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Post–Collisional Central Anatolian Alkaline Plutonism, Turkey

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Abstract: A number of Upper Cretaceous-Palaeogene alkaline plutons intruded into the crustal metamorphic rocks, the pre-Maastrichtian ophiolitic mélange, and the Cretaceous-Lower Tertiary units are located in the Central Anatolia (CA), Turkey. These alkaline plutons constitute an important association in the post-collisional Central Anatolian Granitoids. The Dumluca, Murmana, Karakeban, Kösedağ, Hasançelebi, Karaçayır and Davulalan plutons constitute the eastern; whereas the Eğrialan, Baranadağ, Hamit, Çamsarı, Durmuşlu and Bayındır units the western part of this alkaline association. These plutons are mainly composed of silica oversaturated syenitic to monzonitic, and undersaturated syenitic felsic rocks. However, the Dumluca, Murmana and Karakeban plutons also include some undersaturated alkaline mafic rocks which are derived from a different mafic magma source rather than being the early fractionation derivatives of the felsic rocks in these plutons. There are some diversification or subdivisions on the basis of mineralogical-chemical characteristics, wall-rock, silica saturation and associated ore deposit/mineralization in these alkaline plutons. The diversification is thought to be sourced from either some solidification processes which modify the primary composition of any mantle-derived magma, or some different alkaline magma pulses generated by the partial melting of mantle material with different types and degrees of partial melting processes in water-starved environment. The latter consideration seems to be more reasonable due particularly to LIL and F enrichments in these rocks. They apparently indicate "late orogenic" , "within plate granite (WPG)" and "post-collisional" characteristics on the basis of their major and trace element geochemistry. When the mineralogical-chemical data is considered together with the space-time relations in a regional geological setting, one can suggest such a geodynamic model for the CA post-collisional alkaline plutonism: The magma source of this plutonism can be derived from the partial melting of upwelling upper mantle material by the adiabatic decompression mechanism in the passive margin of the Anatolides in a post-collisional lithospheric attenuation environment within a tensional regime immediately after crustal thickening due to Anatolide-Pontide collision along the northward subduction zone of the northern branch of Neo-Tethys.

Key Words: Post–collisional granitoids, alkaline magmatism, mineralogical–chemical classification, diversification in alkaline plutons, alkaline magma genesis, collision of Anatolides and pontides, Central Anatolia–Turkey.

Çarpışma Sonrası Orta Anadolu Alkali Plütonizması, Türkiye

Özet: Üst Kretase-Paleojen yaşlı birçok alkali plüton, Orta Anadolu bölgesindeki kabuksal metamorfitlere, pre-Maestrihtiyen yerleşim yaşlı ofiyolitik melanja ve Kretase-Alt Tersiyer yaşlı birimlere sokulum yapmaktadır. Bu plütonlar, çarpışma sonrası Orta Anadolu Granitoyidleri içerisinde önemli bir birlik oluştururlar. Dumluca, Murmana, Karakeban, Kösedağ, Hasançelebi, Karaçayır ve Davulalan plütonları bu alkali plütonik birliğin doğu kesimini; Eğrialan, Baranadağ, Hamit, Çamsarı, Durmuşlu ve Bayındır plütonları ise batı kesimini oluşturmaktadır. Bu plütonlar, başlıca, silis bakımından aşırı doygun alkalin karakterli siyenitik-monzonitik ve silis bakımından tüketilmiş alkalin karakterli siyenitik bileşimli kayaçlardan oluşmaktadır. Bununla birlikte Dumluca, Murmana ve Karakeban plütonları silis bakımından tüketilmiş alkalin karakterli mafik kayaçları da içerirler. Bu alkali mafik kayaçların, bu plütonlardaki felsik alkali kayaçları oluşturan magmanın ilk fraksiyonlanma ürünlerinden ziyade, farklı bir magmadan itibaren meydana gelmiş oldukları sonucuna varılmıştır. Çarpışma sonrası Orta Anadolu alkali magmatik birliğini meydana getiren plütonlar mineralojik-kimyasal karakteristikler, yan kayaç, silisçe doygunluk ve birlik oluşturdukları maden yatakları/cevherleşmeler bakımından çeşitli alt gruplara ayrılırlar. Bu alt gruplara ayrılma özelliğinin, mantodan türemiş bir magma kaynağının katılaşması sırasında etkin olan ve böylece bileşimin değişimine neden olan bazı katılaşma süreçleriyle meydana gelebileceği gibi; manto malzemesinin, su bakımından fakir ortamlarda, değişik tip ve derecelerde kısmi erimeye uğraması sonucu oluşan değişik alkali magma getirimlerinden de kaynaklanabileceği düşünülmektedir. Farklı magma getirimleri düşüncesi, bu kayaçların özellikle LIL bakımından zengin olması ve F cevherleşmesi içermesi bakımından daha uygun görülmektedir. Orta Anadolu alkali plütonları ana ve eser element jeokimyası verilerine göre belirgin bir şekilde "geç orojenik", "levha içi" ve "çarpışma sonrası" karakteristikleri gösterirler. Mineralojik-kimyasal veriler, bölgesel jeolojik konum ile birlikte değerlendirildiğinde, çarpışma sonrası Orta Anadolu alkali plütonlarının oluşumu için şöyle bir jeodinamik evrim modeli ileri sürülebilir: Bu plütonizmanın magma kaynağı, Neo-Tetis'in kuzey kolunun, kuzeye doğru dalma-batmaya uğramasıyla meydana gelen sütur zonu boyunca gelişen Anatolid-Pontid çarpışmasına bağlı kabuk kalınlaşmasından hemen sonra gelişen çarpışma sonrası gerilme rejimi altındaki litosferik incelme sırasında, Anatolidlerin pasif kenarında yükselmiş bulunan manto malzemesinin adiyabatik dekompresyon mekanizması ile kısmi erimeye uğraması sonucu meydana gelmiş olabilir.

Anahtar Sözcükler: Çarpışma sonrası granitoyidler, alkali magmatizma, mineralojik–kimyasal sınıflandırma, alkali plütonizmada farklılaşma, alkali magma oluşumu, Anatolid–Pontid çarpışması, Orta Anadolu–Türkiye.

Introduction

The collision event conceptually indicates the final stage of an orogenic phase through which a new rifting/opening of an oceanic basin, i.e. Wilson cycle (Mason, 1985; p.139), has already started, and, also the initialization stage, i.e. triggering, of the following orogenic phase by causing a change of tectonic regime from compressional to tensional (Channel, 1986). So that, the juxtaposition of two plates at the end of an orogenic cycle also triggers a new Wilson cycle in geological context in space and time. This process, so-called collision or juxtaposition, takes several tens of millions of years (aproximately 30-50 Ma, Bonin, 1990). This time span is particularly characterized by some special geological records that appear in magmatism, metamorphism and sedimentation (Coward and Ries, 1986).

Geologically, Turkey constitutes an important part of the Alpine-Himalayan system which is one of the most spectacular collision zones of the planet Earth. As commonly known, the Neo-Tethyan oceanic realm, opened in Triassic and closed in Upper Cretaceous (şengör and Yılmaz, 1981; Poisson, 1986), has been an important convergence system in the evolution of Turkey, and, of course, of the Alpine-Himalayan belt. The Upper Cretaceous subduction and following collision of the Neo-Tethyan oceanic crust with the Rhodope-Pontide fragment has resulted to form some special geological structures (Şengör and Yılmaz, 1981), e.g. Ankara-Erzincan suture zone and eastern Pontide arc magmatism; post-collisional Sivas basin (Cater et al., 1991; Yılmaz, 1994) and other Central Anatolian basins (Görür et al., 1984; Göncüoğlu et al., 1993; Yılmaz, 1994) and post-collisional granitoid magmatism (Akıman et al., 1993; Boztuğ et al., 1994a; Göncüoğlu and Türeli, 1994; Erler and Bayhan, 1995; Erler and Göncüoğlu, 1996; İlbeyli and Pearce, 1997; Ekici et al., 1997).

This paper deals essentially with the geological setting, main mineralogical-chemical characteristics and petrogenetic-geodynamic interpretation of the alkaline plutons among these post-collisional Central Anatolian granitoids.

General Overview to Central Anatolian Granitoids

There are widespread magmatic intrusive associations that intrude the crustal metamorphic rocks of the Kırşehir block (Görür et al, 1984; Poisson, 1986) or Central Anatolian Crystalline Complex (Göncüoğlu et al., 1991), the pre-Maastrichtian ophiolitic mélange and the other units of Cretaceous to Lower Tertiary in age. They are unconformably covered by some Eocene or younger sedimentary units in Central Anatolia (CA) (Figure 1). Therefore, these plutons are considered to have been emplaced in a time interval between Upper Cretaceous (Maastrichtian) and Eocene. There are some radiometric age determinations on some of these plutons as follows: Ayan (1963) has reported a total Pb age of 54 Ma on zircon minerals from the Baranadağ pluton. Ataman (1972) has studied the Cefalıkdağ pluton with the Rb-Sr method. The wholerock-biotite isochron age of this pluton determines an age of 71 Ma. Kalkancı (1974) has reported an age of 42±4 Ma based on Rb-Sr wholerock isochron on the Kösedağ pluton. Göncüoğlu (1986) has studied the metamorphics and Üçkapılı granitoid from Niğde massif in Central Anatolia. He has obtained some radiometric ages sometimes around Upper Cretaceous in both of metamorphics and intrusives, e.g. a Rb-Sr wholerock isochrone age of 95±11 and a Rb-Sr wholerock-mineral age of 77.8±1.2 Ma in the Üçkapılı granitoid (Göncüoğlu, 1986). In addition to those of Rb-Sr geochronological data, the K-Ar radiometric datings have also yielded Upper Cretaceous ages on Üçkapılı granitoid, e.g. two biotite ages indicate 74.9±1.2 Ma and 76.2±1.2 Ma, one muscovite age reveals 78.5±1.2 Ma. The feldspathoidal syenites from Bayındır area has yielded a Rb-Sr wholerock isochron age of 70.7±1.1 Ma with a Sr^{87}/Sr^{86} initial ratio of 0.7085 (Gündoğdu et al.,1988). On the other hand, there are some absolute age datings in the granitoids of Central Anatolia that show some Lower Cretaceous ages. For example, Zeck and Ünlü (1987, 1988a, 1988b) have reported some Rb-Sr ages ranging from 109±5 Ma to 110±5 Ma in the Murmana pluton of Divriği region, SE Sivas. Similar to that of Murmana pluton in Divriği region, the isochron age of three wholerock samples from the megacrystalline granites of Ağaçören granitoid in Aksaray region yields an age of 108±3 Ma, with a Sr^{87}/Sr^{86} initial ratio of 0.708602±0.00008 (Güleç, 1994).

On the other hand, it must be pointed out here that, the K-Ar dating studies carried out in the crustal metasediments of the CACC reveal some ages of 69-74 Ma (Kalkanlıdağ region; Erkan and Ataman, 1981), 76-77 Ma (Niğde massif, Göncüoğlu, 1986), and 68-77 Ma (Yıldızeli-Sivas region; Alpaslan et al., 1996). These data represent a good synchronization between the magmatism and metamorphism in the Central Anatolia. In addition to this synchronization of magmatism and metamorphism, the decreasing of metamorphic grade from north to south (Erkan, 1981), i.e. from the Ankara-Erzincan suture zone to the fossilliferous Paleozoic

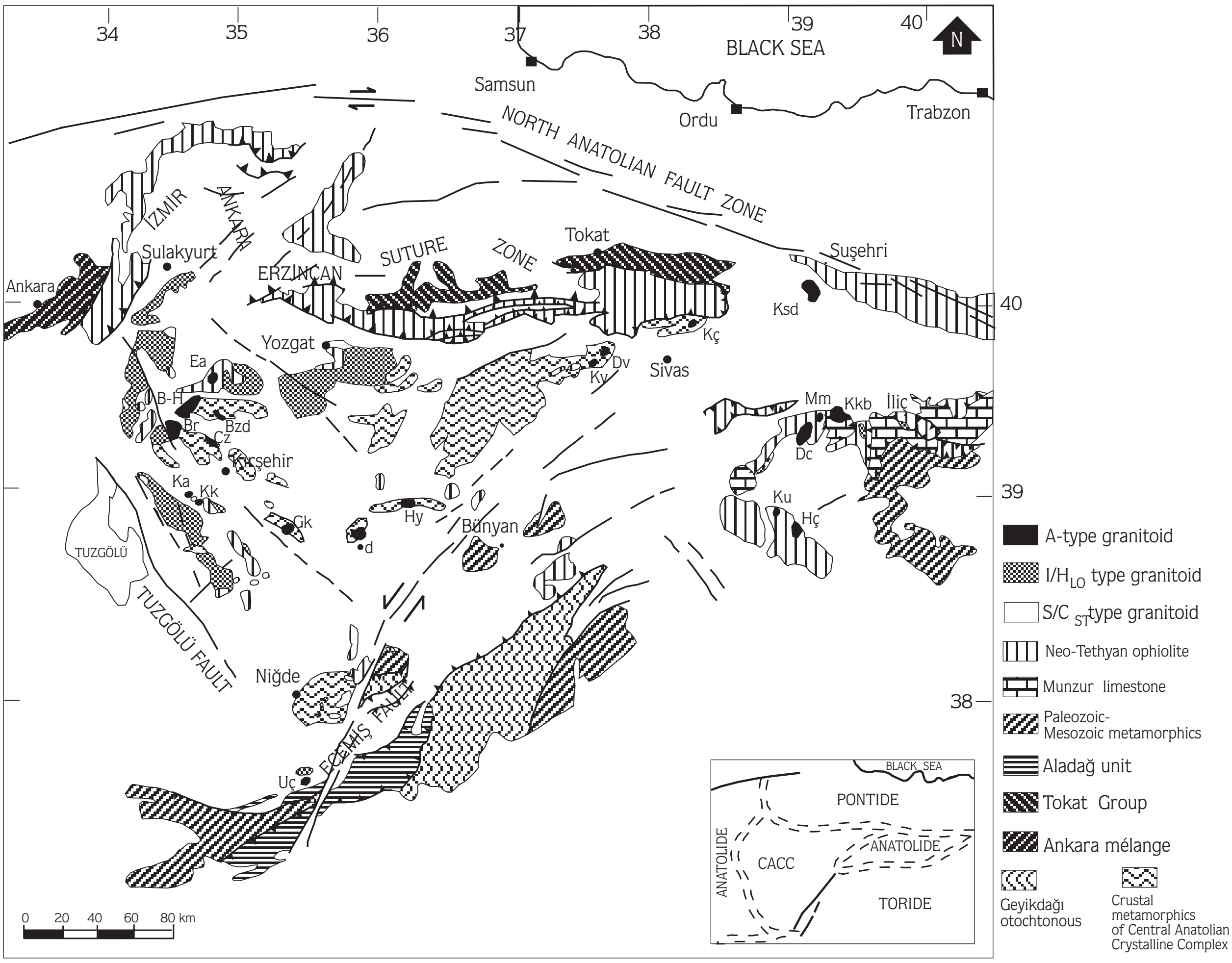

Figure 1. Simplified geographical settings of the plutonic and metamorphic rocks in the Central Anatolia, Turkey (modified after Bingöl, 1989). The abbreviations of plutons are as follow (from west to east): B-H, Bayındır-Hamit; Ea, Eğrialan; Br, Baranadağ; Bzd, Buzlukdağ; Çz, Çayağzı; Ka, Kuruağıl; Kk, Kesikköprü; Gk, Gümüşkent; Uç, Uçurumtepe; İd, İdişdağ; Hy, Hayriye; Kv, Kavik; Dv, Davulalan; Kç, Karaçayır; Ksd, Kösedağ; Ku, Kuluncak; Hç, Hasançelebi; Dc, Dumluca; Mm, Murmana; Kkb, Karakeban.

Taurus authoctonous, may indicate an inverted metamorphism, associated with magmatism induced by the collision of Anatolides and Pontides (the southernmost tip of Eurasia) along the Ankara–Erzincan suture zone, resembling to those in Himalayan (Le Fort, 1986) and Massif Central, France (Burg et al., 1994).

On the basis of existing published and unpublished literature, the Central Anatolian intrusive rocks comprise, from pre-orogenic to syn-orogenic to post-orogenic suites,

• some gabbroic rocks and oceanic plagiogranites (Göncüoğlu and Türeli, 1993; Yalınız et al., 1996);

• calc-alkaline, I-type and arc-related plutons (Ortaköy pluton, E of Tuzgölü, Bayhan, 1990);

• calc-alkaline, alumino-cafemic to cafemic, collision-related plutons, displaying I-type and S-type features (Ekecikdağ pluton, Türeli et al.,1993; Göncüoğlu and Türeli, 1994, and Cefalıkdağ pluton, Geven,1995);

• S-type, syn-collisional, two-mica granites (Üçkapılı pluton, Göncüoğlu, 1986; Yücebaca pluton, Alpaslan and Boztuğ, 1997; Sarıhacılı leucogranite, Ekici et al., 1997);

• calc-alkaline, cafemic, I-type and post-collisional Çaltı pluton (Avcı and Boztuğ, 1993),

• H_{LO} (hybrid late orogenic; Barbarin, 1990) or I-type, high-K calc-alkaline, typically K-feldspar megacrystalline post-collisional monzonitic association of the composite Yozgat batholith (Aydın, 1997; Aydın et al., 1997; Tatar and Boztuğ, 1997);

• post-collisional silica oversaturated alkaline, syenitic-monzonitic and monzogabbroic-monzodioritic plutons (Hasançelebi pluton, Yılmaz et al., 1993; Kösedağ pluton, Boztuğ et al.,1994b; Dumluca, Murmana and Karakeban plutons, Zeck and Ünlü, 1991; Boztuğ et al.,1997; Karaçayır pluton, Boztuğ et al., 1996; Davulalan pluton, Alpaslan and Boztuğ, 1997; Baranadağ quartz monzonite, Hamit quartz syenite, Çamsarı quartz syenite, Bayhan and Tolluoğlu, 1987; Otlu and Boztuğ, 1997; İdişdağ syenite, Göncüoğlu et al., 1995, 1997; Eğrialan syenite, Yılmaz and Boztuğ, 1997) and silica undersaturated alkaline plutons (some parts of Karaçayır and Davulalan plutons and Eğrialan syenite; Hayriye nepheline syenite (Kayseri-Felahiye), Özkan and Erkan, 1994; Durmuşlu nepheline-nosean-melanite syenite porphyry, Bayındır nepheline cancrinite syenite, Otlu and Boztuğ, 1997),

• post-collisional mafic gabbroic/dioritic plutons (Yıldızdağ pluton, Yıldızeli-Sivas region, Boztuğ et al., 1998).

Of these the youngest ones are the alkaline plutons which have already been named as the "Central-Eastern Anatolian (CEA) alkaline province" (Figure 1) by Yılmaz and Boztuğ (1991), and the mafic gabbroic plutons such as Yıldızdağ pluton. Among the alkaline plutons, the silica undersaturated ones are seen to intrude the oversaturated ones. Moreover, these alkaline plutons are also spatially and temporally associated with the formation of post-collisional Sivas (Cater et al., 1991; Yılmaz, 1994) and Central Kızılırmak (Göncüoğlu et al., 1993) basins in Central Anatolia. These authors propose that the development of these basins begins sometimes around Uppermost Cretaceous to Lower Tertiary which is also the emplacement period of the alkaline plutons within or in the marginal parts of the basins. Thus, the term “post-collisional CA alkaline plutonism” seems to be more appropriate than the “CEA alkaline province” because it also emphasizes the regional geology.

Mineralogical-Geochemical Characteristics

Divriği region plutons: Felsic rocks of Divriği region plutons, namely Dumluca, Murmana and Karakeban, display medium to coarse grained texture. They are mainly composed of quartz monzonite, syenite, quartz syenite and some fractionated monzogranite (Figure 2). Mafic rocks, mafic dykes and mafic microgranular enclaves (MME) in these plutons comprise gabbro/diorite and monzogabbro/monzodiorite. The felsic minerals of the felsic rocks is a K-feldspar + plagioclase+quartz association. Percentage of quartz minerals varies from 8-10 % (quartz monzonite and quartz syenites) to 25-30 % (monzogranites). K-feldspar constitutes more than 55-60 % and 70 % of all the feldspar minerals in monzonitic-monzogranitic and syenitic rocks, respectively. The mafic minerals of the monzonitic and syenitic rocks consist mainly of hastingsite/arfvedsonite+biotite. But, those of the monzogranites are composed solely of biotite. These monzogranites have been considered as the final fractionation product of the magma (Boztuğ et al., 1997). Major felsic and mafic minerals of the mafic rocks in the Divriği region plutons are composed of plagioclase(An_{32-44})±K-feldspar±nepheline, and hastingsitic amphibole + augite + aegirineaugite + biotite ± olivine mineral assemblages, respectively. Transformation of clinopyroxene minerals to amphibole, and even to biotite is a common microscopical feature in both of the felsic, and particularly mafic rocks in these plutons. In addition to the MME occurrences in the felsic rocks, as indicators of mafic magma blobs within felsic magma (Barbarin and Didier, 1992), some special textures called antirapakivi texture, blade biotite, acicular apatite and spongy-cellular dissolution/melting textures in plagioclase (Hibbard, 1995) evidence magma mingling/mixing processes between coeval mafic and felsic magmas during emplacement of Divriği region plutons. Major element chemical compositions (Table 1) of these plutons apparently indicate the alkaline feature in the TAS (dividing line taken after Rickwood, 1989) diagram (Figure 4).

Trace element data (Table 1) available for the felsic rocks has been plotted in the PRIM (primordial mantle) by the NEWPET’94 computer program. In fact, all three oversaturated alkaline plutons in Divriği region display a coherent set of patterns (Figure 5). Relative to the normalizing composition, the rocks of Dumluca pluton are enriched in the most incompatible elements together with a negative Ba anomaly, and depleted in Zr, Sm and Y. As commonly known, the Ba readily substitutes for K in feldspar, hornblende and biotite (Wilson, 1989). So that, the negative Ba anomaly pattern in the Dumluca, Murmana and Karakeban plutons can be related to the HT feldspar fractionation rather than hornblende and biotite, i.e. some highly alkaline rocks such as syenites and feldspathoidal syenites could have been crystallized from the same magma. Similarly, the Zr and Y could have consumed by some early phases such as zircon and amphibole minerals of those probable early highly alkaline rocks. However, these trace element patterns can be sourced from the initial mineralogical composition and partial melting model of the source rocks, i.e. the type

Table 1. Averages and standard deviations of the wholerock major (wt %) and trace element (ppm) chemical compositions of the post-collisional Central Anatolian alkaline plutons.

Pluton	Rock Type	n	SiO_2	Al_2O_3	TiO_2	tFe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total
Dcf	qmz	8	65.83	17.18	0.44	3.26	0.05	0.92	1.99	5.02	5.04	0.16	0.74	100.63
			(1.10)	(0.45)	(0.13)	(0.45)	(0.02)	(0.25)	(0.34)	(0.38)	(0.33)	(0.05)	(0.26)	(0.66)
	mzgr	5	70.12	15.54	0.36	2.89	0.04	0.92	1.31	4.06	4.69	0.15	0.73	100.81
			(0.48)	(0.25)	(0.03)	(0.20)	(0.01)	(0.04)	(0.07)	(0.14)	(0.12)	(0.01)	(0.13)	(0.66)
Dcm	mzgo	8	52.28	16.35	1.49	7.70	0.12	6.15	8.60	3.47	2.70	0.30	1.71	100.85
			(1.88)	(1.36)	(0.69)	(1.14)	(0.01)	(1.80)	(1.06)	(0.80)	(0.53)	(0.10)	(0.70)	(0.44)
Mmf	qmz	8	65.00	16.86	0.49	3.36	0.04	1.64	2.84	4.58	4.69	0.21	0.72	100.44
			(2.11)	(0.55)	(0.17)	(0.79)	(0.02)	(0.55)	(0.51)	(0.21)	(0.32)	(0.05)	(0.14)	(0.61)
Mmm	nmzgo	3	46.90	17.08	1.70	7.30	0.37	6.60	13.59	3.18	2.10	0.46	2.52	101.70
			(2.99)	(1.41)	(1.40)	(3.82)	(0.43)	(0.78)	(3.83)	(1.12)	(0.96)	(0.40)	(0.42)	(0.31)
Kkf	mz	2	63.58	17.42	0.59	4.10	0.07	0.73	2.04	5.87	4.54	0.19	0.69	99.81
			(0.75)	(0.39)	(0.03)	(0.06)	(0.21)	(0.91)	(0.35)	(0.76)	(0.08)	(0.02)	(0.11)	(0.11)
	sy	3	62.17	17.40	0.60	5.16	0.10	0.75	1.54	5.94	5.68	0.12	0.95	100.42
			(0.64)	(0.09)	(0.07)	(0.09)	(0.02)	(0.47)	(0.49)	(0.36)	(0.08)	(0.05)	(0.48)	(1.05)
	qs	6	67.69	16.21	0.33	3.29	0.05	0.60	1.05	4.84	5.87	0.11	0.63	100.65
			(1.58)	(0.82)	(0.07)	(0.43)	(0.01)	(0.08)	(0.12)	(0.20)	(0.31)	(0.03)	(0.24)	(0.82)
	mzgr	5	72.30	14.60	0.16	1.65	0.02	0.45	0.59	4.41	4.73	0.10	0.66	99.68
			(1.03)	(0.64)	(0.02)	(0.57)	(0.01)	(0.07)	(0.13)	(0.26)	(0.09)	(0.01)	(0.14)	(0.59)
Kkm	nmzgo	3	49.10	17.60	2.00	10.89	0.15	3.87	5.34	5.52	2.74	0.58	2.20	99.98
			(3.84)	(0.97)	(0.13)	(1.30)	(0.04)	(1.62)	(1.37)	(0.47)	(0.76)	(0.02)	(1.80)	(0.55)
Kd	sy	40	60.18	17.47	0.62	4.75	0.11	2.03	3.04	4.37	5.83	0.29	1.08	99.78
			(2.10)	(0.52)	(0.07)	(0.93)	(0.03)	(0.72)	(0.67)	(0.40)	(0.54)	(0.07)	(1.04)	(1.15)
	qs	30	62.72	17.22	0.54	3.85	0.10	1.60	2.12	4.42	6.18	0.21	0.87	99.82
			(2.26)	(0.38)	(0.07)	(0.73)	(0.03)	(0.76)	(0.57)	(0.29	(0.52)	(0.06)	(0.49)	(1.36)
	mz	2	56.57	17.37	0.73	6.33	0.12	2.76	4.85	3.92	4.61	0.40	1.02	98.66
			(1.51)	(0.74)	(0.00)	(0.20)	(0.01)	(0.13)	(1.31)	(0.02)	(0.58)	(0.06)	(0.26)	(0.16)
	qmz	7	60.11	17.19	0.61	4.98	0.11	2.35	3.29	4.26	5.12	0.29	1.71	100.00
			(2.57)	(0.58)	(0.10)	(0.92)	(0.02)	(0.64)	(0.60)	(0.48)	(0.27)	(0.07)	(1.83)	(1.04)
Hç	sy	2	64.36	17.68	0.71	0.70	0.06	0.48	1.66	4.79	7.19	0.03	1.71	99.34
			(1.18)	(0.91)	(0.00)	(0.17)	(0.02)	(0.55)	(1.20)	(0.43)	(0.22)	(0.00)	(1.39)	(0.90)
	qs	4	65.48	15.89	0.54	1.07	0.14	0.29	1.67	4.19	6.86	0.11	2.20	98.66
			(1.78)	(0.72)	(0.09)	(0.19)	(0.19)	(0.18)	(1.23)	(0.64)	(0.88)	(0.06)	(1.02)	(0.49)
Kç	sy	13	61.77	19.80	0.14	1.21	0.06	0.12	0.49	4.58	8.62	0.04	1.81	98.62
			(2.06)	(1.52)	(0.09)	(0.88)	(0.04)	(0.08)	(0.24)	(1.48)	(1.83)	(0.02)	(0.62)	(0.50)
Dv	qmz	2	69.53	17.78	0.11	0.82	0.01	0.28	1.83	5.22	4.92	0.03	0.86	101.37
			(0.15)	(1.24)	(0.01)	(0.85)	(0.01)	(0.01)	(0.40)	(0.34)	(0.37)	(0.00)	(0.26)	(0.05)
	qs	2	67.21	17.15	0.26	1.63	0.02	0.19	1.06	5.33	6.51	0.05	0.96	100.35
			(1.21)	(0.22)	(0.11)	(0.10)	(0.02)	(0.27)	(0.76)	(0.25)	(0.33)	(0.05)	(0.42)	(0.81)
Eğ	sy	9	61.40	19.06	0.44	3.20	0.10	0.98	2.90	4.77	6.64	0.23	0.73	100.46
			(1.31)	(0.55)	(0.10)	(0.96)	(0.04)	(0.28)	(1.30)	(0.36)	(0.59)	(0.23)	(0.50)	(1.26)
Br	sy	2	60.70	18.93	0.39	3.74	0.09	1.17	3.84	3.48	7.48	0.19	0.55	100.52
			(2.33)	(0.33)	(0.05)	(1.07)	(0.01)	(0.40)	(0.76)	(0.55)	(0.30)	(0.08)	(0.08)	(0.61)
	qmz	9	63.04	18.03	0.42	3.94	0.11	1.73	3.81	3.80	5.05	0.18	0.53	100.63
			(1.43)	(0.06)	(0.04)	(0.28)	(0.01)	(0.23)	(0.54)	(0.15)	(0.20)	(0.03)	(0.12)	(0.59)
	qs	6	63.82	17.97	0.40	3.63	0.10	1.51	3.33	3.82	6.12	0.19	0.47	100.85
			(1.21)	(0.39)	(0.03)	(0.25)	(0.01)	(0.24)	(0.32)	(0.34)	(1.05)	(0.01)	(0.24)	(0.24)
Hm	qmz	6	61.48	18.22	0.45	4.33	0.09	1.69	4.24	3.47	4.86	0.17	1.03	100.03
			(0.93)	(0.45)	(0.05)	(0.47)	(0.01)	(0.27)	(0.33)	(0.17)	(0.27)	(0.02)	(0.44)	(1.12)
	qs	9	64.34	18.00	0.34	3.13	0.08	1.26	2.88	4.05	6.02	0.16	0.59	100.84
			(1.61)	(0.31)	(0.08)	(0.88)	(0.02)	(0.35)	(0.81)	(0.41)	(0.49)	(0.06)	(0.22)	(0.45)
Çs	qs	5	67.27	18.24	0.18	1.54	0.03	0.47	1.12	5.06	6.20	0.06	0.69	100.86
			(1.60)	(0.54)	(0.08)	(0.56)	(0.03)	(0.09)	(0.56)	(0.30)	(0.21)	(0.02)	(0.23)	(0.27)
	mzgr	2	69.99	16.61	0.11	1.10	0.03	0.47	0.96	4.78	5.07	0.04	0.81	99.96
			(0.08)	(0.11)	(0.04)	(0.11)	(0)	(0.04)	(0.29)	(0.04)	(0.17)	(0.01)	(0.44)	(0.09)
Dş	nnmsp	6	57.19	20.72	0.29	2.78	0.09	0.64	3.21	5.79	8.54	0.09	1.66	101.01
			(0.57)	(0.36)	(0.05)	(0.47)	(0.01)	(0.08)	(0.82)	(0.55)	(0.27)	(0.02)	(0.27)	(0.36)
By	sy	3	63.93	19.70	0.22	1.77	0.04	0.37	1.10	5.56	7.37	0.05	0.62	100.74
			(0.49)	(0.18)	(0.03)	(0.15)	(0.04)	(0.05)	(0.37)	(0.64)	(1.32)	(0)	(0.16)	(0.34)
	ncs	7	62.12	20.15	0.21	2.06	0.07	0.51	1.55	6.14	7.25	0.06	0.87	101.06
			(1.91)	(0.70)	(0.12)	(0.96)	(0.03)	(0.20)	(0.68)	(0.97)	(0.93)	(0.05)	(0.32)	(0.46)

Table 1. (continued)

Co	Cu	Pb	Zn	Rb	Ba	Sr	Nb	Zr	Y	Th	Ga
11	7	23	61	172	643	211	51	280	39	24	22
(1)	(2)	(11)	(8)	(22)	(88)	(28)	(5)	(39)	(5)	(15)	(1)
9	6	27	58	210	464	127	39	221	47	23	20
(1)	(1)	(1)	(3)	(7)	(79)	(6)	(4)	(15)	(3)	(14)	(1)
24	53	11	72	71	437	396	33	141	20	16	na
(3)	(28)	(2)	(5)	(18)	(76)	(92)	(9)	(52)	(4)	(14)	-
11	5	13	51	159	959	306	24	216	33	12	na
(3)	(2)	(4)	(8)	(23)	(140)	(40)	(3)	(27)	(2)	(4)	-
23	267	14	63	78	723	488	32	140	21	16	14
(11)	(426)	(3)	(17)	(42)	(574)	(147)	(29)	(35)	(9)	(7)	(1)
na	na	na	na	na	na	na	na	na	na	na	na
-	-	-	-	-	-	-	-	-	-	-	-
17	3	20	95	179	685	118	81	265	47	12	24
(1)	(2)	(7)	(12)	(20)	(501)	(44)	(14)	(58)	(7)	(4)	(1)
10	3	22	74	213	385	92	65	363	50	17	24
(1)	(1)	(3)	(9)	(35)	(192)	(30)	(24)	(59)	(8)	(5)	(1)
5	5	21	61	287	159	42	70	229	65	33	26
(2)	(1)	(3)	(27)	(8)	(46)	(4)	(7)	(9)	(1)	(3)	(1)
na	na	na	na	na	na	na	na	na	na	na	na
-	-	-	-	-	-	-	-	-	-	-	-
37	76	36	100	168	714	515	21	244	46	16	na
(22)	(42)	(26)	(51)	(42)	(196)	(162)	(8)	(78)	(15)	(10)	-
57	55	38	94	222	547	355	28	380	59	26	na
(31)	(9)	(10)	(18)	(43)	(147)	(133)	(7)	(159)	(15)	(10)	-
47	95	30	89	119	777	781	23	208	39	14	na
(2)	(31)	(2)	(2)	(47)	(26)	(72)	(2)	(14)	(6)	(7)	-
35	78	31	94	155	658	54	18	234	39	13	na
(24)	(25)	(6)	(12)	(13)	(117)	(57)	(6)	(31)	(6)	(4)	-
22	32	29	64	95	2804	376	60	510	47	31	78
(8)	(4)	(2)	(4)	(17)	(1133)	(143)	(14)	(200)	(3)	(9)	(2)
23	30	30	69	123	1225	92	72	484	59	47	68
(14)	(1)	(1)	(4)	(5)	(137)	(49)	(25)	(306)	(12)	(15)	(8)
19	32	43	83	182	1622	1356	49	546	44	78	36
(5)	(6)	(21)	(21)	(39)	(1163)	(1188)	(22)	(388)	(8)	(43)	(3)
100	31	31	64	164	1409	1351	24	335	26	63	nd
(3)	(2)	(3)	(2)	(13)	(114)	(234)	(12)	(101)	(2)	(28)	-
80	29	35	73	350	497	294	40	270	58	82	48
(20)	(2)	(3)	(5)	(24)	(48)	(103)	(1)	(181)	(2)	(9)	(8)
10	8	93	103	226	1089	842	36	524	46	40	na
(3)	(3)	(26)	(13)	(48)	(381)	(367)	(14)	(205)	(8)	(25)	-
13	12	38	98	206	858	1111	32	265	41	24	18
(4)	(4)	(2)	(6)	(14)	(468)	(154)	(6)	(58)	(0)	(11)	(0)
13	10	29	93	155	1062	558	18	234	34	31	19
(1)	(3)	(16)	(1)	(17)	(195)	(94)	(1)	(7)	(3)	(18)	(1)
12	15	39	91	202	1091	653	23	276	41	31	19
(1)	(6)	(13)	(2)	(32)	(250)	(93)	(3)	(31)	(5)	(15)	(2)
15	11	54	78	137	2283	741	16	256	27	25	19
(1)	(3)	(30)	(6)	(16)	(250)	(42)	(6)	(8)	(2)	(13)	(1)
10	9	53	81	249	923	615	24	294	46	65	20
(3)	(3)	(15)	(7)	(57)	(473)	(200)	(8)	(46)	(9)	(42)	(1)
4	6	84	68	384	290	235	48	440	66	94	23
(2)	(1)	(21)	(9)	(45)	(163)	(89)	(15)	(140)	(3)	(32)	(1)
3	6	59	58	375	309	191	28	217	59	61	21
(0)	(2)	(16)	(2)	(141)	(299)	(130)	(12)	(7)	(21)	(7)	(3)
9	11	117	109	267	1436	1154	42	473	46	40	19
(1)	(2)	(23)	(9)	(40)	(612)	(269)	(11)	(45)	(4)	(17)	(1)
5	5	67	78	305	256	226	46	523	54	111	23
(1)	(2)	(7)	(3)	(10)	(137)	(82)	(2)	(353)	(1)	(47)	(2)
6	11	97	92	294	651	369	49	430	48	96	22
(3)	(10)	(28)	(8)	(74)	(767)	(379)	(9)	(236)	(10)	(84)	(4)

tFe_2O_3 and LOI represent total iron as ferric oxide and loss on ignition, respectively. The number, given in parenthesis below each value, corresponds the standard deviation. n, the number of analysed rock samples; na, not analysed. The abbreviations of the plutons are as follow: Dcf, Dumluca felsic; Dcm, Dumluca mafic; Mmf, Murmana felsic; Mmm, Murmana mafic; Kkf, Karakeban felsic; Kkm, Karakeban mafic; Kd, Kösedağ; Hç, Hasançelebi; Kç, Karaçayır; Dv, Davulalan; Eğ, Eğrialan; Br, Baranadağ; Hm, Hamit; Çs, Çamsarı; Dş, Durmuşlu; By, Bayındır. The abbreviations of the rock types are as follow: qmz, quartz monzonite; mzgr, monzogranite; mzgo, monzogabbro/monzodiorite; nmzgo, nepheline monzogabbro/monzodiorite; mz, monzonite; sy, syenite; qs, quartz syenite; nsy, nepheline syenite; nnmsp, nepheline-nosean-melanite syenite porphyry; ncs, nepheline-cancrinite syenite.

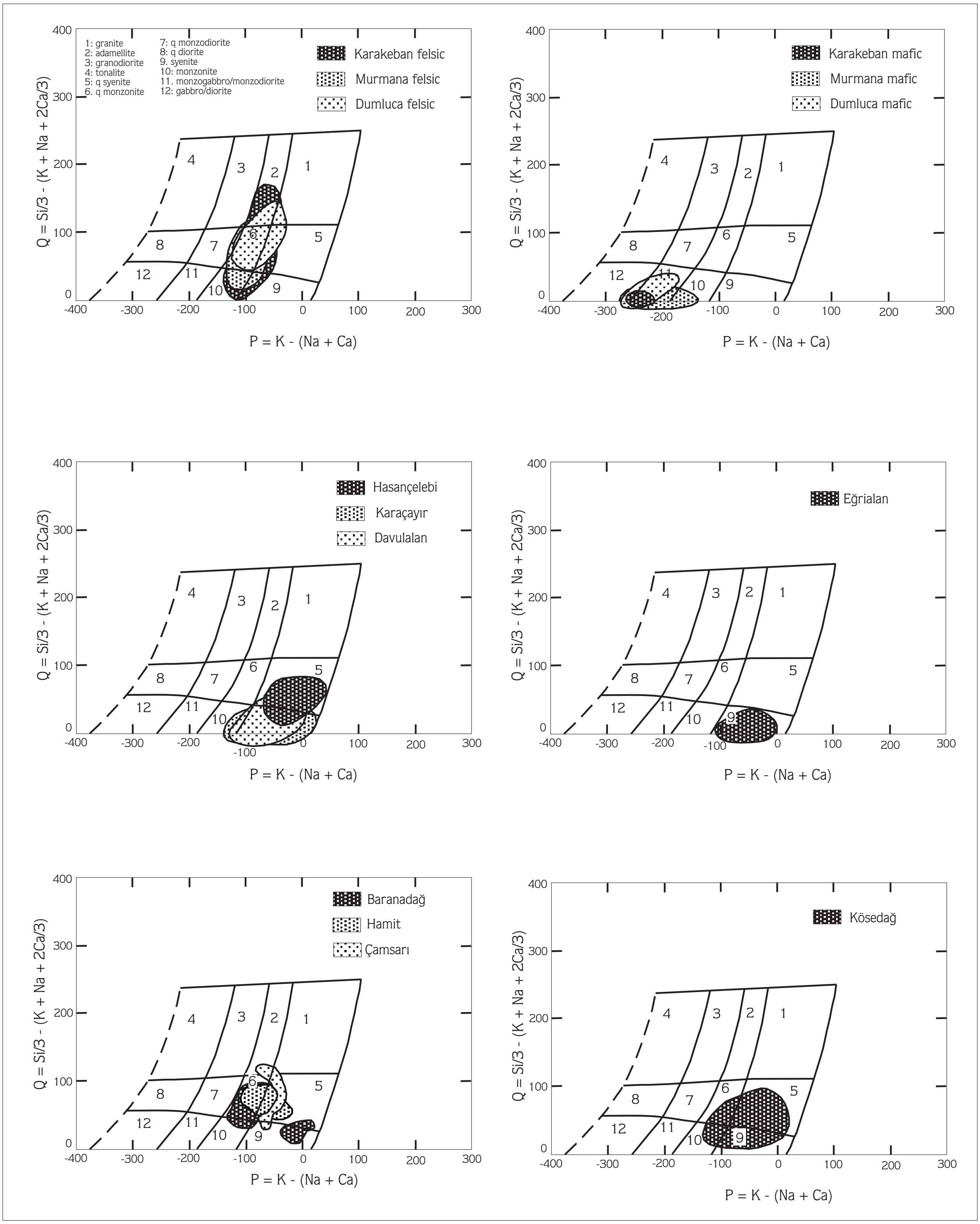

Figure 2. Chemical nomenclature diagram (Debon and Le Fort, 1983) of the silica oversaturated alkaline plutons.

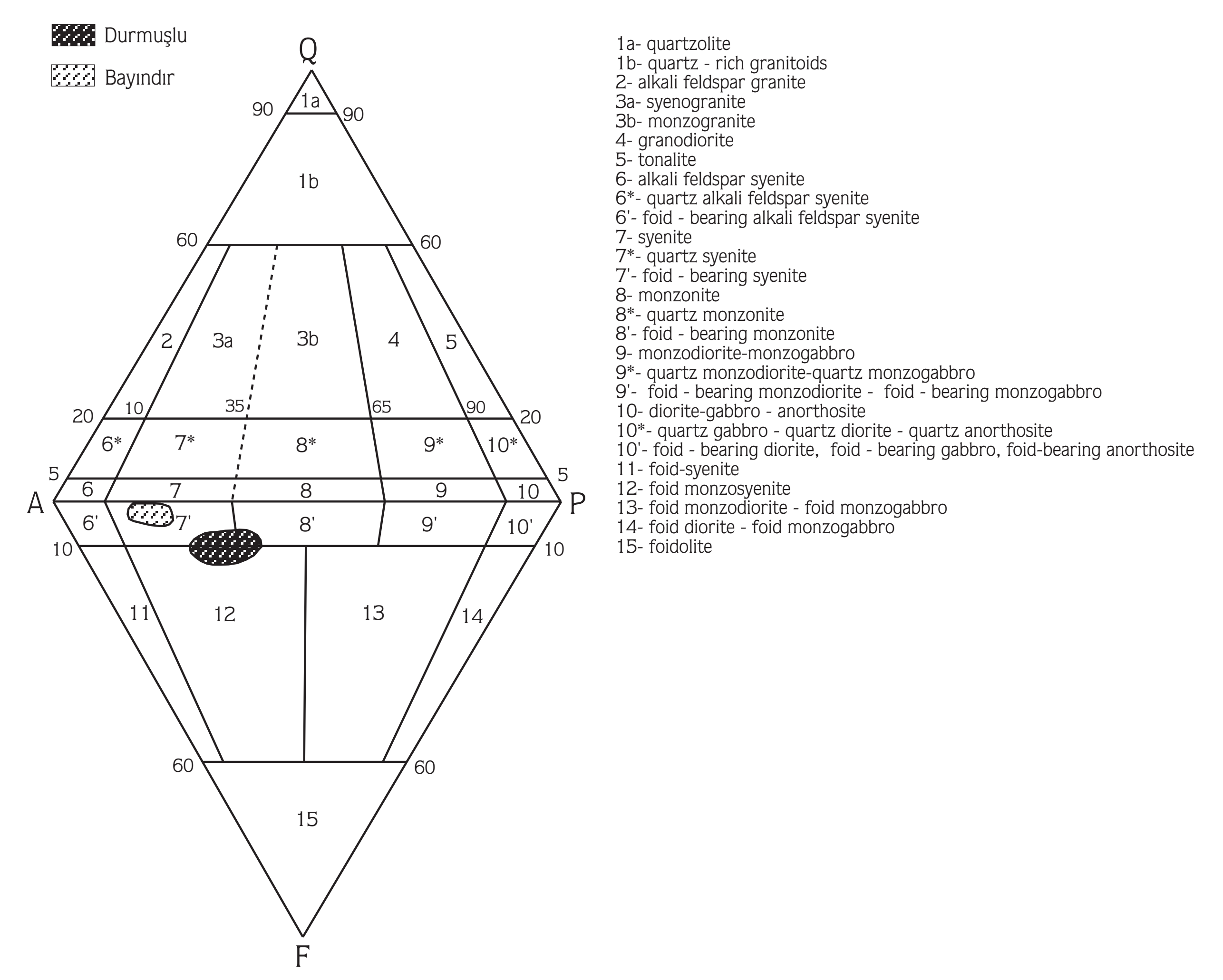

Figure 3. QAPF nomenclature diagram (Streckeisen, 1976) of the silica undersaturated alkaline plutons.

and degree of partial melting and also the garnet content of the source rocks (Wilson, 1989). An important point in the PRIM normalized spider diagram of the Karakeban pluton is that the Th content is notably higher (Figure 5) than the other two plutons in Divriği region. On the other hand, the Karakeban pluton can also be suggested to represent the crustal contamination, or the fractionation, or the low degree partial melting during magma genesis, since, the contents of crustal-derived, or fractionation-related, or low-degree partial melting depended elements like Rb, Th, Nb and Y are higher than those of other plutons (Figure 5). The geotectonic classification diagrams of Batchelor and Bowden (1985) and Pearce et al. (1984) represent "late orogenic" and "WPG" characteristics for all three Divriği region plutons, respectively, (Figures 6, 7), which is convenient for the post-collisional alkaline magmatism (Harris et al., 1986). For the comparision of petrological and petrogenetical data of Zeck and Ünlü (1987, 1988a, 1988b) on Murmana pluton, the reader is suggested to read Boztuğ et al. (1997).

Kösedağ pluton: This pluton consists of medium- to coarse-grained and fine- to medium-grained rocks which can be separately mapped (Boztuğ et al., 1994b). The medium- to coarse-grained rocks from the main body are composed mainly of quartz syenite, syenite and rarely of monzonitic rocks (monzonite and quartz monzonite). Fine- to medium-grained rocks are seen as the fractionated rocks within the main body. The major felsic and mafic constituents of the samples from the Kösedağ pluton are made up of K-feldspar+plagioclase±quartz, and kaersutitic amphibole + clinopyroxene (generally

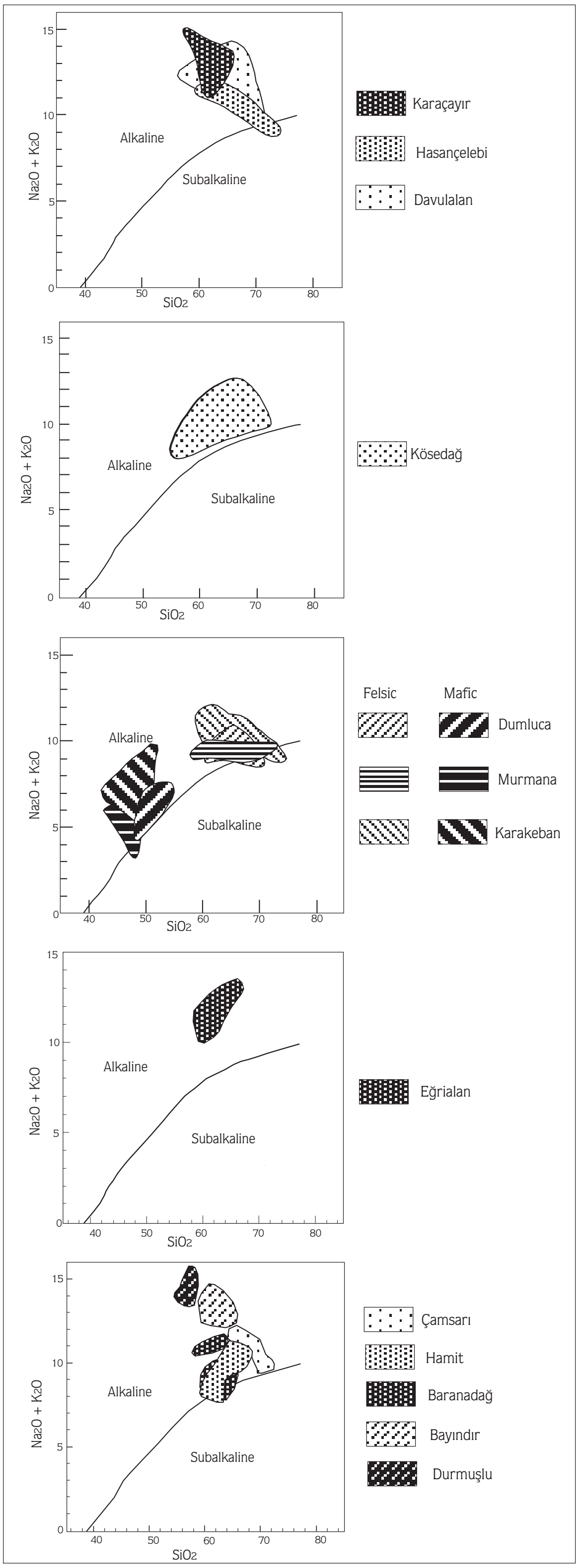

Figure 4. Total alkali versus silica variation diagrams (dividing line has been taken after Rickwood, 1989) of the plutons.

augite, diopsidic augite and rarely aegirine-augite) + biotite minerals, respectively. Quartz is never more than 10 % of mineralogical composition in syenitic and monzonitic rocks in which K-feldspar always constitutes more than a half of all feldspar minerals. There are some special microscopic textures, described by Hibbard (1995) as evidence for the equilibrated hybrid system caused by mixing of coeval mafic and felsic magmas. There are antirapakivi texture, acicular apatite, blade biotite, and K-feldspar / amphibole-clinopyroxene poikilitic texture (Boztuğ et al.,1994b).

Alkaline composition of the Kösedağ batholith is clearly shown in Figure 4. PRIM normalized trace element spider diagram represent a negative Ba anomaly similar to those of Divriği region plutons that can be related to feldspar fractionation. There are also some wide variation ranges in the contents of Th, Nb and Sr elements among which the upper limit of Th is remarkably high. The behaviour of Sr element in this diagram (Figure 5), showing a slight depletion by means of lower limit, can reflect the feldspar crystallization occurred in low temperatures. On the other hand, wide variation ranges in the contents of Th, Nb and Y elements, particularly with high upper limits, may also indicate a fractionation or crustal contamination, or low-degree partial melting of source material. The geotectonic discrimination diagrames, based on both the major and trace elements, reveal "late orogenic" (Figure 6) and WPG (Figure 7) settings for the Kösedağ pluton.

Hasançelebi pluton: This pluton comprises medium-grained syenitic rocks accompanied by lamprophyre dykes. The major components of these rocks are of alkali feldspar (orthoclase, albite, perthite)+ plagioclase(An_{25-30})+quartz+diopside. Quartz is always less than 7-8 % in mineralogical composition of syenitic rocks. K-feldspar constitutes more than 70-80 % of total feldspars. The rocks of Hasançelebi pluton include a wider variety of accessory minerals than the other plutons and include titanite, zircon, xenotime, monazite and apatite. They are plotted in the syenite and quartz syenite fields of the chemical nomenclature diagram (Figure 2) of Debon and Le Fort (1983). There are also some "altered magmatic rocks" (Yılmaz et al.,1993) in this pluton affected by scapolitization, albitization and carbonatization type of alteration. The samples collected from the Hasançelebi pluton describe an apparent alkaline character as seen in Figure 4. The depletions in the contents of Rb and K (Figure 5) are concordant with the albitization type of alteration. On the other hand, the high contents of Th, Nb, Zr and Y may be regarded to show a high degree fractionation of magma or low

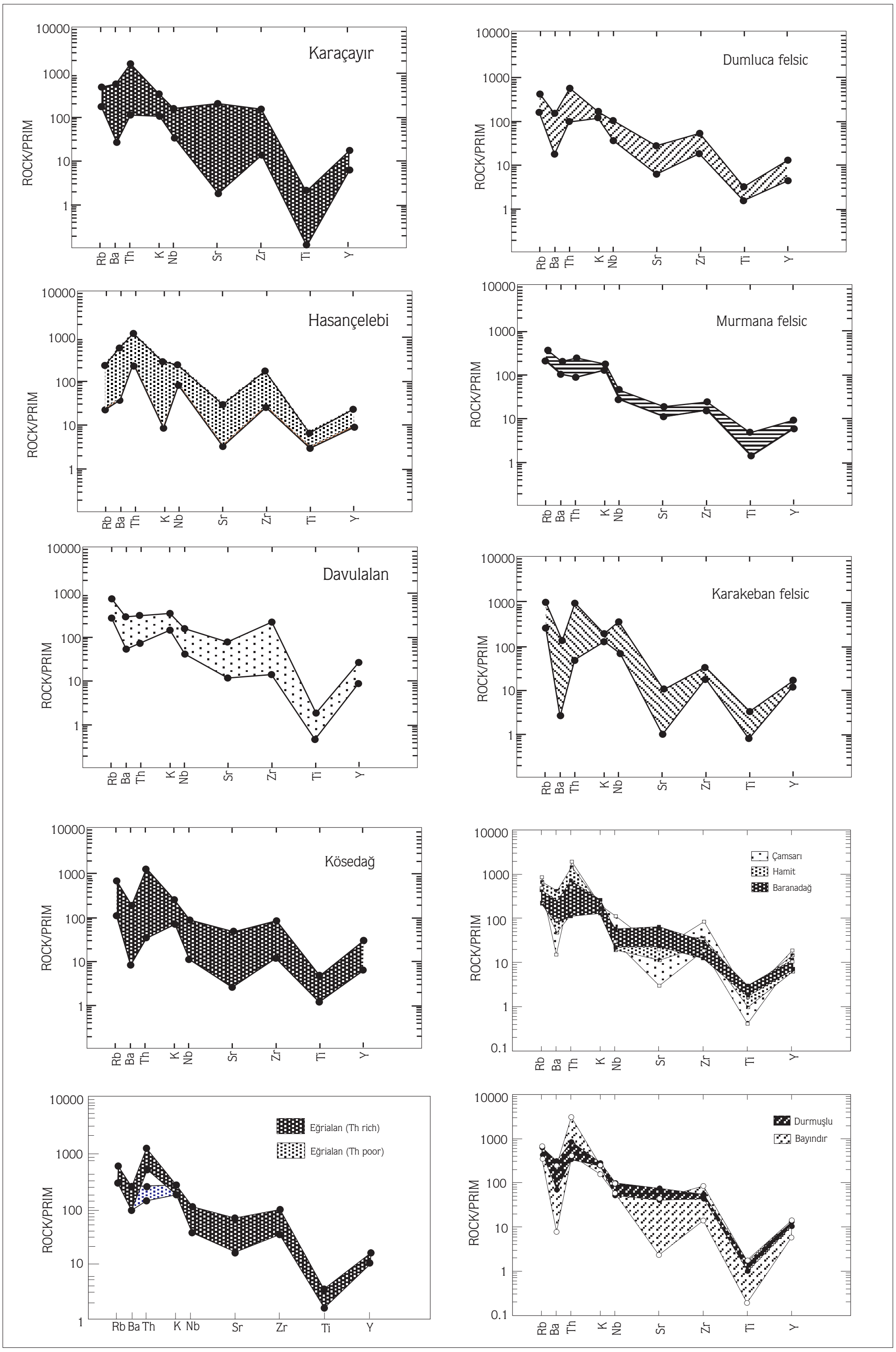

Figure 5. PRIM normalized trace element spider diagrams of the felsic pluton.

degree partial melting of source material during the magma genesis. Similar to the other plutons, major and trace elements geotectonic discrimination diagrams of Batchelor and Bowden (1985) and Pearce et al. (1984), respectively, show the late orogenic to anorogenic and WPG settings for the Hasançelebi pluton (Figures 6,7).

Karaçayır pluton: The commonest rock type of the Karaçayır pluton is medium- to coarse-grained syenites. The felsic components are K-feldspar (orthoclase, microcline and albite), plagioclase and nepheline minerals among which the microcline minerals are always associated with cataclastic zones that is considered to be formed by later cataclastic deformation. Microcline is easily distinguishable by polysynthetic twinning in two directions with twin lamellae are usually spindle shaped and extinction usually wavy which is so-called gridiron or quadrille structure as described by Kerr (1959). K-feldspar minerals are more than 80 % in total feldspars. Nepheline mineral, when it is present, is not more than 7-8 % of rock composition. The mafic minerals are represented by biotite, muscovite,secondary calcite and some accessory phases such as allanite, monazite, xenotime, apatite and opaque minerals. Some nephelines, recognizable only by their short prismatic pseudomorphies, are replaced by zeolite and sericite minerals by some deuteric alteration which also yields some secondary alteration minerals like muscovite, calcite and clayey components. Most of the biotites and muscovite flakes exhibit some evidences of the deuteric processes, for instance, all the biotites represent green color and muscovites show some well-preserved evidences for the derivation from the feldspar minerals, or crystallized from a late stage magmatic fluids because of having been associated with large calcite crystals. The euhedral large calcite minerals in this assemblage is assumed to be crystallized from late stage magmatic fluids, i.e. hydrothermal solutions, which is already interacted with marbles of crustal metasediments of basement rocks (Schuiling, 1961). There is also a third type of mica mineral in some syenites which is of typical phlogopite mineral on the basis of optical properties under the microscopy. Moreover, some syenites include fluorite minerals distinguishable even in hand specimen. All these mineralogical-petrographical data reflect that the Karaçayır syenite has been affected by deuteric alteration processes. This is also convenient with the observation of Schuiling (1961) who has found some thorianite minerals in some of these rocks. These microscopical identifications are also concordant with the chemical nomenclature diagram proposed by Debon and Le Fort (1983). As shown in Figure 2, the rock samples

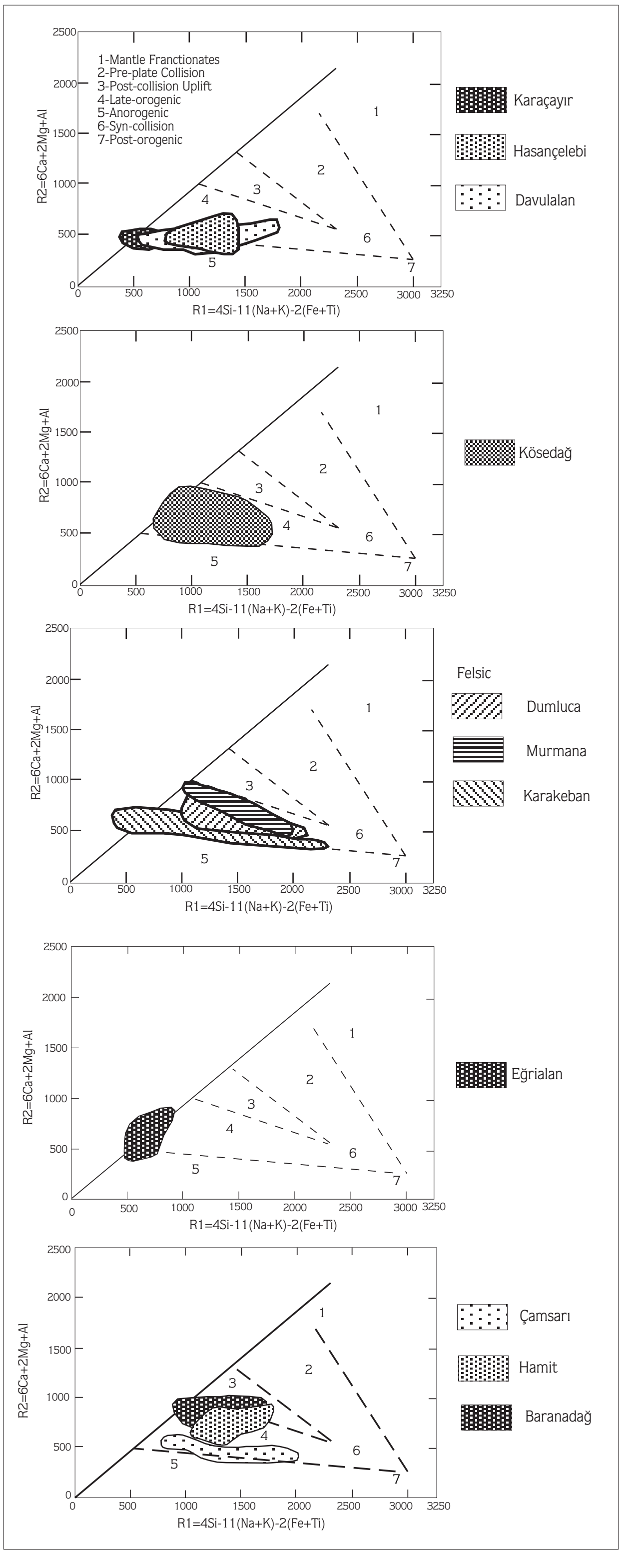

Figure 6. Major element geotectonic discrimination diagrams (Batchelor and Bowden, 1985) of the felsic and silica oversaturated alkaline plutons.

of the Karaçayır syenite are plotted mainly in the syenite and rarely in the feldspathoidal rocks subfields.

In addition to these mineralogical characteristics, the peraluminous chemistry of the Karaçayır syenite is attributed to the assimilation of wall-rocks which are of crustal metasediments of Kırşehir block (Boztuğ et al., 1996). On the other hand, the magma - wall-rock interaction has already been suggested in the genesis of this syenitic body, and even attributed to the formation of carbonatite-looking rocks in the Karaçayır pluton by Schuiling (1961). Similar to those of other plutons, Karaçayır pluton also exhibit alkaline composition in chemistry (Figure 4). The main trend of the PRIM normalized trace element spider diagram of the Karaçayır pluton resembles to that of Hasançelebi pluton, however, its Sr and Ti depletion, and the Th enrichment is distinctly remarkable in Figure 5. Very less amounts of the contents of Sr and Ti are attributed to the mineralogical composition in which plagioclases and mafic minerals, accommodated the Sr and Ti, respectively, are found so less amounts in mineralogy. As for the enrichment of Th content, Schuiling (1961) has already determined the euhedral thorianite minerals (ThO_2) in the mode of accessory mineral in the Karaçayır pluton. The rock samples from the Karaçayır pluton are plotted in the late orogenic to anorogenic fields in Figure 6, and WPG field of Figure 7.

Davulalan pluton: It consists of a medium-grained syenitic stock and some porphyritic monzonitic vein rocks. Syenitic main stock is composed of medium-grained and pink colored rocks which are plotted mainly in the syenite and quartz syenite fields of the chemical nomenclature diagram (Figure 2). Monzonitic vein rocks, porphyritic in texture, fall in the monzonite field in Figure 2. The major felsic rock forming minerals of the syenitic body are orthoclase + plagioclase±quartz, in the absence of quartz, there is negligible amount of nepheline (less than 5 %) so that these rocks are plotted in the feldspathoidal part of Figure 2. The amount of K-feldspar is always more than that of plagioclase in syenites, but it is vice versa in monzonitic vein rocks. As for the mafic minerals, they are composed of hastingsite/arfvedsonite + biotite ± aegirine-augite assemblage. The mineralogical composition of the monzonitic vein rocks resemble to those of syenitic rocks, although, they differ from them by containing more plagioclase than orthoclase and, more augite than biotite minerals. As other plutons, the alkaline character of the Davulalan pluton is clearly observed in Figure 4. The PRIM normalized trace element distribution diagram is more restricted than those of Karaçayır and Hasançelebi plutons which also contain negligible amount of nepheline minerals, and associated with fluorite mineralization. However, there are some distinctive features in Figure 5, the Rb and K contents display sharper positive anomaly than that of Th. On the other hand, the most enriched elements are Zr and Y which may show crustal contribution, fractionation or very low degree of partial melting of the source material during magma formation. The late orogenic to anorogenic (Figure 6) and WPG (Figure 7) settings of the Davulalan pluton are very distinctive.

Eğrialan pluton: This pluton consists of medium-grained and coarse-grained syenitic rocks. Both types plot in the syenite field (Figure 2), however, a few rock samples, containing nepheline+altered feldspathoidal minerals in the actual mineralogical composition, take place in the feldspathoidal part of the Figure 2. The major felsic constituents of the medium- and coarse-grained syenites are mainly orthoclase + plagioclase (An_{32+40} on the basis of optical data), and sometimes, some negligible amounts of nepheline and altered feldspathoidal minerals in some rock samples. Orthoclase minerals may constitute 75-80 % of the total feldspars. In addition to fresh nepheline minerals, less than 6-7 % of mineralogical composition, feldspathoidal minerals altered to aggregates consisting of brownish colored platy zeolite + clay minerals + sericite. The mafic components are made up of riebekite/arfvedsonite + aegirine + biotite, and some melanite type of garnet minerals in some samples. Garnet minerals are particularly observed to rim the aegirine minerals. The accessory minerals of these syenites are titanite, apatite, xenotime, monazite, allanite, zircon (especially in the form of inclusions within reddish-brown biotite flakes) and fluorite. Similar the other alkaline plutons, the alkaline nature of the Eğrialan syenitic body is clearly shown in Figure 4. The PRIM normalized trace element spider diagram of this pluton is also similar to those of other plutons shows enrichment in the Th, Nb, Zr and Y contents (Figure 5) which is consistent with the enriched accessory mineral contents. The Th enriched samples are the coarse-grained rocks including K-feldspar megacrysts and more biotite than other mafic minerals and associated with fluorite mineralization. In the R1-R2 diagram of Batchelor and Bowden (1985) Eğrialan syenite is mainly placed in the silica undersaturated field, however, a few samples are located next to late orogenic to anorogenic fields of Figure 6. On the other hand, trace element tectonic discrimination diagrams of Pearce et al. (1984) undoubtedly shows a WPG setting for the Eğrialan syenite (Figure 7).

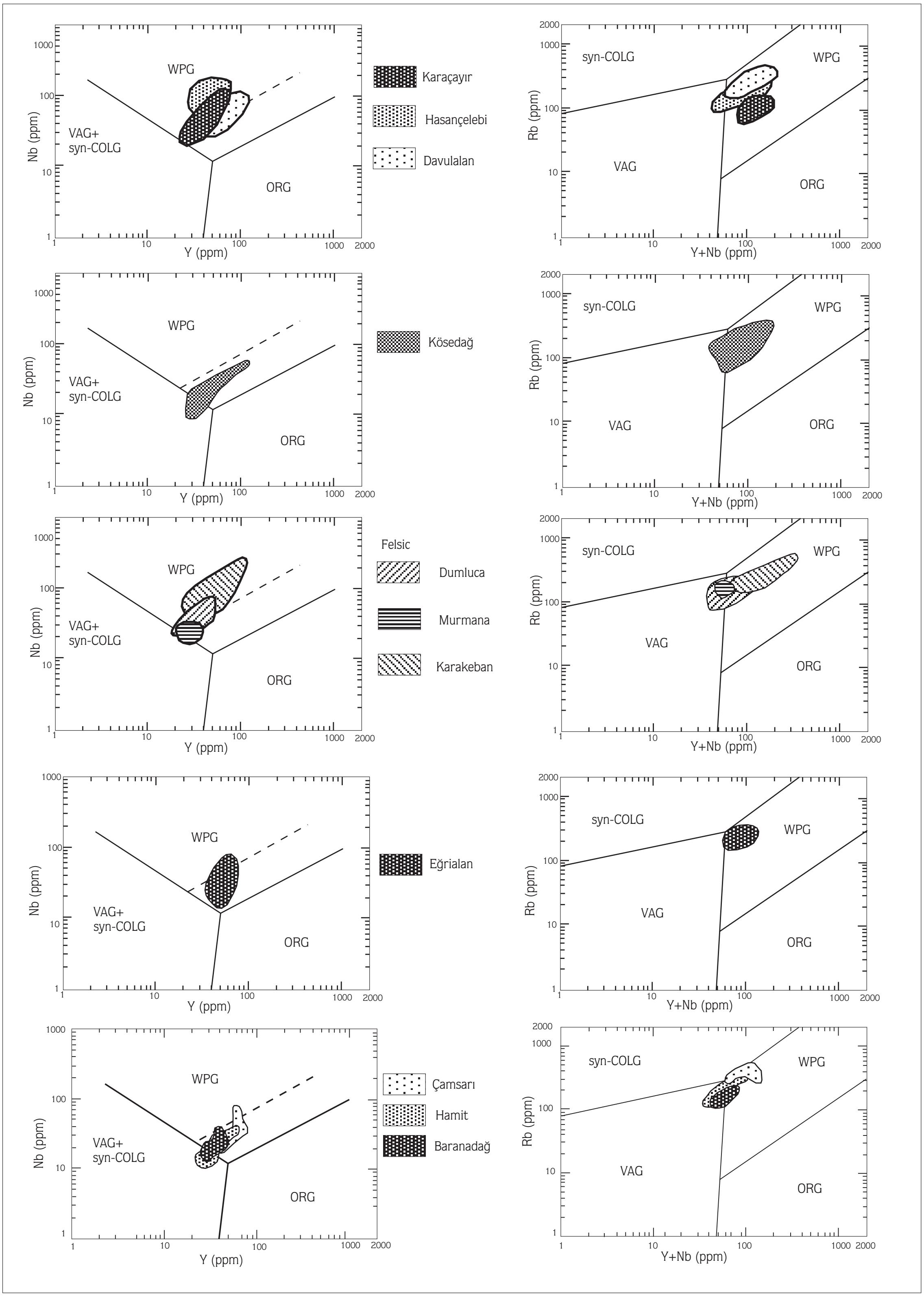

Figure 7. Trace element geotectonic discrimination diagrams (Pearce et al., 1984) of the felsic and silica oversaturated alkaline plutons.

Kaman region plutons: These plutons are subdivided into two subgroups such as silica oversaturated alkaline and undersaturated alkaline among which each subgroup is also subdivided into subunits on the basis of geological setting and mineralogical-chemical characteristics (Otlu and Boztuğ, 1997). The oversaturated alkaline subgroup consists of Baranadağ quartz monzonite, Hamit quartz syenite and Çamsarı quartz syenite; whereas undersaturated alkaline subgroup comprises Durmuşlu nepheline-nosean-melanite syenite porphyry and Bayındır nepheline-cancrinite syenite (Figure 1). The rock samples of Baranadağ quartz monzonite are mainly plotted in the quartz monzonite, and scarcely in the syenite-quartz syenite subfields of chemical nomenclature diagram of Debon and Le Fort (1983) (Figure 2). Hamit quartz syenite takes place in the quartz syenite and quartz monzonite fields, whereas the Çamsarı quartz syenite falls dominantly in the quartz monzonite, and subordinately in the monzogranite fields of Figure 2. Otlu and Boztuğ (1997) have studied the Kaman region plutons in detail, and concluded that the Baranadağ, Hamit and Çamsarı subunits were derived from the same magma by fractional crystallization process in which the first and last products are of Baranadağ and Çamsarı units, respectively. Consequently, the silica undersaturated alkaline plutons, consisting of Durmuşlu nepheline - nosean-melanite syenite porphyry and Bayındır nepheline-cancrinite syenite subunits (Figure 3), have been suggested to be solidified from an undersaturated magma (Otlu and Boztuğ, 1997).

The Baranadağ and Hamit subunits of the oversaturated alkaline subgroup display porphyritic texture with K-feldspar megacrysts, whereas the Çamsarı subunit typically shows fine to medium grained granular texture. Major felsic components of these units are represented by orthoclase+plagioclase+ quartz association. Proportion of plagioclase in total feldspar is more than 50-60 % in the monzonitic rocks, but less than 20-25 % in the syenitic rocks. The mafic constituents are made up of different assemblages like hastingsite±augite+biotite (Baranadağ), hastingsite+ biotite±augite (Hamit) and hastingsite + biotite±fluorite (Çamsarı) minerals. Transformation of augite to biotite is a characteristic feature in thin sections under microscope. Durmuşlu and Bayındır subunits, that belong to the silica undersaturated alkaline subgroup, show porphyritic and granular textures, respectively. The porphyritic texture of Durmuşlu unit is particularly marked by the K-feldspar megacrysts. The groundmass of the porphyritic Durmuşlu unit is made up of feldspars, nepheline, cancrinite and fine-grained riebekite/arfvedsonite and aegirine minerals. The phenocrysts are of orthoclase, cancrinite, plagioclase, nepheline, riebekite/arfvedsonite, aegirine and melanite. The accessory minerals are apatite, titanite, allanite, fluorite and xenotime. Nepheline and nosean minerals may constitute up to 20 % of rock composition. Orthoclase minerals are always more than plagioclase in total feldspars. The most characteristic feature, under the microscope, is that the aegirine minerals are enveloped by the melanite garnets.

The alkaline chemistry of the Kaman region plutons are clearly observed in Figure 4. PRIM normalized trace element spider diagram (Figure 5) indicates that the Ba, Sr and Ti contents of the Çamsarı quartz syenite are lower, and on the contrary, the contents of Rb, Th, Nb, Zr and Y are higher than those of Baranadağ and Hamit subunits. This can be considered as the evidence of fractionation from Baranadağ through Hamit to Çamsarı units. A similar relation is also accounted in the Durmuşlu and Bayındır subunits (Figure 5). Silica oversaturated alkaline plutons of the Kaman region clearly show post-collision uplift to late orogenic trends in Figure 6. Such a geological-geodynamic setting is also supplied by taking place in the WPG subfield of Figure 7.

Petrogenetic Discussion on the Diversification of Central Anatolian Alkaline Plutons

Geological-stratigraphical settings and mineralogical-chemical characteristics of the post-collisional alkaline plutons in Central Anatolia may easily led one to distinguish some subunits on the basis of criteria such as mineralogical-chemical features, type of the wall-rock, silica saturation and associated ore deposit/mineralization. The reasons of these subdivisions are thought to be naturally related to the variabilities in the processes which may modify the compositions of primary magmas, and related to the different types and degrees of partial melting of the same source material (i.e. enriched upper mantle) during magma genesis. For instance, the H_2O efficiency in the magma chamber is known to play an important role in the formation of silica oversaturated or undersaturated alkaline rocks during the solidification of any alkaline magma (Bonin, 1987, 1988, 1990). According to this author, if there is enough water in the partial melting zone of the upper mantle or lower crust, the partial melting yields typical calc-alkaline and hybrid magma. On the other hand, water deficiency and low-degree partial melting of upper mantle source which is already enriched by LIL and particularly F contents produces primary alkaline magmas (McKenzie and Bickle, 1988; Bonin, 1988). The solidification of these types of

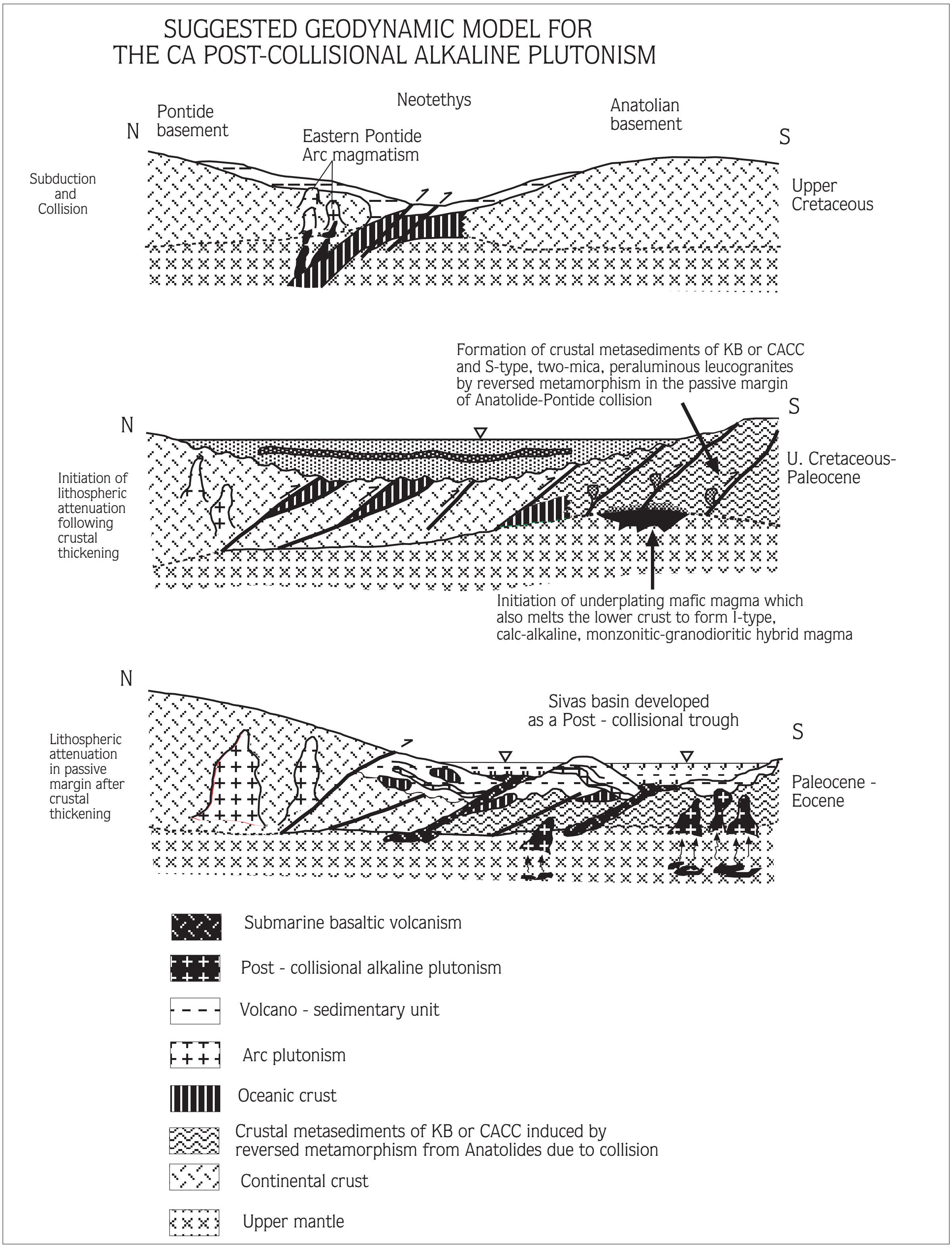

Figure 8. Suggested geodynamic evolutionary model for the CA post-collisional alkaline plutons.

magmas within the crust with high amount of water, i.e. water rich wall-rocks, causes the amphibole fractionation depending on the amount of diffusivity of water from wall-rocks into magma chamber. The residual magmatic liquid after the amphibole fractionation from such a magma may be of silica oversaturated alkaline in composition. On the contrary, if the wall-rocks of the magma chamber is poor in water content, the primary alkaline magma will create the alkaline rocks representing silica undersaturated alkaline trend (Bonin, 1987, 1988, 1990). Apart from the solidification processes modifying the primary composition of any alkaline magma as remarked by Bonin (1987, 1988, 1990) mentioned above, the primary composition of source material, the type and degree of partial melting process may also have important roles in the genesis and evolution of any alkaline magma. The importance of the composition of original source material and the variabilities in the partial melting conditions have been experimentally studied by Patino Douce (1996). Similarly, the importance of the type and degree of melting during the partial melting of any source material is also known to have considerable affects in the composition of resulting magmatic liquid (Wilson, 1989; Rollinson,1993; Albaréde, 1996). On the other hand, the batch and Rayleigh types of melting are assumed to be effective during the formation of the felsic and mafic magmas, respectively (Rollinson, 1993). In this respect, trace element content of a liquid derived from the Rayleigh melting of a mantle lherzolite with a partial melting degree more than 10 % distinctly differs from that of a liquid derived from the batch melting of the same source with the same degree of melting (Wilson, 1989, p.65).

By taking considerations all these theoretical backgrounds, one can suggest that the diversification, i.e. subdivisions, in the alkaline plutons in Central Anatolia may be sourced from the H_2O efficiency in the magma chamber during solidification as pointed out by Bonin (1987, 1988, 1990). In this circumstance, silica oversaturated alkaline trends in the Divriği region plutons and Kösedağ batholith can be induced by the amphibole fractionation due to high water content in magma chamber which may be infiltrated from the water rich wall-rocks, e.g. ophiolitic and volcano-sedimentary rocks, respectively, in the Divriği and Kösedağ districts. The silica undersaturated alkaline rocks of the Karaçayır, Davulalan and Bayındır plutons, intruding into medium-grade crustal metasediments and associated with fluorite mineralization, can be formed under the solidification conditions in which there was no enough water activity due presumably to emplacement within already dehydrated and deformed crustal metasediments. On the other hand, when it is taken into account that another fluorite mine bearing pluton, namely Kuluncak part of Hasançelebi pluton, intrudes Cretaceous-Lower Tertiary sediments of the post-collisional Hekimhan basin (Öztürk et al., 1996), the assumption related to water poor wall-rocks does not work well. Moreover, the Kuluncak (Hasançelebi), Karaçayır and Davulalan plutons do not include only undersaturated rocks, but also oversaturated alkaline rocks. So that, instead of this assumption, i.e. the processes modifying the composition of any primary magma, it would be reasonable to take into account the originally derivation of the magmas of these plutons, consisting both of the silica oversaturated and undersaturated rocks with fluorite mine and high contents of LIL elements, under very low degree partial melting of mantle material under water deficiency condition as mentioned by McKenzie and Bickle (1988) and Bonin (1988). On the other hand, the magmas of mafic and felsic parts of the Divriği region plutons can be derived from different types and degress of partial melting of the same mantle peridotites that a Rayleigh type of melting with a high degree and, subsequently, a batch melting with a low degree could yield the mafic/silica undersaturated and felsic/silica oversaturated alkaline magmas, respectively.

As the concluding remarks, the diversification of the alkaline plutons in Central Anatolia such as felsic/oversaturated, mafic/undersaturated and felsic/undersaturated with fluorite mine can be sourced from either the processes (i.e. H_2O efficiency in magma chamber) modifying the composition of any primary magma, or from the different primary magmas derived from mantle source by different types and degrees of partial melting under water poor conditions.

Geodynamic Interpretation

As pointed out in the introduction part of this paper, there are different suggestions on the evolutionary model of granitoids which have been summarized by Göncüoğlu and Türeli (1994; p.39) as follow:

1. The southward emplacement of ophiolitic nappes (Bozkır ophiolitic nappes) from the İzmir-Ankara ocean has caused crustal thickening and metamorphism during Upper Campanian-Maastrichtian times. The subsequent northwards subduction of the Inner Tauride ocean beneath the crystalline complex, called Kırşehir block (Görür et al., 1984; Poisson, 1986) during Lower Paleocene-Eocene times initiated the calc-alkaline arc magmatism in the region (Şengör and Yılmaz, 1981).

2. The eastwards subduction of the Inner Tauride ocean during Paleocene-Early Eocene under the CACC created an Andean-type arc magmatism which produced the granitoids in the region (Görür et al., 1984).

3. The granitoids are formed by the Late Cretaceous collision of an ensimatic arc which is represented by Çiçekdağ igneous complex and numerous overthrusted bodies with the main trunk of Central Anatolian Crystalline Complex (Göncüoğlu and Türeli, 1994).

As clearly seen from all these data given above, there is no any agreement on the geodynamic and petrogenetic interpretation of calc-alkaline granitic plutonism, tholeiitic gabbroic plutonism and alkaline plutonism in Central Anatolia. Therefore, by taking into account all the existing literature data and particularly some most recent studies (Erler and Göncüoğlu, 1996; Kadıoğlu and Güleç, 1996; Yalınız et al., 1996, 1997; Boztuğ et al., 1997; Ekici et al., 1997; Tatar and Boztuğ, 1997; Otlu and Boztuğ, 1997) in this region, and some benchmark studies on the alkaline rocks (Harris et al., 1986; Fitton and Upton, 1987; Liegois and Black, 1987; Bonin, 1990), the following geodynamic model is suggested in this paper (Figure 8).

There is a good synchronization between the granitic intrusion and metamorphism in Central Anatolia where both events are mainly Upper Cretaceous in age although, there are some radiometric ages on some granitoid plutons indicating Lower Cretaceous, e.g. Ağaçören granitoid (Güleç, 1994); Murmana pluton (Zeck and Ünlü, 1987, 1988a, 1988b), and Lower Tertiary, i.e. Baranadağ pluton (Ayan, 1963) and Kösedağ batholith (Kalkancı, 1974). Such a time interval, ranging from Upper Cretaceous to Lower Tertiary, is interpreted as a normal duration for the evolution of a collision related magmatic episode, thus Bonin (1990) suggests a time span of 30-50 Ma for the evolution of collision zone magmatism. Moreover, the degree of metamorphism decreases from north to south (Erkan, 1981), i.e. from the collision zone (suture zone) towards the Taurus belt, in Central Anatolia. Thus, the synchronization of metamorphism and plutonism and the southward decreasing of metamorphic grade (Erkan, 1981) may be assumed that these events can be related to Upper Cretaceous collision of Anatolides and Pontides along the Ankara-Erzincan suture zone. The consumption of the northern branch of the Neo-Tethyan ocean with a northward subduction beneath the Pontide basement (Şengör and Yılmaz, 1981) and ophiolite obduction due to Anatolide-Pontide collision in Turkey should have been completed before the Maastrichtian (Figure 8). This is because the allochthonous ophiolitic slabs derived from this suture zone are exposed and unconformably overlain by the Buldudere member (Yılmaz et al., 1993) containing Orbitoides medius (d'Archiac) fossils (determined by Dr. A. POISSON, Univ. of Paris-Sud, Orsay Cedex, France) in the Hekimhan-Hasançelebi area, SE Sivas, CA, Turkey. The metamorphic event could be created by an inverted metamorphism (Le Fort, 1986; Burg et al., 1994) which is induced by the juxtaposition of two plates along Ankara-Erzincan suture zone in Central Anatolia. During such a metamorphism, the overthrusting and related crustal thickening may cause to derive some syn-collisional granitic melts of S-type, peraluminous and two-mica granite in composition, e.g. the Yücebaca, Celaller, Üçkapılı and Sarıhacılı granitic plutons in Figure 1. In fact, such a petrogenetic interpretation has been firstly mentioned by Göncüoğlu (1986) for the genesis of Üçkapılı granitoid in Niğde massif. Erler and Göncüoğlu (1996) also points out that the S-type and two mica granites in the Yozgat batholith are the oldest rocks. This leucogranitic association in Central Anatolia, regarded as syn-collisional magmatism, can be correlated with group II magmatism of Harris et al. (1986). Towards or at the end stages of crustal thickening, the lithospheric delaminations could generate underplating mafic magma which also melts the lowermost part of crust that yields voluminous post-collisional, calc-alkaline, I-type monzonitic-granodioritic hybrid association in Central Anatolia. This magmatic association may be regarded as the equivalent of group III magmatism of Harris et al. (1986). After the emplacement of this magmatic pulse, the tectonic regime could have been changed from compression to tension due to simple isostatic balance in the crust (Channel, 1986) that initiates the lithospheric attenutaion. So, such a tectonic regime associated with lithospheric attenuation may cause the partial melting of the upwelled mantle material under the conditions of adiabatic decompression which produces post-collisional alkaline magma. This magmatic association in Central Anatolia is compared with group IV magmatism of Harris et al. (1986). During the formation of this alkaline magma, different magma pulses can be generated depending upon the different type and degree of partial melting of the enriched upper mantle source material under water poor conditions which causes diversification, i.e. formation of subdivisons, in the alkaline plutons. On the other hand, some processes modifying the composition of any primary magma could have been active during the solidification of magma which may also cause the diversification in the formation of alkaline plutons. This magma genesis scenario is, in fact, convenient with the general geology in Central Anatolia that syn-collisional, S-type, peraluminous and two-mica leucogranites are always associated with medium to high grade crustal metasediments. Although, there is no any direct stratigraphic contact between these leucogranites and post-collisional I-type, hybrid, calc-alkaline voluminous monzonitic-granodioritic association, the alkaline rocks clearly cut the leucogranitic and monzonitic-granodioritic associations, i.e. they are the youngest intrusives.

Conclusion

The alkaline plutons constitute an important association in the post-collisional Central Anatolian granitoid plutonism (Göncüoğlu and Türeli, 1994; İlbeyli and Pearce, 1997). These plutons represent some subdivisions or diversifications by means of mineralogical-chemical characteristics, wall-rock, silica saturation and associated ore deposit/mineralization. This diversification could be generated by either some solidification processes which modify the primary composition of any mantle-derived alkaline magma, or some different alkaline magma pulses derived from the partial melting of the same mantle material with the different types and degrees of partial melting under water poor conditions.

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