)	47 (07)	49	64 (03)	60 (23)	66	66 (4)	75 (15)	71 (7)	66 (13)	73 (5)	69 (7)	73	59 (1)	80 (7)	83 (18)	78 (5)	72 (6)
Co	87 (24)	119 (66)	98	69 (35)	125 (110)	54	29 (7)	35 (6)	40 (20)	50 (37)	13 (16)	114 (43)	175	186 (40)	41 (14)	22 (6)	39 (18)	34 (4)
Cu	14 (25)	12 (06)	05	22 (57)	04 (02)	47	35 (10)	46 (7)	28 (18)	47 (35)	33 (13)	31 (7)	31	29 (3)	36 (50)	60 (27)	42 (35)	37 (11)

Exp: gr, granite; ad,adamellite; gd, granodiorite; to, tonalite; s,syenite; sq,quartz syenite; mz, monzonite; mzq, quartz monzonite; mzdq,quartz monzodiorite; d, diorite; go, gabbro; dq, quartz ; n,sample number; values in paranthesis, standart deviations.

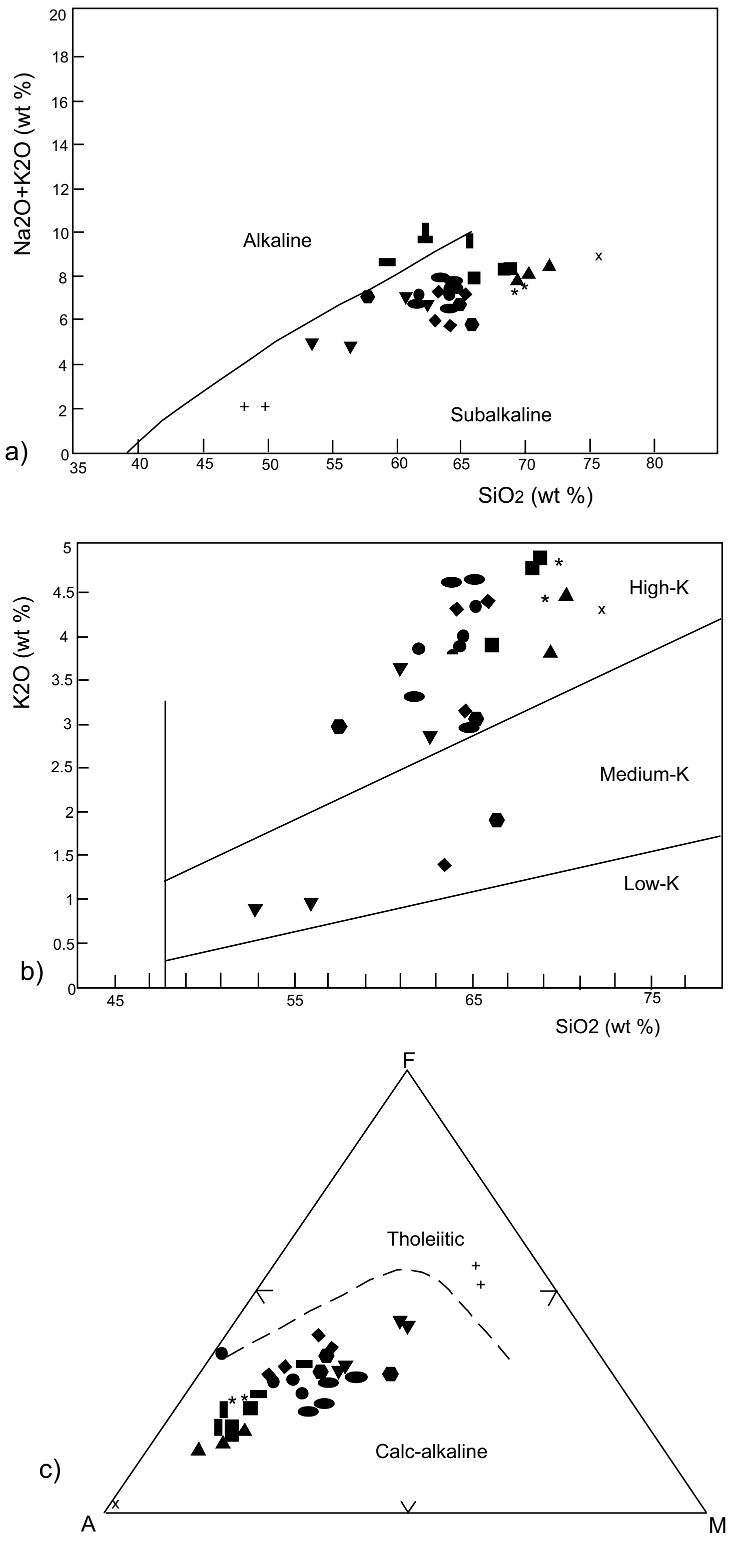

Fig. 6. (a) Total alkali vs. silica (Irvine and Baragar, 1971); (b) K_2O vs. silica (Peccerillo and Taylor, 1976) (c) AFM diagrammes (Irvine and Baragar, 1971) of the rock samples of some plutons of Dereli-Şebinkarahisar, Araklı and Kaçkar regions from the Kaçkar batholith. See Fig. 5 for explanation of symbols.

clase. The precence of corroded quartz just like in Boğalı unit is also a characteristic property of these rocks. Hydrothermal alteration is very common. As a result of alteration, secondary chlorite, epidote and clay minerals are observed.

3.3 Kaçkar region

Granitoids in Kaçkar region from gabbro to granite in composition, originated from different magma sources and under various interaction processes between felsic and mafic magmas (Güngör *et al.*, 1997; Boztuğ *et al.*, 2001, 2002a, b). In this study, four units belonging to Kaçkar batholith

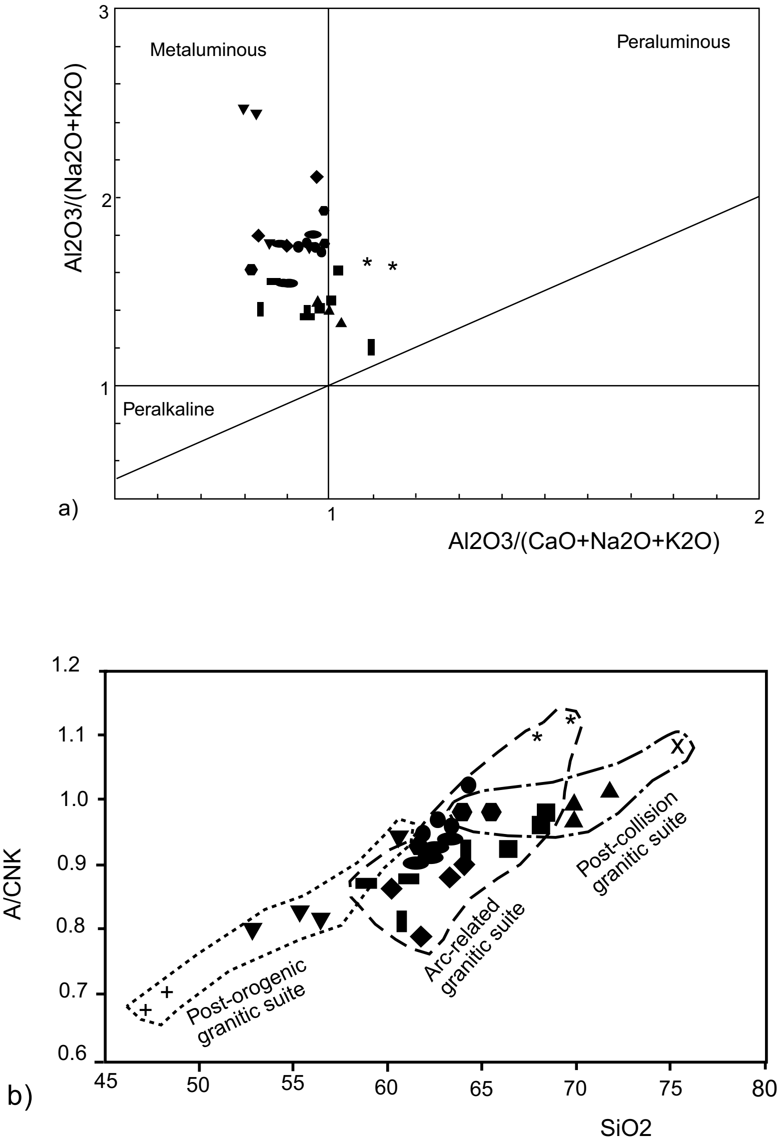

Fig. 7. (a) $Al_2O_3/(Na_2O+K_2O)$ vs. $Al_2O_3/(CaO+Na_2O+K_2O)$ diagram (Maniar and Piccoli, 1989); (b) ASI vs. SiO_2 diagram of plutons of CKB. See Fig. 5 for explanation of symbols.

are dealt with and compared with the plutons in the west. These plutons are Marselavat quartz monzodiorite, Ayder K-feldspar megacrystalline granodiorite, Sasmistal microgranite and Halkalıtaş granodiorite. Marselevat quartz monzodiorite and are mostly located in the quartz monzodiorite region but some of the samples are located in the quartz monzonite, granodiorite and adamellite region in the QP classification diagram (Fig. 5). The moderate-coarse grained, equigranular textured Marselavat unit contains hornblende, biotite and clinopyroxene as mafic minerals; MME's as evidence of magma mingling and also antirapakivi, poikilitik K-feldspar textures as some special mixing textures are observed. Ayder K-feldspar megacrystalline granodiorite which includes K-feldspar megacrystal of about 0.5–3 cm in diameter, are mostly porphyritic, less equigranular- and thought to be generated from the different magma source than that of Marselavat unit in Kaçkar Batholith. In the QP classification diagram they are situated in the granodiorite, adamellite and granite area (Fig. 5). Especially in granodiorites there are hornblende and clinopyroxene besides biotite. Not only the presence of K-feldspar megacrystals, but also the existence of MMEs, proves the mixing/mingling of mafic and felsic magmas. In addition, antirapakivi texture, poikilitic/oikocrystic K-feldspar, spongy cellular dissolution/melting plagioclase and boxy cellular growth plagioclase textures are observed as the evidence of magma mixing. Entirely granitic Sasmistal microgranite is a fractionation product that is emplaced in a subvolcanic position of Ayder unit. It shows mostly phaneritic and less aphanitic, fine-grained texture and vein type occurrences. Rocks include quartz, orthoclase, plagioclase and a small amount of biotite. Related to post-orogenic extension, Halkalıtaş granodiorite generated from the third magma source, intruded into shallow crustal levels as the forms of small stocks or sometimes N-S, NE-SW, NW-SE and E-W trending vein rocks. This unit is late Eocene in age and porphyritic rocks contain coarse plagioclase (An_{35-50}), hornblende and pyroxene phenocrysts in a fine matrix of feldspar and mafic min-

Table 2. Rock types, magma series, magmatic processes, geodynamic setting, K-Ar age dating (hornblende minerals) and apatite-sphene-zircon fission track analyses results of various plutons of Dereli-Şebinkarahisar, Araklı and Kaçkar regions.

	Unit	Rock type	Magma Series	Magmatic processes	Magma sources	Geodynamic setting	Apatite-sphene-zircon fission–track K-Ar (Hornblend minerals) dating	References
DERELİ-ŞEBİNKARAHİSAR	Yücedere	dq, d/go	Thooleiitic-Low-K		M-Type	Post-orogenic rifting		
	Aksu biotite	ad,gr	Subalkalin, High-K, Calk-alkaline	Slightly CC	Hybrid, I-type	Mature Arc	58-48 Ma (Apatite)	Boztuğ et al., 2002a
	Sürmen	ad,gd, mzq,dq	"	Magma mixing, mingling	"	"	"	"
	Tamdere	mzq,ad, mzdq,gd	"	FC, Magma mixing,/mingling	"	Initial Arc	80-60 Ma (Apatite)	"
	Gökçebel	sq,s	Alkaline-transalkaline, High-K calk-alkaline	Slightly CC	"	"	"	"
	Şebinkarahisar	sq,mzq	"		"	"	"	"
ARAKLI	Uzuntarla	gd,to, mzdq	"	CC, Magma mixing/mingling	"	Mature Arc	75.7$\pm$1.55-61.4$\pm$1.47 (hornblend K/Ar)	Yılmaz-Şahin, 2004
	Boğalı	ad,gr,gd	"	FC, CC, Magma mixing/mingling	"	Post-COLG	42.4$\pm$0.87-41.2$\pm$0.89 (hornblend K/Ar)	"
KAÇKAR	Halkalıtaş	gd,d/go, dq,mzdq	Subalkaline, Middle-High-K, calk-alkaline	FC, Magma mixing/mingling	Hybrid, I-type	Post-Orogenic rifting	53.0$\pm$2.8-45.3$\pm$2.5 (Sphene-Zircon)	Boztuğ et al., 2002b
	Sasmistal	gr	Subalkaline, High-K calk-alkaline			Post-COLG	46.5$\pm$2.4 Ma (Sphene-Zircon)	"
	Ayder	gd, ad, gr	"	CC, Magma mixing/mingling		"	46.5$\pm$2.4 Ma "	"
	Marselavat	qu-mz, gd, ad	"	FC, Magma mixing/mingling		Mature Arc	53.0$\pm$2.8 "	"

Explanations: gr, granite; ad,adamellite; gd, granodiorite; to, tonalite; s,syenite; sq,quartz syenite; mz, monzonite; mzq, quartz monzonite; mzdq,quartz monzodiorite; d, diorite; go, gabbro; dq, quartz

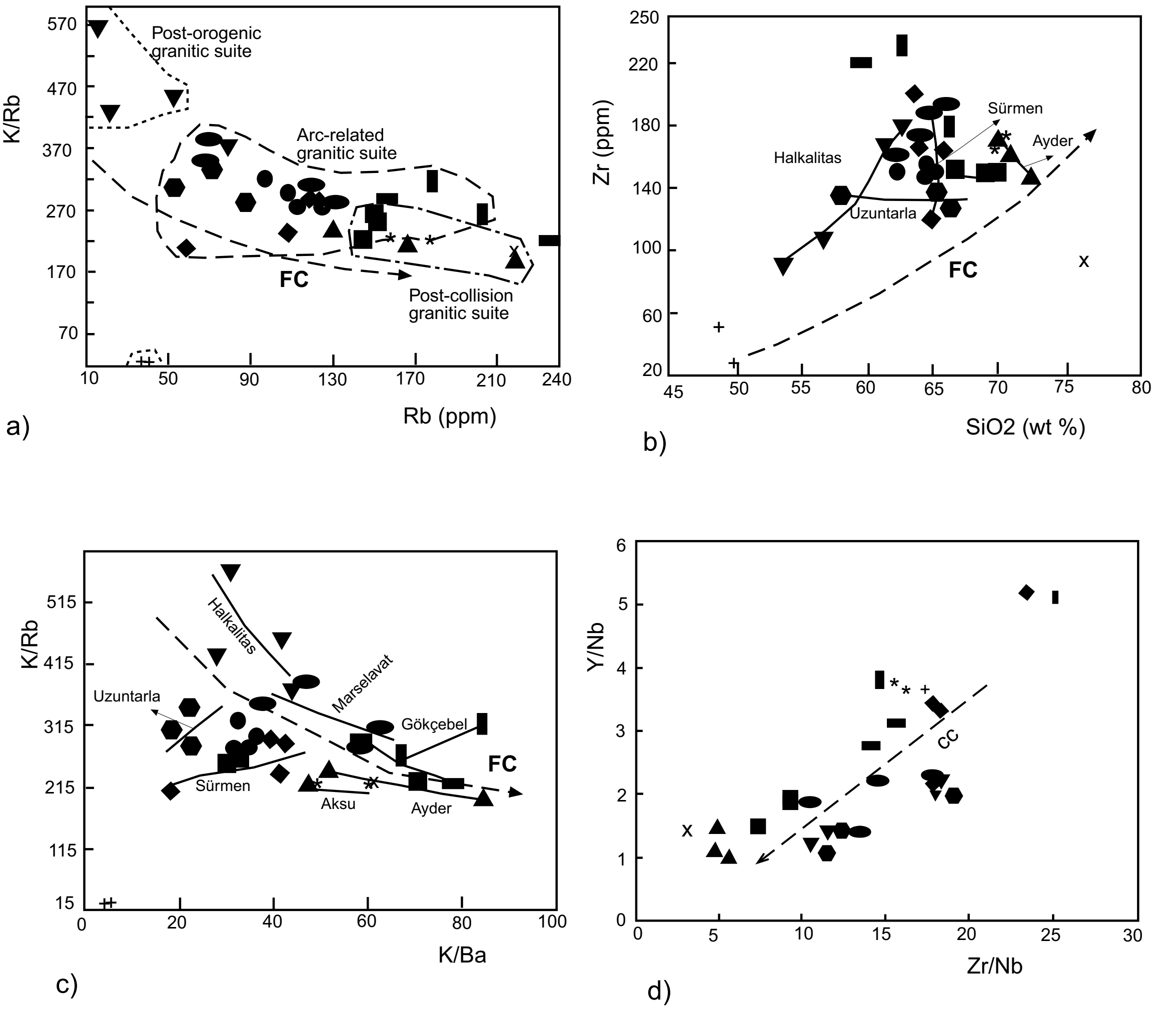

Fig. 8. Some LILE and HFSE variation diagram of the some plutons of Dereli-Şebinkarahisar, Araklı and Kaçkar regions. FC, fractional crystallization; CC, Crustal contamination. See Fig. 5 for explanation of symbols.

erals.

When the petrographical properties of the plutons of the three different regions are compared to each other (Table 2), Şebinkarahisar and Gökçebel units are similar but display differences from the Dereli-Şebinkarahisar area. There is not another unit similar to these plutons at the eastern part of Kaçkar Batholith, whereas Tamdere unit is like Marselavat unit in the Kaçkar region. Sürmen granodiorite resembles Uzuntarla porphyritic granodiorite and Halkalıtaş granodiorite, but shows textural and genetic differences from the rest. Boğalı and Ayder units are similar to each other in terms of rock-type but differ in their time of formation (Table 2).

4. Comparision of the Geochemical Features of the Plutons

The whole rock major and minor element analyses were done with the Rigaku-3270 E-WDS XRF spectrometer using USGS and CRPG rock standards (Govindaraju, 1989) for calibration at Cumhuriyet University Mineralogy-Petrography Research Laboratory (MIPJAL) and at ACME (ACME Analytical Laboratories Ltd., Canada), K-Ar geochronological studies at Israel Geological Survey and the apatite-sphene-zircon fission-track studies were held at Max Planc Instute in Hielderberg-Germany. A deal of whole rock major and minor element chemical analyses are evaluated by the Debon and Le Fort (1983) nomenclature diagram and then their average values (n) and standard deviations are calculated (Table 1).

The geochemical studies clarify the characters of the three plutonic phases in the *Dereli-Şebinkarahisar region*: The first phase is subalkaline–trans-alkaline, high-K calc-alkaline, the second phase is entirely subalkaline and the third phase is subalkaline-low-K tholeiitic (Figs. 6(a), (b), (c)). According to alumina saturation index (ASI) by Shand's (1947), most of the plutons of Dereli-Şebinkarahisar region are metaluminous except to Aksu biotite monzogranite (Maniar and Piccoli, 1989; Table 1; Fig. 7(a)). Arc, post-collision and post-orogenic associations are shown A/CNK-SiO_2 diagram (Fig. 7(b)). Aksu unit is a weakly peraluminous felsic I-type granite similarly to the ones—resultant largely from partial melting rather than fractional crystallization—in the Lachlan Fold Belt, (Chappell, 1999). According to the K/Rb-Rb, K/Rb-K/Ba and Zr-SiO_2 diagrams, every three plutonic phase originated from different magma source and particularly the first and the second phases arose due to fractional crystallization (Figs. 8(a), (b), (c)). The Y/Nb and Zr/Nb diagram is used to consider the degree of crustal contamination (Wilson, 1989).

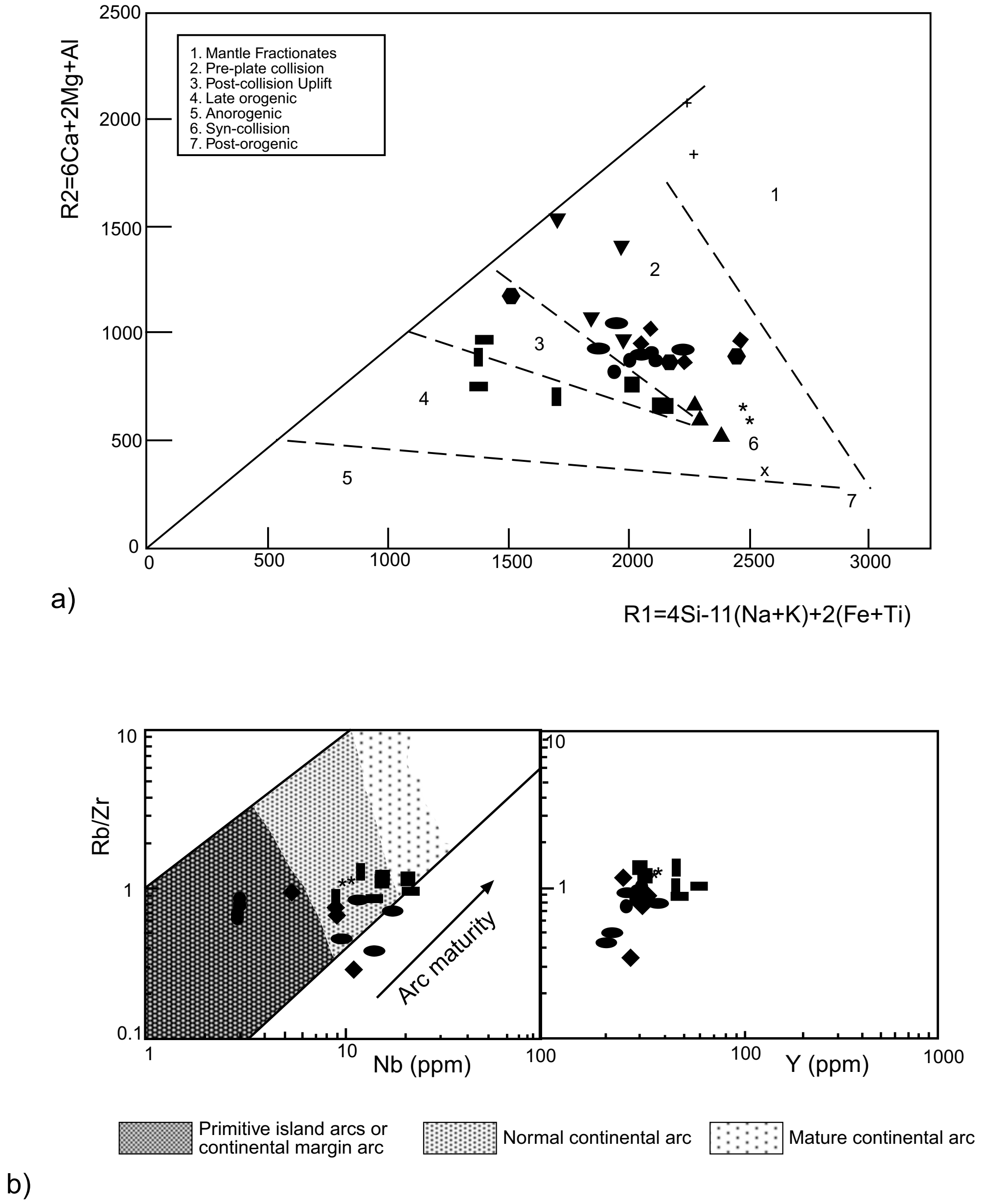

Fig. 9. (a) R1–R2 major element geotectonic discrimination diagram (Batchelor and Bowden, 1985) of the some plutons of Dereli-Şebinkarahisar, Araklı and Kaçkar regions. (b) Rb/Zr vs Nb, Y diagrams (after Brown *et al.*, 1984) for some units (Şebinkarahisar, Gökçebel, Tamdere, Sürmen, Aksu, Boğalı and Marselavat). See Fig. 5 for explanation of symbols.

In this diagram, the first, second and third phases show no or slight contamination (Fig. 8(d)). In the R1–R2 geotectonic discrimination diagram (Batchelor and Bowden, 1985), units of the first phase like Şebinkarahisar and Gökçebel are situated in the post-collision uplift field whereas Tamdere quartz monzonite is situated in the pre-plate collision field (Fig. 9(a)). Though the three units are the products of arc magmatism, because of the alteration, they are located in the post-collision uplift field in this diagram. Sürmen granodiorite of the second phase is located in the pre-plate collision field whereas Aksu biotite monzogranite plots near the area of syn-collision (Fig. 9(a)). Yücedere diorite/gabbro is located in the mantle fractionates field due to its M-type origin (Fig. 9(a)). In Nb-Rb/Zr and Y versus the Rb/Zr diagrams (Brown *et al.*, 1984), four plutons of Araklı region plot in normal arc area, two plutons (Tamdere and Sürmen) plot in primitive arc-normal arc transition (Fig. 9(b)). Rb, K, Th, Y display higher values than Ti in MORB normalized diagrams (Fig. 10).

Studies in the *Araklı region* point out that Boğalı and Uzuntarla units present differences in terms of geochemistry as well as their geodynamic position. Both units are subalkaline and each presents high-K calc-alkaline and moderate-high-K calc-alkaline, respectively (Figs. 6(a), (b), (c)). Granitic rocks of Araklı region are metaluminous based on the $Al_2O_3/(Na_2O+K_2O)$ versus $Al_2O_3/(CaO+Na_2O+K_2O)$ diagram (Maniar and Piccoli, 1989; Fig. 7(a)). ASI values of the plutons range from 0.82 to 0.99 (Table 1; Fig. 7(b)). In the K/Rb-Rb, K/Rb-K/Ba and Zr-SiO_2 diagrams, fractionation trends are clearly identified (Figs. 8(a), (b), (c)). In the Y/Nb- Zr/Nb diagram the trend indicates crustal contamination (Fig. 8(d)). Boğalı unit takes place in a post-collision

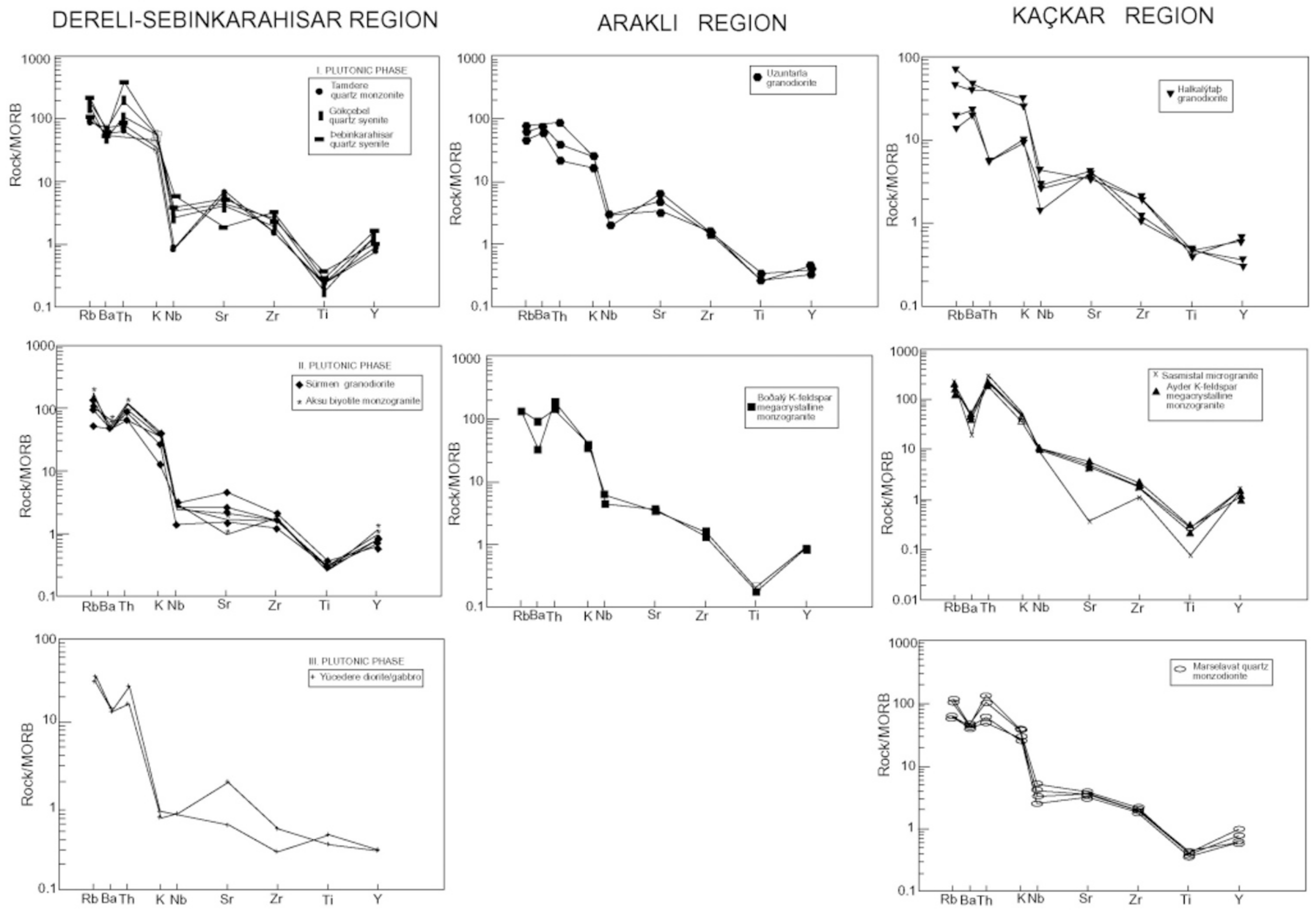

Fig. 10. Rock/MORB diagrams of some plutons of Dereli-Şebinkarahisar, Araklı and Kaçkar regions.

uplift area but Uzuntarla unit is settled at a pre-plate collision area based on R1–R2 diagram (Fig. 9(a)). Some samples of Boğalı unit plot in a normal arc area, as the others plot in a mature-arc area at the Nb-Rb/Zr and Y versus Rb/Zr diagrams (Fig. 9(b)). There are clear negative anomalies in Rock/MORB diagrams of Boğalı and Uzuntarla units in Th, Nb and Ti values (Fig. 10).

Granitoids from three different magma sources in the *Kaçkar region* represent differences in geochemical characteristics. Marselavat, Ayder with Sasmistal and Halkalıtaş units are classified as the first, second and third magmatic pulses, respectively (Güngör, 1997; Güngör *et al.*, 1997). The first and the second magmatic pulses are subalkaline, high-K calc-alkaline whereas the third pulse represents subalkaline, weakly tholeiitic and moderate-high-K calc-alkaline properties (Figs. 6(a), (b), (c)). Most samples of the units are plotted in metaluminous areas in the $Al_2O_3/(Na_2O+K_2O)$ versus $Al_2O_3/(CaO+O+Na_2O+K_2O)$ diagram (Maniar and Piccoli, 1989) except for Ayder unit (Fig. 7(a)). ASI of all of the units are <1.1 (Table 1) and show a fractionation trend in ASI versus SiO_2 diagram (Fig. 7(b)). In the diagrams of K/Rb-Rb, K/Rb-K/Ba and Zr-SiO_2, Marselavat and Halkalıtaş units show crystallization properties themselves. Sasmistal microgranite of the highly fractionated Ayder unit has a clear fractionation trend (Figs. 8(a), (b), (c)). In the Y/Nb-Zr/Nb diagram the crustal contamination trend is seen in all of them (Fig. 8(d)). In the R1–R2 geotectonic discrimination diagram, Marselavat is located in the pre-plate collision and Ayder and Sasmistal in the collision related region (Fig. 9(a)). Halkalıtaş granodiorite is located in the arc related region (Fig. 9(a)). Some samples of Marselavat unit plot in normal-arc area in the Rb/Zr-Nb and Rb/Zr-Y diagrams (Fig. 9(b)). The values of elements like Th, K, Sr, Zr, Y and Ti show positive anomaly in Rock/MORB diagrams. Similar characteristics are observed for Ayder and Sasmistal units. Besides, more fractionation causes a general decrease in the whole elements of Sasmistal unit (Fig. 10).

When the plutons of the three regions are compared in terms of geochemistry; Tamdere, Marselavat, Uzuntarla units and Halkalıtaş granodiorite present parallel fractionated trends in some of the fractional crystallization diagrams such as K/Rb-Rb, K/Rb-K/Ba and Zr-SiO_2 (Figs. 8(a), (b), (c)). In crustal contamination diagrams as Zr/Nb-Y/Nb, Ayder, Boğalı and Uzuntarla units seem to be much more contaminated than Halkalıtaş and Marselavat units but Şebinkarahisar, Gökçebel, Aksu and Yücedere units are the least contaminated by crustal material (Table 2, Fig. 8(d)). In the R1–R2 diagram; the majority of units take place in pre-plate collision area whereas a small part of the units are settled in post-collision uplift and collision related area (Fig. 9(a)). These units are not evaluated only by these diagrams, but are also considered according to the situation of their regional geological setting and geochronological ages

(Table 2). For example, though Halkalıtaş granodiorite is in the arc related region, it is thought to be a product of an old arc relevant to uplift after collision (Fig. 9(a)). Although most of arc related plutons are plotted in the normal arc area in the Rb/Zr-Nb and Rb/Zr-Y diagrams, some of them are plotted a normal arc-mature arc transition area. Only Tamdere unit settled in a primitive arc area (Fig. 9(b)). The plutons have properties resembling genetic and elementary behavior in Rock/MORB diagrams. For example, element behavior trends of Tamdere resemble arc related plutons, similar to trends of Marselavat unit (Fig. 10). Some elements such as Th, K, Sr and Zr show positive anomaly whereas others as Ba, Nb and Ti show negative anomaly in these diagrams. These types of element behaviors are seen at the active continental margins (Wilson, 1989). The display of values which are enriched in crustal originated elements such as Rb, K, Th, Y than in mantle derivate elements such as Ti and P (Mason and Moore, 1982; Wilson, 1989) in MORB normalized diagrams support arc magmatism with excess crustal contribution (Fig. 10). Yücedere and Halkalıtaş units present similar properties, especially, Sr, Zr, Ti and Y elements which are depleted than the Rb, Ba and Th elements (Fig. 10).

5. Discussion and Conclusions

Arc related calc-alkaline magmatism in Eastern Pontides began during the Turonian and continued till the end of the Paleocene (Tokel, 1995; Yılmaz and Boztuğ, 1996; Güngör *et al*., 1997; Okay and Şahintürk, 1997; Yılmaz *et al*., 1997; Yılmaz *et al*., 2000; Boztuğ *et al*., 2002a, b). During the same period granitic rocks of CKB kept intruding into the calc-alkaline volcanic rocks. Arc related granitic suite is calkalkaline, high-K subalkaline, hybrid and mostly metaluminous except Aksu unit which is slightly peraluminous and I-type in character (ASI < 1.1). This I-type character differs from fractionated and unfractionated I-type Lachlan Fold Belt granitoids (Chappell, 1999), for its distinctly high Sr and lower SiO_2 values. Due to this difference CKB may be suggested to be derived from hybrid magma formed from mantle and crust.

Different types of mafic microgranular enclaves (MME) and some special microscopic textures indicating magma mingling and magma mixing reflect a voluminous hybridization in the genesis of the magma source of the granitic suites. MMEs, especially, represent the hybrid liquids formed by the mixing of mantle derived magma with lower crustal melts.

The CKB granitoids derived from Eocene post-collision magmatism are called as post-collision granitic suite. The collision of the Pontide and Anatolide basements began around the Paleocene in the Eastern Pontides (Yılmaz and Boztuğ, 1996) and formed Uzuntarla unit, Ayder, and its highly fractionated derivative Sasmistal unit in the studied area.

Post-collisional magmatism might have been derived from the crustal rocks and the underplating mafic magma source. It is generally accepted that underplating and emplacement of significant volumes of hot basaltic liquids into the lower crust or at the crust-mantle interface may supply the heat needed to initiate and promote large scale crustal anatexis in a continental collision zone (Dewey *et al*., 1988; Bergantz, 1989). Peraluminous Ayder unit similar to the I-type Huangbai granites from Central China (Chen *et al*., 2002) is an example of this type of magma genesis.

After the crustal thickening, following this collision, an early to middle Eocene extensional regime occurred in Eastern Pontides resulting deformation of a post-orogenic granitic suite composed of Yücedere and Halkalıtaş units in CKB. These are tholeiitic, low-K, M-type and subalkaline, middle-high potassic, calcalkaline, hybride and I-type character, respectively.

Subsequent post-orogenic magmatism comprising entirely intraplate magmatic suites generally occurred from a new undepleted and enriched mantle source (Bonin *et al*., 1998). The Dabie UHP complex in Central China (Chen *et al*., 2002) is one of these types. Mantle-derived mafic/ultramafic magmas intruded into the thickened continental crust in the granitoids of Central China (Chen *et al*., 2002); In contrast, however, Yücedere unit intruded into the thinning continental crust, by extensional regime in post orogenic suite of CKB.

The intrusion of mantle derived mafic magma within the crust accompanied by extensive interaction with crustal and mantle derived melts produced hybrid parental magma which formed Halkalıtaş Unit.

All these intrusive suites representing various stages of a convergence system, i.e. subduction, post-collisional and post orogenic, are considered to be related to the evolution of the northward subduction of the northern branch of the neo-Tethyan Ocean beneath the Eurasian continent along the Ankara-Erzincan suture zone and subsequent compressional and extensional tectonic regimes.

The granitoid and the country rock studies done in the three different areas in the Eastern Pontides points out the results below;

- Arc related granitic suite is composed of Şebinkarahisar, Gökçebel, Tamdere, Sürmen, Aksu, Boğalı and Marselavat units. These units might have been crystallized from different magma sources under the effects of different magmatic processes (i.e. fractional crystallization, partial melting, crustal contamination, magma mixing/mingling), and they exhibit subalkaline, metaluminous, high-K, calkalkaline, I-type properties.

- Post-collision granitic suite comprises Uzuntarla, Ayder and Sasmistal units. Petrological features of this suite resemble the arc related granitic suite. Only the magma source of this suite presents differences from the other suites. The presence of K-feldspar megacrysts and MMEs in both of these suites suggest a hybrid magma source formed by the mixing of felsic and mafic magmas.

- Post-orogenic granitic suite consisting of Yücedere and Halkalıtaş units were formed under the extensional regime in Eastern Pontides. These units are tholeiitic, low-K, M-type and subalkaline, middle-high-K, calcalkaline, hybrid and I-type character, respectively.

- Boğalı and Uzuntarla units in Araklı region yield some hornblende K-Ar ages ranging from 75.7 ± 1.55 to 61.4 ± 1.47 Ma and from 42.4 ± 0.87 to 41.2 ± 0.89 Ma, respectively (Table 2).

- The plutons, outcropped in Kaçkar region are derived from three different magma sources and are comprised of different aged granitoids. One of these plutons is the Late Cretaceous-Early Tertiary (Paleocene) Marselavat unit displaying subalkaline, high-K calkalkaline, arc related character. Paleocene Ayder unit which is comprised of a different magma source, and its highly evolved fractionated derivative Sasmistal unit have subalkaline, high-K calc-alkaline, post-collision related magma genesis. The third and latest unit is the Late Eocene Halkalıtaş granodiorite which has middle-high K. The majority of samples are calc-alkaline, post orogenic extensional regime.

- Late Cretaceous–Paleocene Şebinkarahisar, Gökçebel, Tamdere Aksu, Sürmen, Boğalı and Marselavat units have arc character. On the other hand, Paleocene-Eocene Uzuntarla, Ayder and Sasmistal units have post collision character. Yücedere and Halkalıtaş units have post orogenic rifting features.

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References

Batchelor, B. and P. Bowden, Petrogenetic interpretation of granitoid rock series using multicationic parameters, *Chemical Geology,* **48**, 43–55, 1985.

Bergantz, G. W., Underplating and partial melting: implications for melt generation and extraction, *Science,* **245**, 1093–1095, 1989.

Bonin, B., A. Azzouni-Sekkal, F. Bussy, and S. Ferrag, Alcali-calcic and alkaline post-orogenic (PO) granite magmatism: petrologic constraints and geodynamic settings, *Lithos,* **45**, 45–70, 1998.

Boztuğ, D., İ. A. Erçin, D. Göç, M. Er, A. İskenderoğlu, M. K. Kuruçelik, and İ. Kömür, Petrogenesis of the composite Kaçkar batholith along a north-south geotraverse between Ardeşen (Rize) and İspir (Erzurum) towns, eastern Black Sea region, Turkey, Fourth International Turkish Geology Symposium (ITGS IV), 24–28 September 2001, Adana/Turkey, Abstracts, p. 210, 2001.

Boztuğ, D., R. Jonckheere, G. A. Wagner, S. Yılmaz Şahin, and Z. Yeğingil, Apatite fission-track ages provide uplift rates and time-temperature paths for the exhumation of Eastern Black Sea plutons in the Dereli-Şabinkarahisar area, S Giresun, NE Turkey, 1st International Symposium of the Faculty of Mines (İTÜ) on Earth Sciences and Engineering, 16–18 May 2002, Istanbul, Turkey, Abstracts, p. 116, 2002a.

Boztuğ, D., G. A. Wagner, A. İ. Erçin, D. Göç, Z. Yeğingil, A. İskenderoğlu, M. K. Kuruçelik, İ. Kömür, and Y. Güngör, Sphene and zircon fission-track geochronology unravelling subduction- and collision-related magma surges in the composite Kaçkar Batholith, Eastern Black Sea region, Turkey, 1st International Symposium of the Faculty of Mines (İTÜ) on Earth Sciences and Engineering, 16–18 May 2002, Istanbul, Turkey, Abstracts, p. 121, 2002b.

Brown, G. C., R. S. Thorpe, and P. C. Webb, The geochemical characteristics of granitoids in contrasting arcs and comments on magma sources, *J. Geol. Soc. London,* **141**, 413–426, 1984.

Chappell, B. W., Aluminium saturation in I- and S-type granites and the characterization of fractionated haplogranites, *Lithos,* **46**, 535–551, 1999.

Chen, B., B. Jahn, and C. Wei, Petrogenesis of Mesozoic granitoids in the Dabie UHP complex, Central China: trace element and Nd-Sr isotopic evidence, *Lithos,* **60**, 67–88, 2002.

Çoğulu, H. E., *Gümüşhane ve Rize bölgelerinde petrolojik ve jeokronolojik araştırmalar,* İstanbul Teknik Üniversitesi Yayını, v. 1034, 112 pp., 1975.

Debon, F. and P. Le Fort, A chemical-mineralogical classification of common plutonic rocks and associations, *Transactions of the Royal Society of Edinburg: Earth sciences,* **73**, 135–149, 1983.

Dewey, J. F., R. M. Shackleton, C. Chang, and Y. Sun, The tectonic evolution of the Tibetian Plateau, *Philos. Trans. R. Soc. London,* Ser., **A327**, 379–413, 1988.

Didier, J. and B. Barbarin, The different types of enclaves in granites-Nomenclature, in *Enclaves and Granite Petrology,* edited by J. Didier and B. Barbarin, Developments in Petrology 13, Elsevier, 19–23, 1991.

Elmas, A., Geology of the Kop Dağı area (Bayburt, Erzurum): evolution of a fore-arc basin (in Turkish), Türkiye Petrol Jeologları Derneği Bülteni, v. 6, p. 19–37, 1995.

Gedikoğlu, A., Harşit granite complex and neighboring rocks (Giresun-Doğankent), Habilatation thesis, Black Sea technical University, Trabzon, Turkey, 161 pp., 1978.

Govindaraju, K., 1989 Compilation of working values and sample description for 272 geostandards, *Geostandards Newsletter,* **13**, 1–113, 1989.

Güngör, Y., Kaçkar granitoyidi orta kesiminin mineralojik-petrografik ve litojeokimyasal incelenmesi, İstanbul Üniv., Fen Bilimleri Enst., Doktora tezi, 171s, 1997 (unpublished).

Güngör, Y., D. Boztuğ, and O. Yılmaz, Kaçkar Batoliti Altıparmak Dağı-Soğanlı Dağı arası kesiminin petrografik, jeokimyasal ve petrojenik incelenmesi, Yerbilimleri 30, s. 637–663, 1997.

Hibbard, M. J., Textural anatomy of twelve magma-mixed granitoid systems, in *Enclaves and Granite Petrology,* edited by J. Didier and B. Barbarin, Developments in Petrology 13, Elsevier, pp. 431–444, 1991.

Hibbard, M. J., *Petrography to Petrogenesis,* 587 pp., Prentice Hall, 1995.

Irvine, T. N. and W. R. A. Baragar, A guide to the chemical classification of common volcanic rocks, *Canadian Journal of Earth Sciences,* **8**, 523–548, 1971.

Kazmin, V. G., A. A. Schreider, and A. A. Bulychev, Early stages of evolution of the Black Sea, Geological Soc. London, Special Publ., 173, 235–249, 2000.

Maniar, P. D. and P. M. Piccoli, Tectonic discrimination of granitoids, *Geol. Soc. of America Bull.*, **101**, 635–643, 1989.

Mason, B. and C. B. Moore, *Principles of Geochemistry,* 344 pp., John Wiley and Sons, Hong Kong, 1982.

Moore, W. J., E. McKee, and Ö. Akıncı, Chemistry and geochronology of plutonic rocks in he Pontide mountains, Northern Turkey, in *European Copper Deposits, Belgrade,* pp. 209–216, 1980.

Okay, A. I. and Ö. Şahintürk, Geology of the Eastern Pontides, in *Regional and Petroleum Geology of the Black Sea and Surrounding Region,* edited by A. G. Robinson, AAPG Memoir, 68, pp. 291–311, 1997.

Peccerillo, A. and S. R. Taylor, Geochemistry of Eocene calc-alkaline rocks from the Kastamonu area, northern Turkey, *Contrib. Mineral. Petrol.*, **58**, 63–81, 1976.

Pelin, S., Geological study of the area southeast of Alucra (Giresun), with special reference to its petroleum potential, Karadeniz Teknik Üniversitesi, Yerbilimleri Dergisi, Jeoloji, v. 1, pp. 15–20, 1977 (in Turkish).

Şengör, A. M. C. and Y. Yılmaz, Tethyan evolution of Turkey: A plate tectonic approach, *Tectonophysics,* **75**, 181–241, 1981.

Shand, S. J., *Eruptive Rocks,* p. 488, Thomas Murby and Co., London, 1947.

Taner, M. F., Etude geologique et petrographique de la region de Güneyce, İkizdere, située au sud de Rize (Pontides orientales, Turquie), Ph.D these no. 1788, Geneve, 180 pp., 1977.

Tokel, S., Magmatic and geochemical evolution of the Pontide segment of the northern Tethys subduction system, Geology of the Black Sea region, Proceedings of the International Symposium on the Geology of the Black Sea Region, September 7–11, 1992, Ankara, edited by A. Erler, T. Ercan, E. Bingöl, and S. Örçen, published by the General Directorate of Mineral Research and Exploration and Chamber of Geological Engineers, Ankara, Turkey, 163–170, 1995.

Topuz, G., R. Altherr, A. Kalt, M. Satır, O. Werner, and W. H. Scwarz, Aluminous granulites from the Pulur complex, NE Turkey: a case of partial melting, efficient melt extraction and crystallization, *Lithos,* 2004 (in press).

Ustaömer, T. and A. Robetson, Tectonic-Sedimentary Evolution of the North Tethyan Margin in the Central Pontides of Northern Turkey, in *Regional and Petroleum Geology of the Black Sea and Surrounding Region,* edited by A. G. Rabinson, AAPG Memoir, 68, pp. 255–290, 1997.

Wilson, M., *Igneous Petrogenesis,* 456 pp., Unwin Hyman, London, 1989.

Yılmaz, A., S. Adamia, A. Chabukiani, T. Chkhotua, K. Erdoğan, S. Tuzcu, and M. Karabıyıkoğlu, Structural correlation of the southern Transcaucasus (Georgia)–eastern Pontides (Turkey), in *Tectonics and Magmatism in Turkey and Surrounding Area,* edited by E. Bozkurt, J. A. Winchester, and J. D. A. Piper, Geological Society of London Special Publications, 173, 171–182, 2000.

Yılmaz, S., Dereli-Şebinkarahisar (Giresun güneyi) arası granitoyid plütonlarının karşılaştırmalı incelenmesi, Doktora Tezi, Cumhuriyet Üniv., Fen Bilimleri Enstitüsü, 310 s, 2 Ek, Sivas, 1995 (unpublished).

Yılmaz, S. and D. Boztuğ, Space and time relations of three plutonic phases in the Eastern Pontides, Turkey, *Int. Geology Review,* **38**, 935–956, 1996.

Yılmaz Şahin, S., Petrogenesis of Some Shallow-Seated Granitoids from the Eastern Black Sea Plutonism in the South of Araklı Region, East Trabzon, Northern Turkey, 1st International Symposium of the Faculty of Mines (İTÜ) on Earth Sciences and Engineering, 16–18 May 2002, Istanbul, Turkey, Abstracts, p.117, 2002.

Yılmaz Şahin, S., Transition from arc-to post-collision extensional setting revealed by K-Ar dating and Petrology: An Example from the granitoids of the Eastern Pontide Igneous Terrain, Araklı-Trabzon, NE Turkey, *Geological Journal,* 2004 (submitted).

Yılmaz, Y., O. Tüysüz, E. Yiğitbaş, Ş. C. Genç, and A. M. C. Şengör, Geology of tectonic evolution of the Pontides, in *Regional and Petroleum Geology of the Black Sea and Surrounding Region,* edited by A. G. Robinson, AAPG Memoir, 68, 183–226, 1997.

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