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Fractional Crystallization and Magma Mingling/Mixing Processes in the Monzonitic Association in the SW Part of the Composite Yozgat Batholith (Şefaatli–Yerköy, SW Yozgat)

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Abstract: The Yozgat batholith takes place in the passive margin of the Anatolide-Pontide convergence system. It includes; syn-collisional S-type, two-mica granites; post-collisional I-type, calcalkaline monzonitic association, and post-collisional, M-type, tholeiitic gabbroic/dioritic association. Among these associations, the monzonitic association is also subdivided into five mapable units such as Cankılı monzogabbro/monzodiorite, Akçakoyunlu quartz monzodiorite, Adatepe quartz monzonite, Yassıağıl monzogranite and Karakaya monzogranite. All these subunits, except the Karakaya monzogranite, include K-feldspar megacrysts. These five subunits represent some evidence of fractional crystallization (FC) and magma mingling/mixing processes by means of field, mineralogical-petrographical and geochemical characteristics. There is a good zonation in the field that the Cankılı monzogabbro/monzodiorite forms the core, and Karakaya monzogranite forms the rim. Mafic mineral assemblage of the Cankılı monzogabbro/monzodiorite, first product of FC process, comprizes clinopyroxene + amphibole (hornblende + hastingsite) + biotite. Those of Akçakoyunlu and Adatepe subunits, crystallized just after the Cankılı by FC during cooling of magma, are composed of amphibole (hornblende + hastingsite) + clinopyroxene + biotite. As for the mafic minerals of the Yassıağıl and Karakaya subunits, solidified as final FC products comprise amphibole (hornblende + hastingsite) + biotite ± clinopyroxene, and biotite + amphibole (hornblende + hastingsite) ± clinopyroxene, respectively. The major element oxides such as tFe_2O_3, MnO, MgO, CaO, TiO_2 and P_2O_5 apparently decrease with the increasing silica content, whereas K_2O content increases. The trace elements like Co, Cu, Zn, Rb and Ga determine good FC trend, on the contrary Cr, Pb, Nb, Y, Zr and Th elements exhibit slightly FC trend versus silica content. Variations in the Sr and Ba elements versus silica also describe recognizable FC trend from Cankılı to Karakaya units, although, some secondary mobilizations in the contents of these trace elements, particularly depletions in some Cankılı rock samples do not fit well this trend. The most reliable variograms indicating FC trend are those of K/Rb versus Rb, K/Ba versus Ba and of K/Rb versus K/Ba. Some mafic microgranular magmatic enclaves (MME), commonly found in the field, are considered to be evidences of the magma mingling process. There are also some microscopic textures (antirapakivi, poikilitic/oikocrystic feldspars, small lath shaped plagioclase within large plagioclase, spike zones in plagioclase and spongy cellular dissolution/melting textures in plagioclase) indicating the magma mixing process.

Key Words: Composite Yozgat batholith, fractional crystallization, magma mingling/magma mixing, S type, I type, Mtype assosiations.

Kompozit Yozgat Batoliti GB Kesimindeki (Şefaatli–Yerköy, GB Yozgat) Monzonitik Birlikte Fraksiyonel Kristalleşme ve Magma Mingling/Mixing Süreçleri

Özet: Yozgat batoliti, Anatolid-Pontid çarpışma sisteminin pasif kenarında yer almaktadır. Bu batolit S-tipi, çarpışmayla eş zamanlı iki-mikalı granitler; I-tipi, çarpışma sonrası, kalkalkalin, monzonitik birlik ve M-tipi, çarpışma sonrası, toleyitik mafik magmayı karakterize eden gabroyik / diyoritik birlikten oluşmaktadır. Bu birliklerden monzonitik birlik, kendi arasında haritalanabilir beş alt birime ayrılabilmektedir. Bunlar Cankılı monzogabro/monzodiyoriti, Akçakoyunlu kuvars monzodiyoriti, Adatepe kuvars monzoniti, Yassıağıl monzograniti ve Karakaya monzogranitidir. Bu alt birimlerden Karakaya monzograniti hariç, diğerlerinin tümü K-feldispat megakristalleri içermektedir. Bu beş alt birim, hem arazi, hem de mineralojik-petrografik ve jeokimyasal karakteristikleri bakımından fraksiyonel kristalleşme (FC) ve magma mingling/mixing süreçlerinin iyi korunmuş kanıtlarını gösterirler. Bunlardan FC süreci, içten dışa doğru gelişmeyi karakterize edecek şekilde olup; Cankılı birimi batolitin en iç, Karakaya birimi ise en dış kesiminde yüzeylenmektedir. FC süreciyle ilk önce oluşan Cankılı monzogabro/monzodiyoritinin mafik mineral topluluğu klinopiroksen + amfibol (hornblend + hastingsit) + biyotitten oluşurken; Cankılı'dan hemen sonra katılaşan Akçakoyunlu ve Adatepe birimlerinin mafik mineralleri ise amfibol (hornblend + hastingsit) + klinopiroksen + biyotitten oluşmaktadır. İlerleyen FC sürecine bağlı olarak gelişen Yassıağıl ve Karakaya monzogranitlerinin mafik mineral toplulukları ise, sırasıyla, amfibol (hornblend + hastingsit) + biyotit ± klinopiroksen ve biyotit + amfibol (hornblende + hastingsit) ± klinopiroksen minerallerinden oluşmaktadır. Ana element oksit bileşenlerinden tFe_2O_3, MnO, MgO, CaO, TiO_2 ve P_2O_5 değerleri artan silis içeriğine bağlı olarak düşme; K_2O içeriği ise artma göstermektedir. Artan silis içeriğine bağlı olarak, eser elementlerden Co, Cu, Zn, Rb ve Ga mükemmel; buna karşılık Cr, Pb, Nb, Y, Zr ve Th elementleri ise zayıf FC trendi sergilemektedir. Sr ve Ba elementlerinin silise göre değişimi Cankılı'dan Karakaya'ya doğru mükemmel bir FC trendi tanımlamakla birlikte, özellikle Cankılı birimine ait bazı kayaç örneklerindeki feldispat minerallerinin alterasyonu ile belirginleşen Sr ve Ba mobilizasyonları bu trende uyumsuzluk gösterebilmektedir. FC sürecinin en güvenilir jeokimyasal göstergeleri ise K/Rb-Rb, K/Ba-Ba ve K/Rb-K/Ba variogramlarıdır. Arazide görülen mikrogranüler dokulu mafik magmatik enklavlar (MME), eş yaşlı mafik ve felsik magmaların heterojen karışımını gösteren magma mingling sürecinin; antirapakivi, poikilitik/oikokristik feldispat, iri plajiyoklazlar içerisindeki küçük plajiyoklaz lataları, çivi başlarına benzer zonlar ile erime/çözünme dokuları olarak tanımlanan bazı mikroskopik özellikler ise bu magmaların homojen karışımını gösteren magma mixing sürecinin kanıtları olarak değerlendirilmektedir.

Anahtar Sözcükler: Kompozit Yozgat batoliti, fraksiyonel kristalleşme, magma mingling/magma mixing, S tipi, I tipi, M tipi birlikler.

Introduction

The Yozgat batholith (Figure 1), constituting the biggest one in the post-collisional Central Anatolian granitoid magmatism (Erler et al., 1991; Boztuğ et al., 1994; Göncüoğlu and Türeli, 1994; Erler and Bayhan, 1995; Erler and Göncüoğlu, 1996; İlbeyli and Pearce, 1997), is suggested to consist of various mapable igneous rock units derived from different magmas. It is composed of silica oversaturated alkaline monzonites in the south of Sorgun town (Boztuğ, 1994-1995); of Sarıhacılı leucogranite consisting of syn-collisional, S-type, peraluminous, two-mica granites; of Lökköy and Büyüklök monzogranite unites comprising post-collisional I-type, calc-alkaline monzogranitic rocks, and of Başnayayla diorite/gabbro made up of post-collisional, M-type, tholeiitic-mafic rocks (Ekici, 1997; Ekici et al., 1997; Ekici and Boztuğ, 1997). Erler and Göncüoğlu (1996) suggested that the Yozgat batholith comprises eight units on the basis of (1) structural features, (2) units at the boundaries and (3) textural-mineralogical features. These units are, from west to east, (1) Yerköy-Şefaatli, (2) Yozgat, (3) Kerkenez, (4) Karlıtepe, (5) Gelingüllü, (6) Sivritepe, (7) Ocaklı, and (8) Mugallı. Therefore, the Yozgat batholith is suggested to be a composite batholith on the basis of all these data (Tatar and Boztuğ, 1997).

There are some monzonitic rocks outcropping in an area between Şefaatli and Yerköy towns located to the SW part of the batholith which has recently been determined as the *monzonitic association* by Tatar (1997), Tatar et al. (1997) and Tatar and Boztuğ (1997) (Figure 1). This paper deals essentially with the representation of the field and laboratory evidences of some solidification processes (i.e. fractional crystallization and magma mingling/mixing) modifying the primary composition of a source magma to yield monzodiorite/monzogabbro, quartz monzodiorite, quartz monzonite and monzogranite types of rocks. For this purpose, an area of approximately 300 km^2 has been geologically mapped to the scale of 1/25 000, and some 164 rock

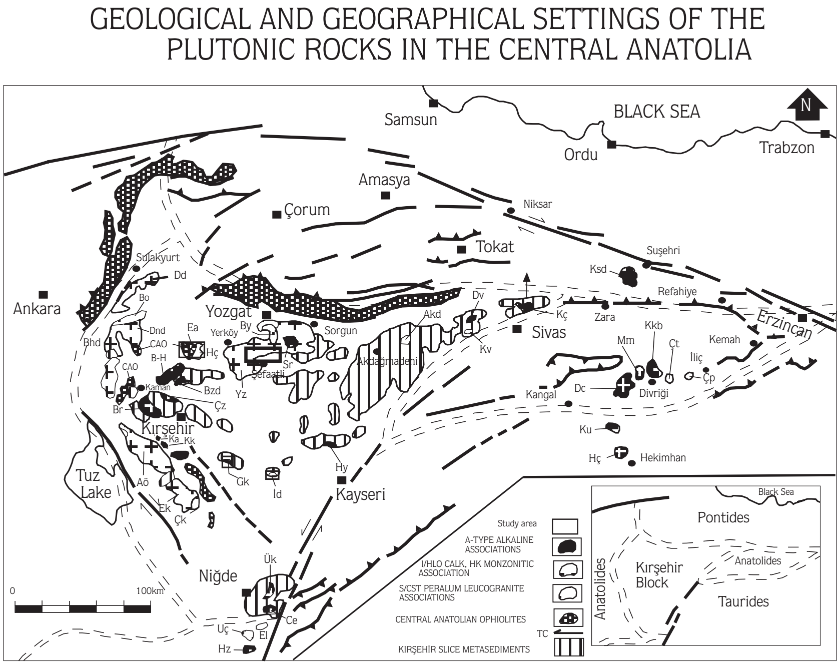


Figure 1. The location map of the investigated area (after Bingöl, 1989). The abbreviations of pluton are as follow (from E to W): Aö: Ağaçören; Ak: Akçakent; Akd: Akdağmadeni; Bhd: Behrekdağ; Bzd: Buzlukdağ; Ce: Celaller; Çt: Çaltı; Çz: Çayağzı; Çk: Çokumkaya; Çp: Çöpler; Dv: Davulalan; Dc: Dumluca; Ea: Eğrialan; Ek: Ekecikdağ; El: Elmalı; Gk: Gümüşkent; Ha: Halaçlı; Hç: Hasançelebi; Hy: Hayriye; Hz: Horoz; İd: İdişdağ; Kç: Karaçayır; Kv: Kavik; Kgd: Karagüneydağ; Kkb: Karakeban; Kk: Kesikköprü; Ksd: Kösedağ; Ku: Kuluncak; Ka: Kuruağıl; Mm: Murmana; Uç:Uçurumtepe; Ük: Üçkapılı; Yz: Yozgat.

samples were collected from the mapped area. All the rock specimens have been studied under a Nikon-Labophot-Pol type binocular microscopy for the determination of mineralogical-petrographical compositions and textural features (Tatar, 1997). Some 79 fresh and representative rock samples have been analysed for wholerock major and trace element compositions. The chemical analyses (Tables 1) have been performed at the CU-MIPJAL (Mineralogical-Petrographical and Geochemical Research Laboratories of the Dept. of Geological Engineering of Cumhuriyet University, Sivas) with XRF spectrometer (Rigaku-3270 E-WDS) using some CRPG and USGS rock standards (Govindaraju, 1989).

Geological Setting

The intrusive rocks, outcropping in the area between Şefaatli and Yerköy in the SW part of the Yozgat batholith, can be determined as two major associations, e.g. monzonitic and gabbroic/dioritic. The monzonitic association is subdivided into some mapable subunits such as, Cankılı monzogabbro/monzodiorite, Akçakoyunlu quartz monzodiorite, Adatepe quartz monzonite, Yassıağıl monzogranite and Karakaya monzogranite. The gabbroic/dioritic association (Başnayayla diorite/gabbro) consists of only one unit. All these intrusive units are cut by Hacımusalı microgranite (Figures 2, 3). There is neither radiometric age data on these intrusive rock units, nor the age of the host rocks are known. The only stratigraphical evidence on the geological age of the plutonics is that all these units are unconformably covered by Lower-Middle Eocene Höke limestone in the mapped area (Figures 2, 3), and by the Lower Eocene Topçu formation just to the north of mapped area (Ekici, 1997; Ekici and Boztuğ, 1997). The geological age of these intrusive units are, therefore, considered on the basis of previous work (Ketin, 1955; Boztuğ, 1994–1995; Erler

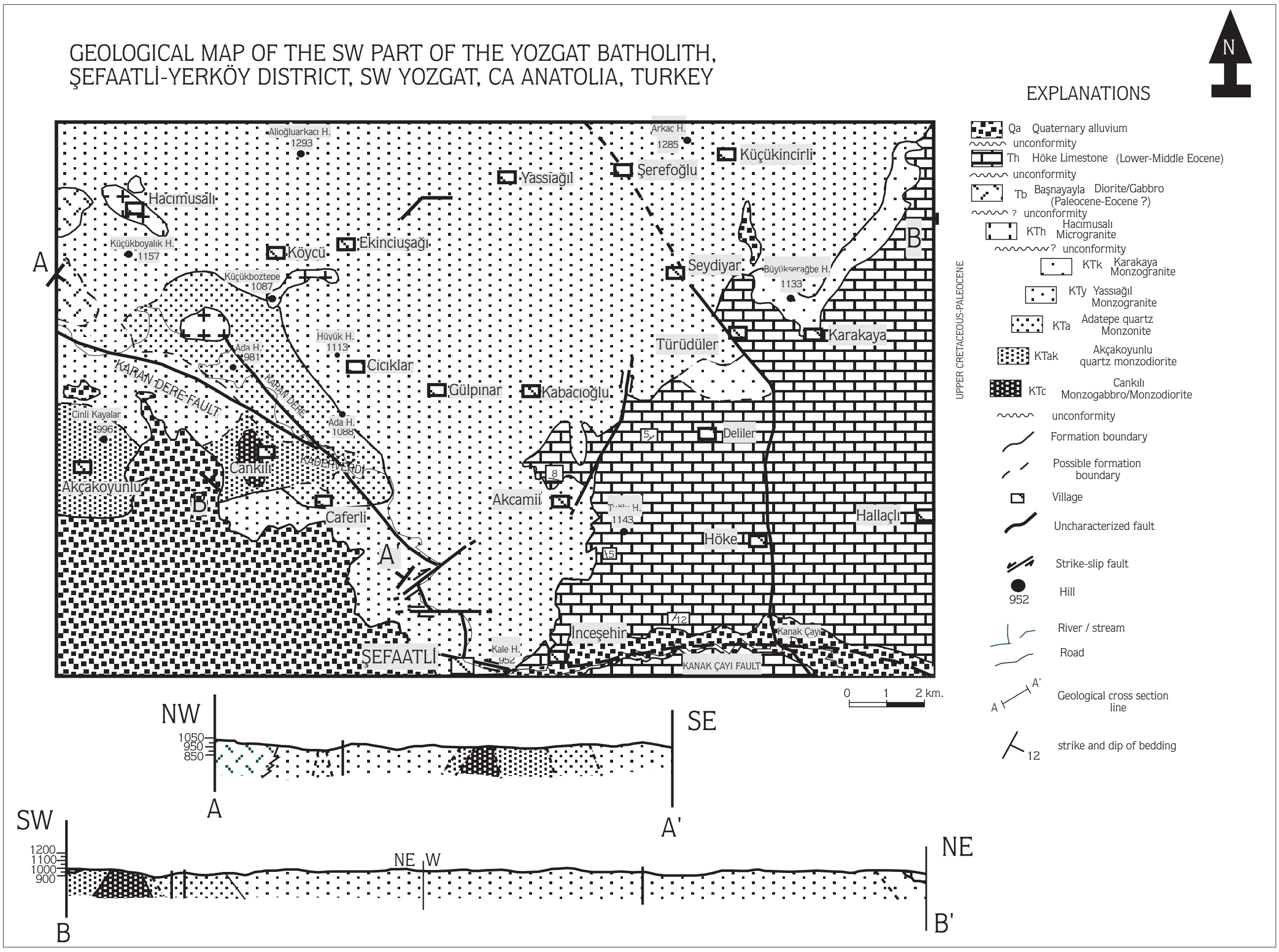


Figure 2. Geological map of the SW part of the Yozgat batholith, Şefaatli-Yerköy district, SW Yozgat, CA Anatolia, Turkey.

Table 1. The wholerock major and trace element compositions of the rock samples taken from the subunits constituting the monzonitic association in the SW part of Yozgat batholith.

						CANKILI							
Sample	SiO_2	Al_2O_3	TiO_2	tFe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Cr
ST-65	54.10	17.10	0.90	7.20	0.10	3.50	8.50	3.10	3.00	0.50	0.70	98.70	34
ST-159	53.60	17.10	1.00	8.30	0.10	3.10	8.70	2.90	2.60	0.40	0.80	98.60	38
						AKÇAKOYUNLU							
Sample	SiO_2	Al_2O_3	TiO_2	tFe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Cr
ST- 58	59.40	16.90	0.80	6.30	0.10	2.60	6.00	2.60	3.80	0.30	0.50	99.30	20
ST-61	57.38	16.12	0.76	7.40	0.14	3.14	6.25	2.82	3.63	0.27	0.94	98.90	57
ST-62	57.26	15.58	0.75	7.50	0.14	3.19	5.93	2.69	3.86	0.28	0.97	98.20	51
ST-64	56.90	15.60	0.80	7.90	0.20	3.50	6.60	2.70	3.40	0.30	1.00	98.90	65
ST-136	56.70	17.00	0.90	7.30	0.10	3.20	8.00	3.20	3.50	0.40	0.10	100.40	21
ST-160	54.70	17.30	0.90	7.00	0.10	3.10	8.30	3.20	3.10	0.40	0.90	99.00	34
ST-162	58.80	15.90	0.60	7.70	0.10	2.80	6.60	2.90	3.90	0.30	0.90	100.50	24
						ADATEPE							
Sample	SiO_2	Al_2O_3	TiO_2	tFe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Cr
ST-106	62.20	15.60	0.50	5.30	0.10	1.90	4.50	2.70	5.00	0.20	0.90	98.90	21
ST-109	63.75	15.79	0.51	4.82	0.11	1.53	4.15	2.98	4.50	0.17	0.56	98.90	9
ST-114	62.58	13.87	0.71	7.31	0.13	2.82	5.10	2.71	3.55	0.27	0.46	99.50	45
ST-115	62.65	15.56	0.52	5.31	0.10	2.11	4.27	2.81	4.52	0.20	0.65	98.70	36
ST-120	64.71	15.80	0.39	4.19	0.08	1.63	3.49	2.84	5.16	0.15	0.38	98.80	29
ST-122	63.40	15.10	0.42	4.38	0.09	2.10	4.03	2.69	5.36	0.18	0.89	98.60	47
ST-123	63.40	14.98	0.46	5.11	0.10	2.37	3.99	2.67	4.79	0.19	0.80	98.90	18
ST-124	61.20	15.50	0.70	6.50	0.10	2.10	4.90	2.80	4.20	0.20	0.60	98.80	11
ST-137	61.80	15.74	0.68	5.77	0.10	2.53	6.49	2.99	2.83	0.31	0.68	99.90	25
ST-138	55.10	16.57	0.89	7.45	0.12	3.37	7.93	3.14	2.97	0.41	0.70	98.70	26
ST-139	64.20	15.40	0.50	4.90	0.10	1.80	3.90	2.90	4.40	0.20	0.20	98.50	nd.
ST-145	61.50	15.50	0.70	5.40	0.10	2.40	5.10	2.40	4.10	0.20	1.30	98.70	15
ST-157	59.25	15.71	0.58	6.70	0.13	2.54	6.63	2.84	2.88	0.24	0.57	98.10	41
ST-161	63.87	16.19	0.42	4.40	0.08	2.40	3.36	2.87	5.58	0.17	1.32	100.70	11
						YASSIAĞIL							
Sample	SiO_2	Al_2O_3	TiO_2	tFe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Cr
ST-1	62.68	17.45	0.45	3.96	0.09	2.02	4.88	3.09	4.79	0.25	0.34	100.00	7
ST-20	64.00	15.70	0.64	4.46	0.08	1.92	4.09	2.62	4.18	0.19	0.65	98.50	26
ST-21	64.20	15.30	0.50	4.30	0.10	1.70	4.00	2.50	4.70	0.20	1.00	98.50	32
ST-23	64.90	15.40	0.60	4.40	0.10	1.70	3.90	2.50	4.40	0.20	0.80	98.90	21
ST-30	62.00	16.00	0.50	4.60	0.10	1.90	4.30	2.90	4.90	0.20	1.50	98.90	23
ST-32	62.80	15.50	0.60	5.20	0.10	2.00	4.90	2.80	4.50	0.20	0.50	99.10	22
ST-47	66.94	15.38	0.54	4.33	0.08	1.81	3.60	2.56	4.40	0.17	0.54	100.40	21
ST-48	66.20	16.00	0.50	4.20	0.10	1.70	3.80	2.70	4.30	0.10	0.50	101.10	22
ST-70	64.84	16.63	0.48	3.73	0.08	1.74	4.45	3.41	4.41	0.23	0.19	100.20	28
ST-72	62.12	16.61	0.55	4.56	0.10	2.32	5.22	3.08	4.13	0.27	0.36	99.30	16
ST-73	64.10	16.38	0.50	4.04	0.07	1.43	4.08	2.93	4.42	0.18	0.37	98.50	11
ST-74	63.60	16.07	0.58	4.35	0.08	1.73	4.42	2.97	4.01	0.18	0.54	98.50	20
ST-87	60.66	16.21	0.52	4.61	0.09	2.38	5.09	3.22	4.16	0.25	1.58	98.80	12
ST-113	64.50	16.40	0.50	4.00	0.10	1.90	4.30	3.00	4.30	0.20	0.20	99.40	14
ST-127	65.98	15.41	0.53	4.44	0.08	1.91	3.85	2.57	4.56	0.18	0.24	99.80	34
ST-129	67.21	15.77	0.52	4.25	0.08	1.80	3.63	2.63	4.63	0.16	0.73	101.40	11
ST-130	68.21	15.07	0.42	3.32	0.06	1.46	2.92	2.62	4.90	0.13	0.23	99.40	18
ST-131	68.10	15.80	0.50	4.00	0.10	1.70	3.60	2.80	4.40	0.10	0.30	101.40	17
ST-132	65.55	15.22	0.55	4.34	0.08	1.91	3.99	2.54	4.26	0.17	1.32	99.90	25
ST-133	62.73	15.96	0.69	5.01	0.08	2.18	4.61	2.60	4.22	0.19	0.87	99.10	24
ST-134	66.10	15.73	0.56	4.30	0.08	1.90	3.73	2.60	4.70	0.17	1.20	101.10	10
ST-140	62.99	16.64	0.59	4.33	0.08	1.62	4.55	3.09	3.75	0.19	1.02	98.90	18
ST-142	63.97	16.46	0.48	3.93	0.08	1.85	4.75	3.34	4.57	0.25	0.28	100.00	21
ST-148	66.00	15.52	0.52	4.21	0.08	1.72	3.99	2.60	4.40	0.17	1.05	100.30	18
ST-152	64.90	15.00	0.60	4.50	0.10	1.70	4.10	2.60	4.10	0.20	0.90	98.70	22
ST-153	67.20	16.01	0.50	3.84	0.07	1.57	3.56	2.70	4.71	0.15	1.09	101.40	16
ST-158	67.83	15.80	0.47	3.35	0.06	1.44	3.17	2.79	4.56	0.14	0.61	100.20	19
						KARAKAYA							
Sample	SiO_2	Al_2O_3	TiO_2	tFe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Cr
ST-29	68.90	14.99	0.42	2.95	0.05	1.29	2.69	2.60	4.90	0.13	0.61	99.50	30
ST-31	68.70	15.70	0.50	3.20	0.05	1.40	3.40	2.70	4.50	0.10	1.00	101.30	28
ST-34	67.75	15.73	0.49	3.28	0.06	1.55	3.17	2.77	4.68	0.16	0.81	100.50	34
ST-35	66.81	15.31	0.48	3.10	0.05	1.46	3.19	2.72	4.69	0.14	0.61	98.60	28
ST-44	67.66	15.61	0.53	3.47	0.06	1.52	3.49	2.63	4.60	0.16	0.62	100.40	23
ST-50	67.29	14.98	0.47	3.02	0.05	1.29	3.09	2.69	4.59	0.14	0.55	98.20	21
ST-55	68.09	15.73	0.47	3.21	0.06	1.55	3.52	2.76	4.56	0.16	0.36	100.50	34

Table 1. (continued)

						CANKILI						
Ni	Co	Cu	Pb	Zn	Rb	Sr	Ga	Th	Nb	Zr	Y	Ba
nd.	25	18	26	106	74	910	18	7	12	208	18	1451
nd.	28	13	22	108	66	865	21	21	13	227	18	822
						AKÇAKOYUNLU						
Ni	Co	Cu	Pb	Zn	Rb	Sr	Ga	Th	Nb	Zr	Y	Ba
nd.	21	10	26	96	107	788	19	16	15	285	24	1358
nd.	26	41	33	101	114	558	17	7	15	198	26	1054
nd.	26	24	35	98	109	551	17	15	15	198	25	1163
nd.	27	19	32	102	106	506	17	21	17	210	27	916
nd.	24	12	32	104	97	979	19	7	10	210	19	1532
nd.	24	14	25	102	80	971	21	17	10	206	19	1126
nd.	25	15	38	97	90	598	18	14	16	236	29	1262
						ADATEPE						
Ni	Co	Cu	Pb	Zn	Rb	Sr	Ga	Th	Nb	Zr	Y	Ba
nd.	17	16	52	86	159	600	18	21	18	224	34	1186
nd.	16	5	71	112	151	680	19	17	20	239	34	1280
nd.	26	nd.	32	97	123	330	19	17	27	270	34	228
nd.	18	13	47	86	157	491	18	27	24	222	34	851
nd.	14	10	67	82	185	601	17	29	17	192	37	1098
nd.	15	14	65	83	215	497	18	22	22	194	42	1040
nd.	17	7	50	81	159	500	18	35	21	209	32	914
nd.	21	5	43	99	106	670	18	20	25	248	32	1242
nd.	20	8	28	98	82	867	19	14	10	211	19	995
nd.	26	17	30	110	84	921	20	26	11	232	20	1058
nd.	17	11	48	91	149	544	19	78	20	227	33	1027
nd.	18	nd.	48	90	133	733	18	22	17	259	28	1201
nd.	23	30	28	92	86	661	18	41	11	220	20	758
nd.	15	6	47	76	170	578	18	20	25	210	35	1654
						YASSIAĞIL						
Ni	Co	Cu	Pb	Zn	Rb	Sr	Ga	Th	Nb	Zr	Y	Ba
nd.	14	10	34	69	176	920	19	14	14	230	33	1690
nd.	15	10	44	84	148	684	20	16	16	237	30	1119
nd.	14	7	47	81	156	667	18	17	15	225	32	1141
nd.	15	6	43	83	144	656	21	16	17	233	31	1105
15	15	16	70	82	160	574	16	24	19	209	32	1173
nd.	17	9	46	81	149	566	20	17	17	223	32	917
nd.	15	7	52	86	163	590	20	21	17	213	34	987
nd.	14	8	56	84	160	629	18	19	16	224	34	982
nd.	13	12	57	91	166	761	18	15	16	208	31	1246
nd.	16	8	42	78	132	809	19	16	15	207	27	1263
nd.	14	10	48	89	161	639	20	13	17	235	32	1182
nd.	15	11	37	92	156	607	22	15	16	230	32	1086
nd.	16	6	38	78	134	885	20	14	16	220	27	1170
nd.	13	15	36	84	147	643	20	15	14	190	26	1300
nd.	15	8	61	83	156	629	18	17	16	215	33	1084
nd.	14	6	55	82	165	640	16	74	16	226	32	992
nd.	15	11	48	93	131	742	20	16	13	256	27	1119
nd.	13	9	46	85	165	636	17	35	18	247	34	896
nd.	15	12	42	83	156	622	19	22	21	242	32	887
nd.	17	8	49	89	140	745	19	16	20	259	29	1339
nd.	15	5	44	83	158	646	16	36	18	235	33	1198
nd.	15	11	48	93	131	742	20	16	13	256	27	1119
nd.	13	12	42	81	170	805	18	34	18	234	32	1111
nd.	14	8	51	82	156	646	19	59	16	233	32	1084
nd.	15	nd.	36	85	146	632	19	15	16	239	33	974
nd.	13	8	55	82	160	682	20	23	13	228	31	1013
nd.	11	6	47	78	186	626	21	23	15	249	34	972
						KARAKAYA						
Ni	Co	Cu	Pb	Zn	Rb	Sr	Ga	Th	Nb	Zr	Y	Ba
nd.	10	8	54	74	196	531	19	16	14	219	33	932
nd.	11	7	38	76	183	608	20	18	16	229	33	835
nd.	11	8	52	77	194	634	20	17	17	236	35	1014
nd.	10	7	47	77	189	578	20	15	14	235	31	1011
nd.	12	6	38	78	180	628	21	58	17	248	33	967
nd.	10	10	38	76	184	597	21	11	15	239	33	1051
nd.	11	8	38	75	180	644	20	18	21	246	34	940

Explanation: Major and trace elements are given in weight % and ppm, respectively. tFe_2O_3 represent total iron oxide as ferric iron. LOI represents loss on ignition.

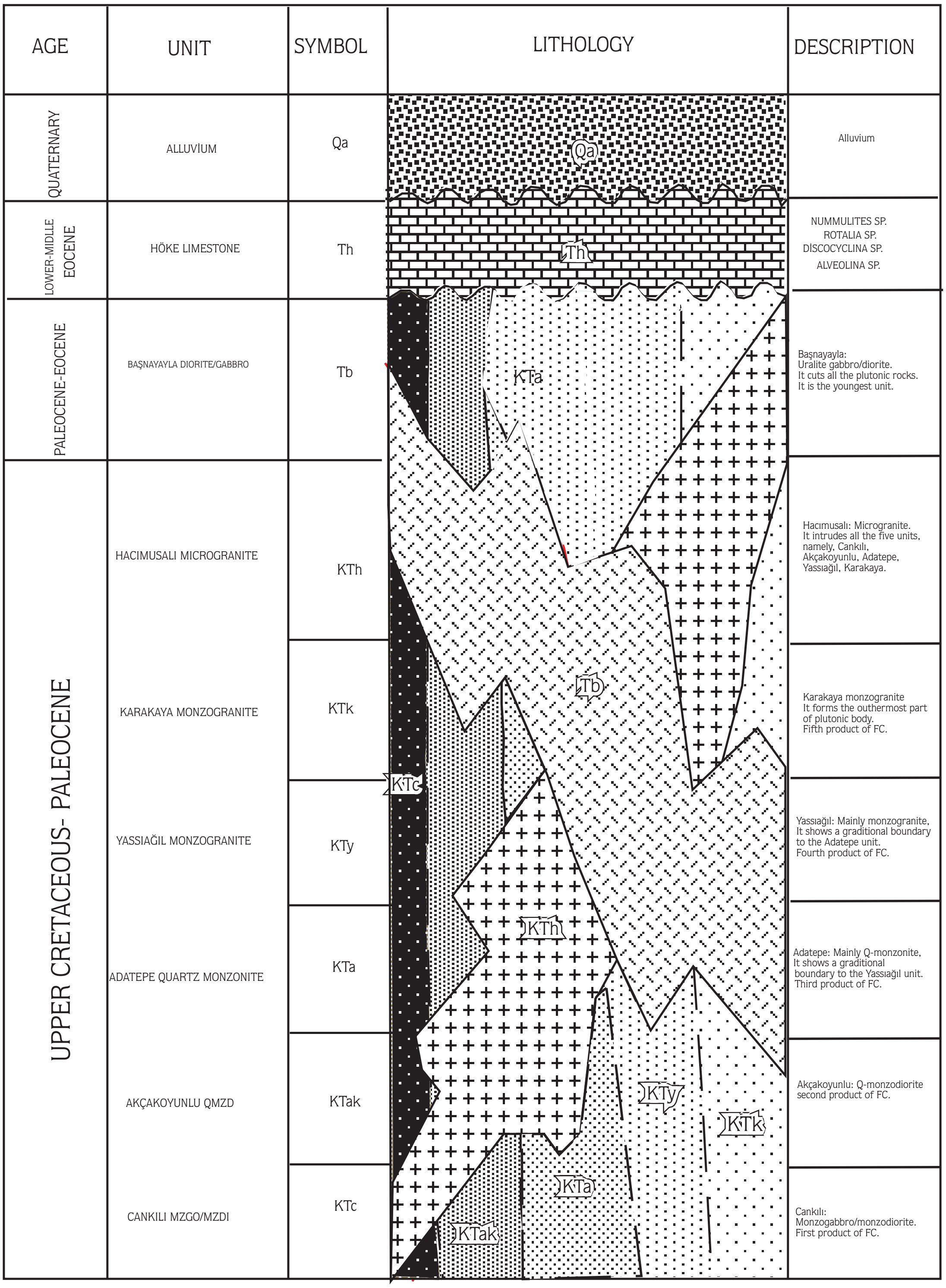


Figure 3. Generalized stratigraphical columnar section of the SW part of the Yozgat batholith, Şefaatli - Yerköy region, SW Yozgat (not to scale).

et al., 1991; Erler and Bayhan, 1995; Erler and Göncüoğlu, 1996). The monzonitic association, the oldest association in the mapped area, is proposed to have an age of Upper Cretaceous-Paleocene (?). The Hacımusalı microgranite cuts the monzonitic association, and is cut by some mafic veins belonging presumably to the Başnayayla diorite/gabbro. Thus, the Başnayayla unit is younger than Hacımusalı microgranite (Figures 2, 3). This assumption is also consistent with the data of Ekici (1997) from the north of the mapped area.

Main structural elements are faults in the mapped area (Figure 2). The Karandere fault, taking place in the SW part of the studied area and affecting essentially the monzonitic association, is the most important fault, however, its character has not been determined. Some NW-SE and N trending S (Figure 2) faults are also observed in the eastern part of the mapped area.

Petrography and Bulk Chemistry

The naming of subunits of the monzonitic association is based on chemical nomenclature diagram of Debon and Le Fort (1983) (Figure 4). All these subunits, except the Karakaya monzogranite, typically contain K-feldspar megacrysts up to 5-6 cm in the field. The Karakaya monzogranite displays medium-grained granular texture. The major felsic and mafic components of the Cankılı unit consist of plagioclase + orthoclase ± quartz and augite + hastingsitic amphibole + biotite, respectively. The proportion of plagioclases within total feldspar may vary between 75 and 85 %. The amount of quartz is less than 5 %. There are some well-preserved augite minerals in the cores of the amphibole minerals that reflect equilibrium crystallization (Wilson, 1989). The mineralogical compositions of the Akçakoyunlu quartz monzodiorite and Adatepe quartz monzonite resemble each other and are represented by plagioclase + orthoclase + quartz + amphibole (hornblende + hastingsite) + augite + biotite assemblage. On the other hand, the quartz content of the Adatepe unit is higher than that of Akçakoyunlu, and its plagioclase proportion is always more than 60 % in total feldspar phase. The transformation of augite minerals into amphibole and even biotite is a characteristic microscopical feature in the rocks of Akçakoyunlu quartz monzodiorite. Yassıağıl and Karakaya monzogranites are also similar by means of their mineralogical composition, but the Karakaya unit differs from the Yassıağıl by it's medium-grained granular texture and containing more biotite than amphibole. The transformation of augites into amphibole in the Yassıağıl monzogranite, and the graphic intergrowth texture between quartz and K-feldspar minerals in the Karakaya monzogranite is commonly observed under the microscope.

Main bulk chemical characteristics of the monzonitic association determine calc-alkaline (Figure 5), cafemic (Figure 6), I-type composition with normative diopside (Figure 7).

Magma Mingling/Mixing

The observations related to the hybrid magma origin of the monzonitic association in the composite Yozgat batholith are based on the field, micro textural and mineralogical-chemical data.

First of all, the mafic microgranular enclaves and large K-feldspar megacrysts have been considered to be field evidences of the mingling and mixing type of interaction between the coexisting felsic and mafic magmas (Didier and Barbarin, 1991; Barbarin and Didier, 1992). As commonly known, the mafic microgranular enclaves enveloped within the felsic host granitoids show mafic magma blobs during the mingling (Didier and Barbarin, 1991; Fernandez and Barbarin, 1991; Barbarin and Didier, 1992). Similarly, the K-feldspar megacrysts found in the felsic granitoids are also evaluated to represent the mingling/mixing type of interaction between the felsic and mafic magmas (Vernon, 1986; Pitcher, 1993). These field and textural data have been evaluated as the indicators of the magma mingling/mixing process at the beginning of the fieldworks in the SW part of the composite Yozgat batholith. This evaluation has been tested by means of petrographical and geochemical studies in the laboratory.

Fractional Crystallization (FC)

There is a compositional zonation in the monzonitic association of the composite Yozgat batholith that the Cankılı monzogabbro/monzodiorite is exposed in the central part. From Cankılı unit towards the marginal parts of the batholith, one can observe the zonation Akçakoyunlu quartz monzodiorite, Adatepe quartz monzonite, Yassıağıl monzogranite and Karakaya monzogranite (Figure 2). The boundaries between these subunits are always gradational. The graditional contact between the Adatepe quartz monzonite and Yassıağıl monzogranite can be observed 1 km to the east of Kaderverdi district (Figure 2). In addition to the gradational boundary, the decreasing in the contents of mafic minerals as cpx → amph → bio from core to marginal parts of the batholith emphasizes the FC

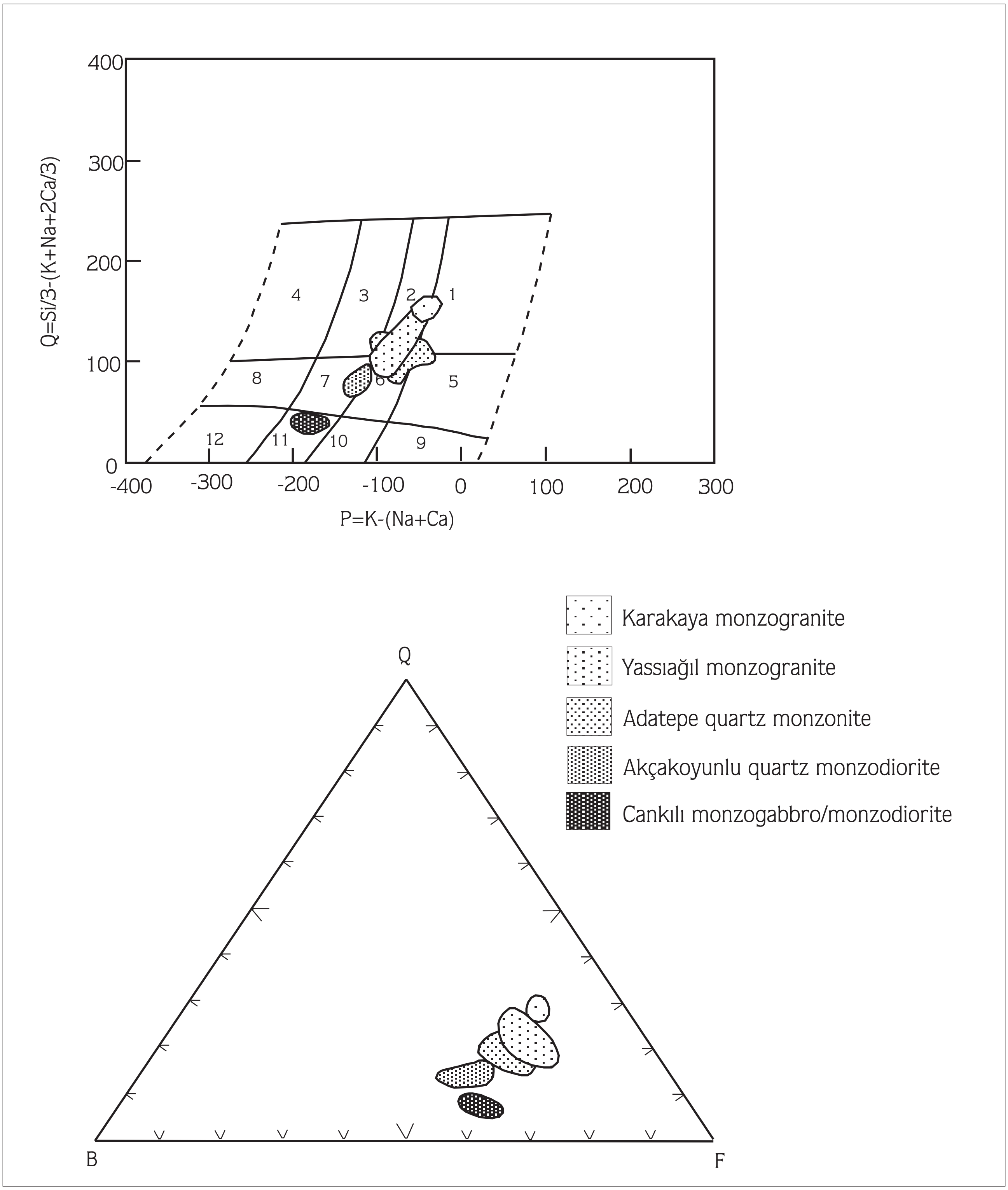


Figure 4. Plotting of rock samples from the subunits constituting the monzonitic association in the SW part of Yozgat batholith in the chemical nomenclature diagram (Debon & Le Fort, 1983).

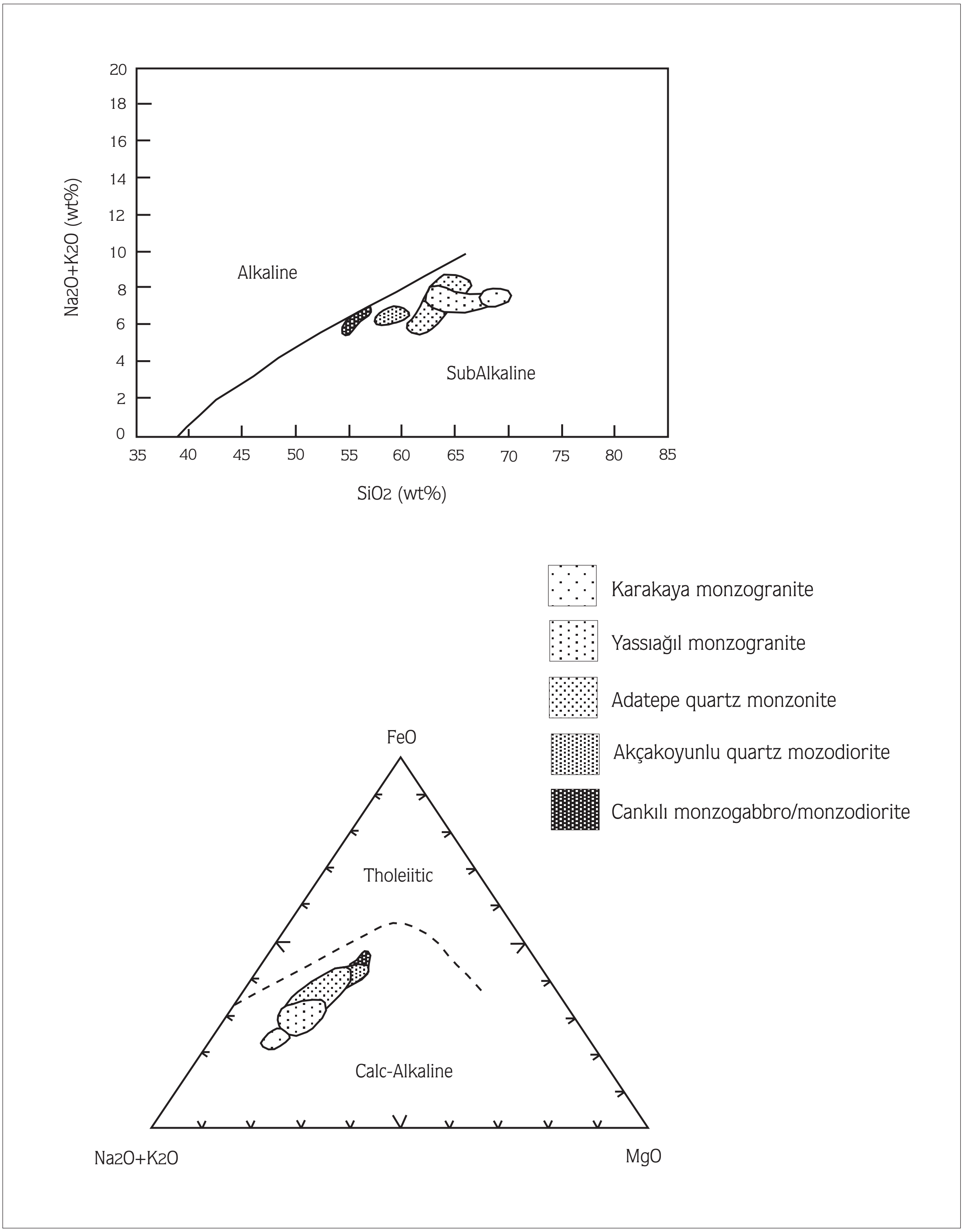


Figure 5. Plotting of rock samples from the subunits constituting the monzonitic association in the SW part of Yozgat batholith in the total alkalis-silica diagram and AFM triangular diagram (Irvine and Baragar, 1971).

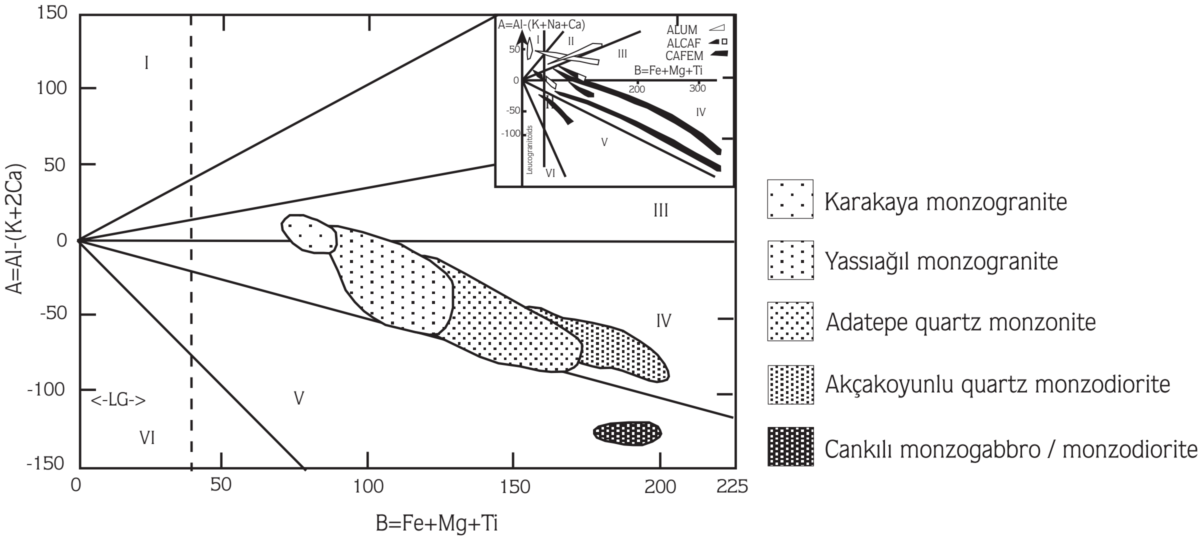


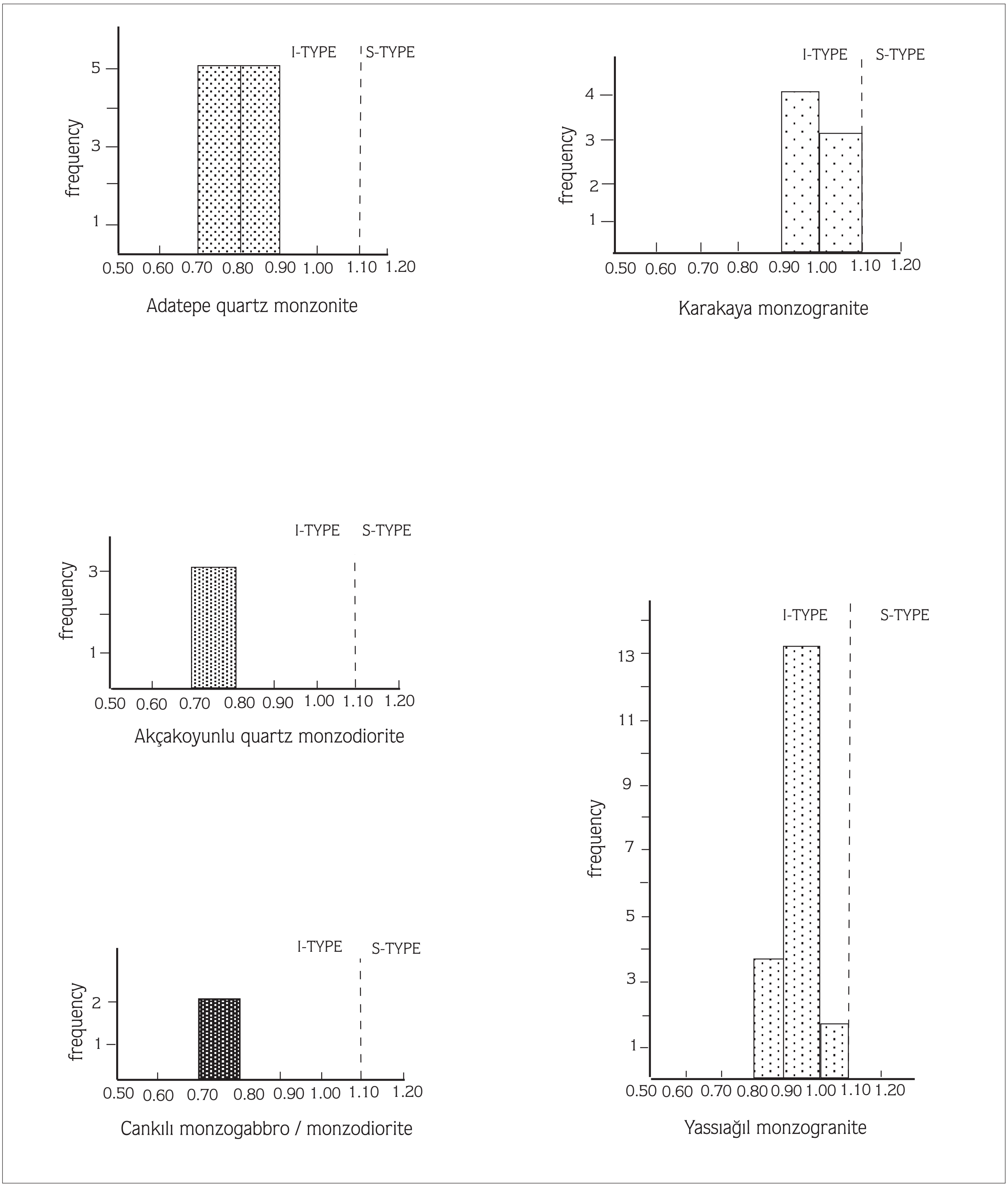
Figure 6. Plotting of rock samples from the subunits constituting the monzonitic association in the SW part of Yozgat batholith in the characteristic minerals diagram (Debon & Le Fort, 1983).

process during the solidification of the magma source. This FC process, inferred from the field and mineralogical data, has also been tested by the Harker variograms. The TiO_2, Al_2O_3, tFe_2O_3, MgO, CaO and P_2O_5 content decrease versus increasing silica content (Figure 8). Similarly, K_2O content also supplies the FC that it increases with silica content (Figure 9). However, the K_2O content of the Adatepe quartz monzonite, differs from those of other units, and varies between 3% - 5.5%. Such a heterogenous K variation is thought to be derived from either irregular occurrences of K-feldspar megacrysts, or analytical errors during sampling. The FC process is also supported by the behaviour of Rb and Ba elements with respect to K content Ba and Rb behave as incompatible elements during the crystallization of magmatic liquid, so they are enriched in late stage liquids (Jakes and White, 1970, 1972; McCarthy and Hasty, 1976; Wilson, 1989). Thus, K/Rb versus Rb and K/Rb versus K/Ba variograms (Figure 9) represent the FC trend appeared from Cankılı monzogabbro/monzodiorite to Karakaya monzogranite as well as other diagrams.

The trace element variograms show that there is an increasing in the contents of Co and Zn with increasing silica content (Figure 10). On the other hand, the fluctuation in the K content with increasing silica is also identified in the variation of Rb content (Figure 10) which is consistent with the considerations mentioned above that Rb element is always associated with K during the solidification of magma (Mason and Moore, 1982; Wilson, 1989).

Conclusion and Discussion

The Yozgat batholith, constituting the biggest pluton within the Central Anatolian Granitoids, is a composite batholith. It consists of various intrusive associations derived from different magma sources which define different tectonic settings (Boztuğ, 1994-1995; Erler et al., 1991; Erler and Bayhan, 1995; Erler and Göncüoğlu, 1996; Tatar, 1997; Tatar and Boztuğ, 1997). The field and mineralogical-geochemical studies carried out in the SW part of this composite batholith suggests that the



Adatepe quartz monzonite

Karakaya monzogranite

Akçakoyunlu quartz monzodiorite

Cankılı monzogabbro / monzodiorite

Yassıağıl monzogranite

Figure 7. Frequency distrubition of ASI (Aluminium Saturation Index; White and Chappel, 1988) values of rock samples from the subunits constituting the monzonitic association in the SW part of Yozgat batholith. The dividing line between the I-type and S-type rocks has been taken after Chappel and White (1974).

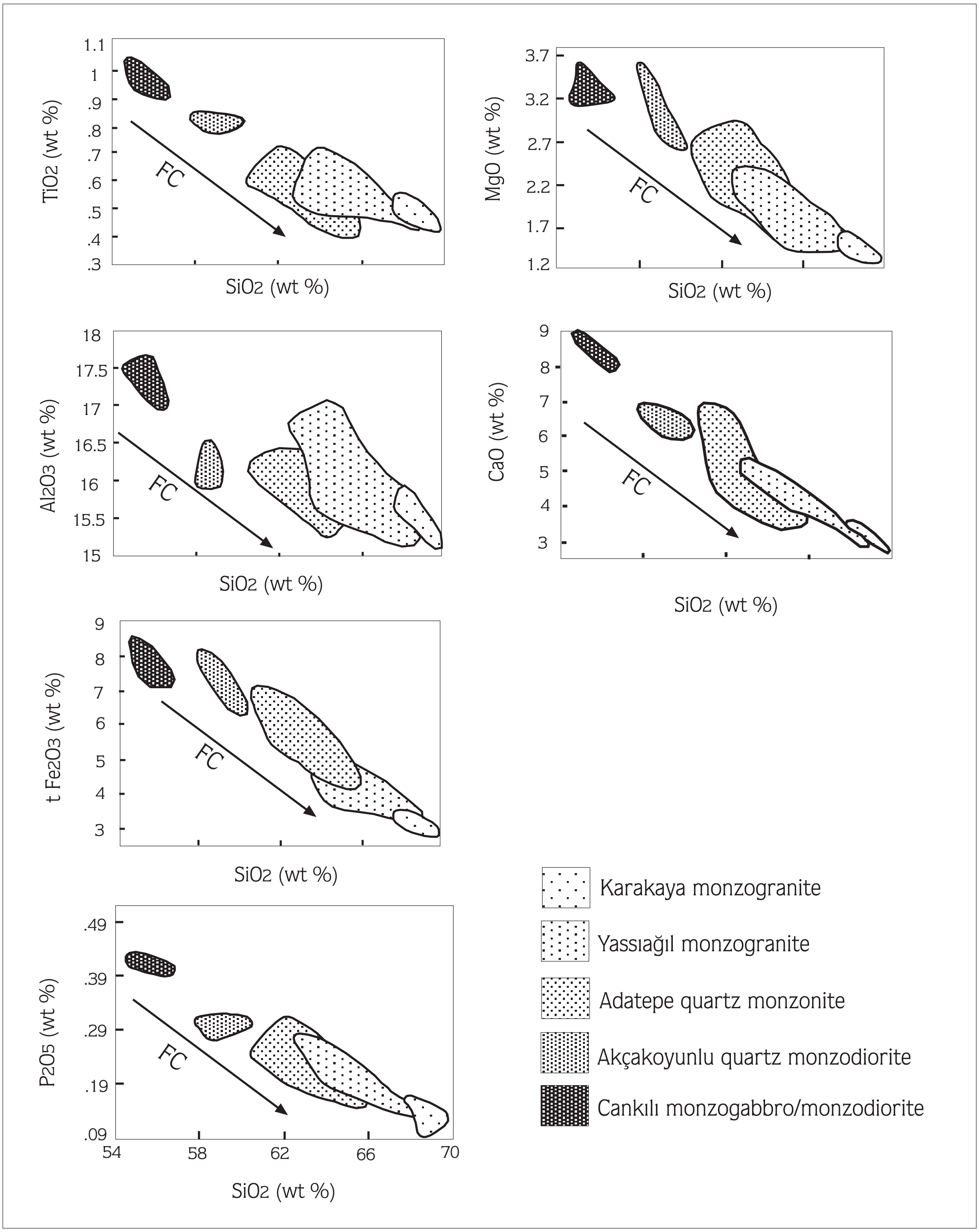


Figure 8. Harker variation diagrams of the contents of TiO_2, Al_2O_3, tFe_2O_3, P_2O_5, MgO, CaO versus silica content of rock samples from the subunits constituting the monzonitic association in the SW part of Yozgat batholith. FC arrow represents the course of fractional crystallization.

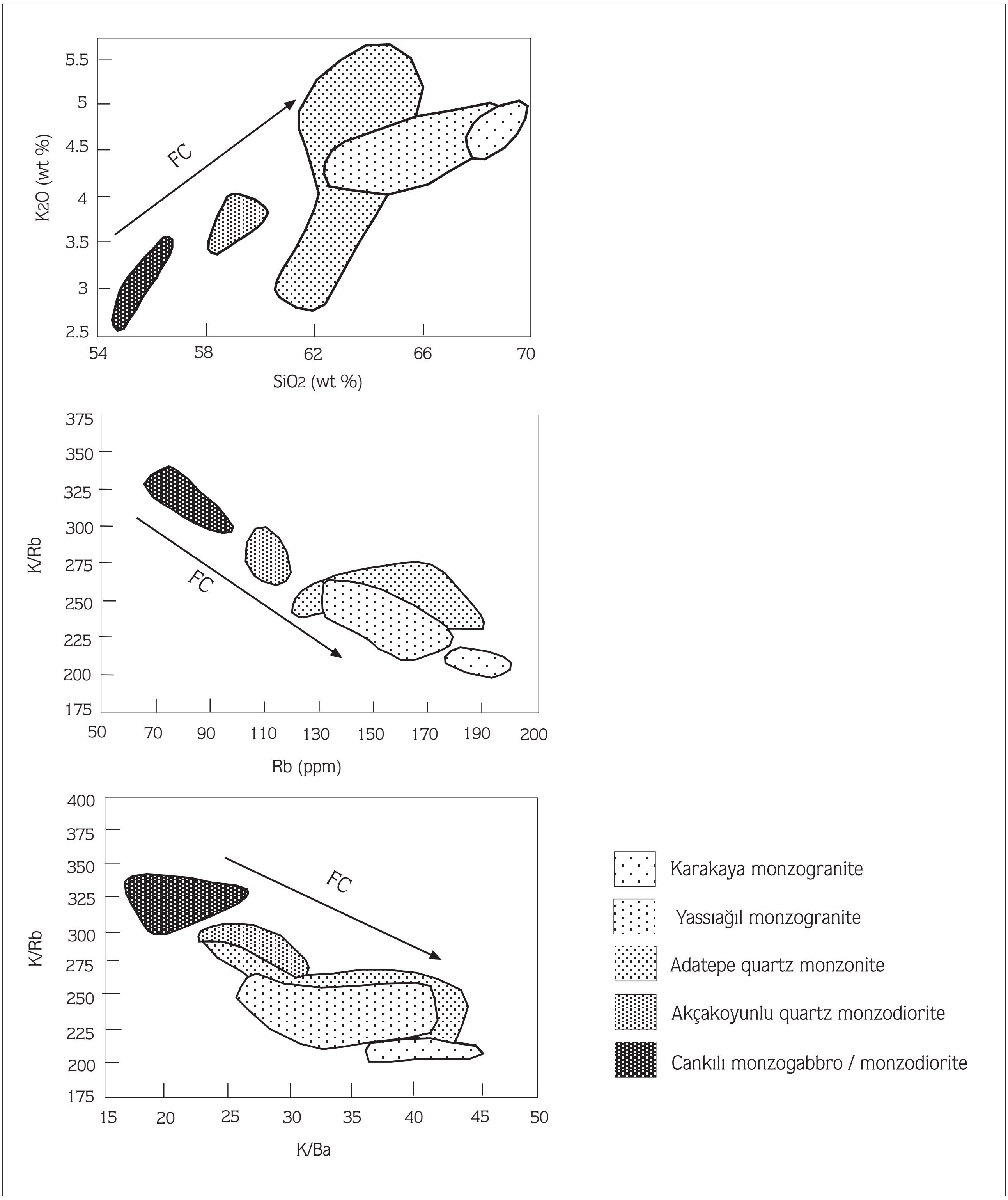


Figure 9. K_2O vs SiO_2 , K/Rb vs Rb and K/Rb vs K/Ba variation diagrams of the rock samples from the subunits constituting the monzonitic association in the SW part of Yozgat batholith. FC arrow represents the course of fractional crystallization.

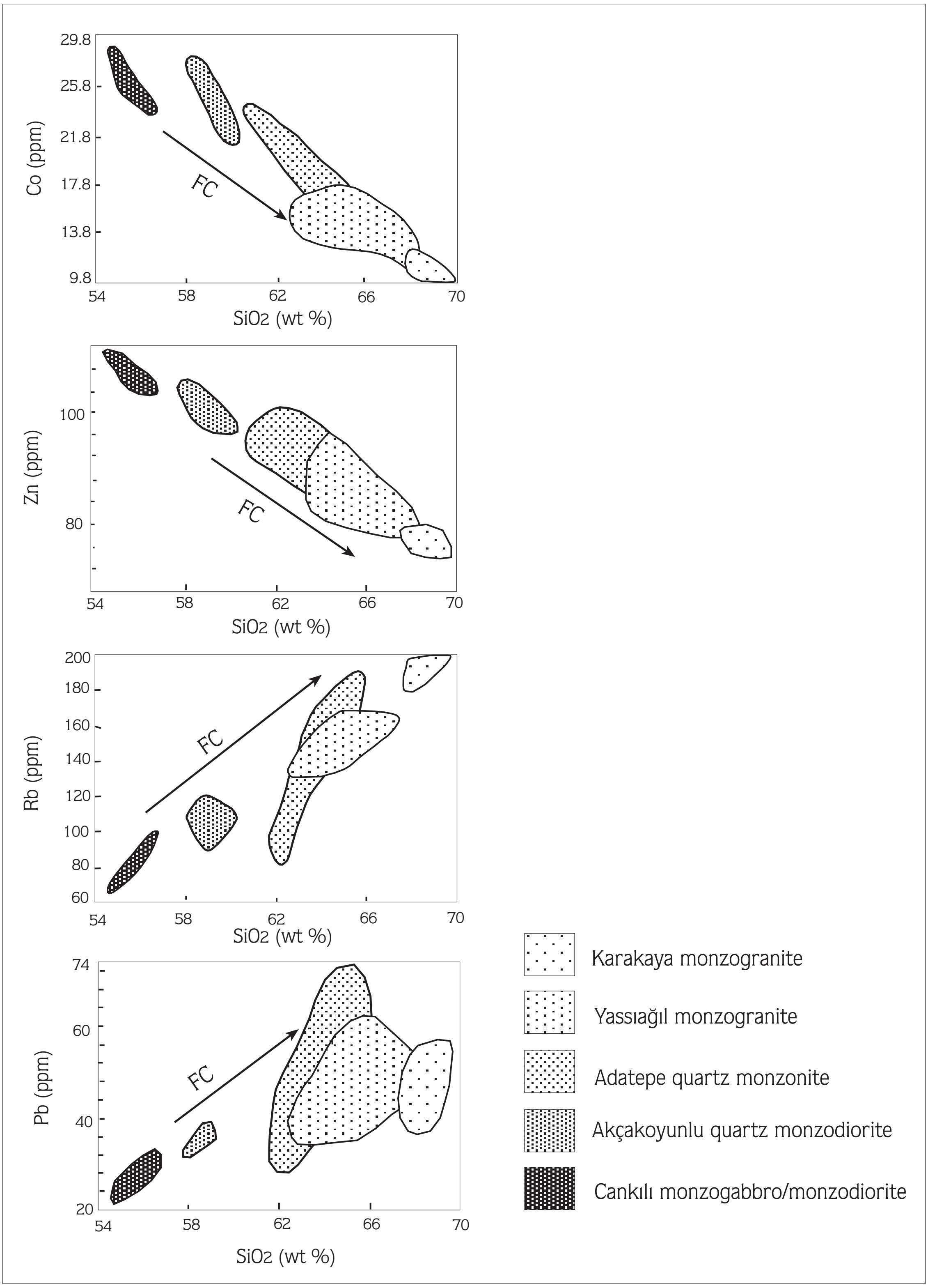


Figure 10. Harker variation diagrams of the contents of Co, Zn, Pb and Rb versus silica content of rock samples from the subunits constituting the monzonitic association in the SW part of Yozgat batholith. FC arrow represents the course of fractional crystallization.

hybrid magma source of the monzonitic association has been derived from the mixing of coexisting felsic and mafic magmas. All the subunits of the monzonitic association display some microscopical textures indicating the homogenous mixing of coexisting mafic and felsic magmas with newtonian behaviour in viscosity (Hibbard, 1991). These textures are of antirapakivi mantling, mafic mineral inclusions within plagioclases, dissolution/melting textures in the plagioclases, spike zones within plagioclases and blade biotites.

During the solidification of this hybrid magma, the FC process has been effective to yield, from inner to outer, Cankılı monzogabbro/monzodiorite → Akçakoyunlu quartz monzodiorite → Adatepe quartz monzonite → Yassıağıl monzogranite → Karakaya monzogranite.

Some absolute age datings, isotope geochemistry, REE and mineral chemistry studies are necessary for a better understanding of the tectono-magmatic evolution of the composite Yozgat batholith.

References

Barbarin, B. and Didier, J., 1992, Genesis and evolution of mafic microgranular enclaves through various types of interaction between coexisting felsic and mafic magmas. Transactions of the Royal Society of Edinburgh: Earth Sciences, 83, 145-153.

Bingöl, E., 1989, 1/2.000.000 ölçekli Türkiye Jeoloji Haritası. MTA Yayını, Ankara.

Boztuğ, D., 1994-1995, Kırşehir bloğundaki Yozgat batoliti doğu kesiminin (Sorgun güneyi) petrografisi, ana element jeokimyası ve petrojenezi. İstanbul Üniversitesi, Yerbilimleri, 9, 1-2, 1-20.

Boztuğ, D., Yılmaz, S. and Kesgin, Y., 1994, İç-doğu Anadolu alkalin provensindeki Kösedağ plütonu (Suşehri-KD Sivas) doğu kesiminin petrografisi ve petrojenezi. Türkiye Jeol. Kur. Bült. 37, 2, 1–14.

Chappel, B.W. and White, A.J.R., 1974, Two contrasting granite types: Pasific Geol., 8, 173-174.

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

Didier, J. and Barbarin, B., 1991, Enclaves and Granite Petrology: Devolopments in Petrology 13, Elsevier, 625 pp. Amsterdam.

Ekici, T., 1997, Yozgat Batoliti Yozgat Güneyi Kesiminin Petrolojisi. C.Ü. Fen Bilimleri Ensititüsü Yüksek Lisans Tezi, (yayınlanmamış) 75 s., 1ek.

Ekici, T. and Boztuğ, D., 1997, Anatolid-Pontid Çarpışma Sisteminin Pasif Kenarında Yer Alan Yozgat Batolitinde Syn-COLG ve Post-COLG Granitoyid Birlikteliği. Çukurova Üniversitesi'nde Jeoloji Mühendisliği Eğitiminin 20. Yılı Sempozyumu, Bildiri özleri, S. 217, Adana.

Ekici, T., Boztuğ, D., Tatar, S. and Otlu, N., 1997, The coexistency of the syn-COLG and Post-COLG Granitoids in the Yozgat Batholith from the Passive Margin of the Anatolide-Pontide Collision. European Union of Geosciences (EUG-9), Abstracts, P. 503, Strasbourg–France.

Erler, A., Akıman, O., Unan, C., Dalkılıç, F., Dalkılıç, B., Geven, A. and Önen, P., 1991, Kaman (Kırşehir) ve Yozgat yörelerinde Kırşehir Masifi magmatik kayaçlarının petrolojisi ve jeokimyası. Doğa - Tr. J. of Engineering and Environmental Sci., 15, 76-100.

Erler, A. and Bayhan, H., 1995, Orta Anadolu Granitoidleri'nin genel değerlendirilmesi ve sorunları. Yerbilimleri 17, 49-67.

Erler, A. and Göncüoğlu, M.C., 1996, Geologic and tectonic setting of the Yozgat batholith, Northern Central Anatolian Crystalline Complex, Turkey. International Geology Review, 38, 8, 714-726.

Fernandez, A.N. and Barbarin, B. 1991, Relative rhology of coeval mafic and felsic magmas: Nature of resulting interaction processes. Shape and mineral fabrics of mafic microgranular enclaves. In: Didier, J. and Barbarin, B.(eds), Enclaves and Granite Petrology: Developments in Petrology, Elsevier, 13, 263-275.

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

Göncüoğlu, M.C. and Türeli, T.K., 1994, Alpine collisional-type granitoids from Western Central Anatolian Crystalline Complex, Turkey. Jour. of Kocaeli Univ., Earth Sci., 1, 39–46.

Hibbard, M. J., 1991, Textural anatomy of twelve magma mixed granitoid systems. In: Didier, J. and Barbarin, B (eds.), Enclaves and Granite Petrology, Development in Petrology, 1Elsevier, 13, 431-444.

Irvine, T. N. and Baragar, W. R. A., 1971, A guide to the chemical classification of common volcanic rocks. Can. Jour. Earth. Sci., 8, 523-548.

İlbeyli, N. and Pearce, J., 1997, Petrogenesis of the collision - related Central Anatolian Granitoids, Turkey. European Union of Geosciences (EUG) 9, P. 502, Strasbourg–France.

Jakes, P. and White, A. R. J., 1970, K/Rb ratios of rocks from Islands arcs. Geochim. et Cosmochim. Acta, 34, 849-856.

Jakes, P. and White, A. R. J., 1972, Major and trace element abundances in volcanic rocksand orogenic areas. Bull. Geol. Soc. Am., 83, 29-40.

Ketin, I., 1955, Yozgat Bölgesinin Jeolojisi ve Orta Anadolu Masifinin Tektonik Durumu. Türkiye Jeol. Kur. Bült. I, 12–27.

Mason, B. and Moore, C. B., 1982, Principles of Geochemistry, John Wiley and Soons, 344 pp. New York.

Mc Charty, T. S. and Hasty, R. A., 1976, Trace element distribution patterns and their relation to crystallization of granitic melts. Geochim. Cosmochim. Acta, 40, 1351-1358.

Pitcher, W.S., 1993, The Nature and origin of Granite. Chapman and Hall, 321 pp.

Tatar, S., 1997, Yozgat Batoliti Şefaatli Kuzey Kesiminin (Güney Yozgat) Petrolojik İncelenmesi. C.Ü. Fen Bilimleri Ensititüsü Yüksek Lisans Tezi, (yayınlanmamış) 94 s.

Tatar, S. and Boztuğ, D., 1997, Yozgat Batoliti GB Kesiminde (Şefaatli-Yerköy arası) FC ve Magma Mingling/Mixing Süreçlerinin Kanıtları. Çukurova Üniversitesi' nde Jeoloji Mühendisliği Eğitiminin 20. Yılı Sempozyumu, Bildiri özleri, S. 215, Adana.

Tatar, S. and Boztuğ, D., Ekici., T. and Otlu, N., 1997, Outward fractional crystallization and magma mingling/mixing processes in the SW part of the Yozgat Batholith, Central Anatolia, Turkey. European Union of Geosciences (EUG-9), P. 460, Strasbourg–France.

Vernon, R. H., 1986, K-feldspar megacrysts in granites Phenocrysts, not porphyroblasts. Earth-Sci.Rev., 23,1-63.

White, A. J. and Chappel, B.W., 1988, Some supracrustal (S-type) granites of the Lachlan Folt Belt. Transactions of the Royal Society Edinburgh: Earth Sciences, 79, 169-181.

Wilson, M., 1989, Igneous Petrogenesis, Unwin Hyman, 466 pp. London.