Tr. J. of Earth Sciences
8 (1999) 1–17

Mafic Microgranular Enclaves in the Kozak Granodiorite, Western Anatolia

Cüneyt AKAL, Cahit HELVACI
Dokuz Eylül Üniversitesi, Mühendislik Fakültesi, Jeoloji Mühendisliği Bölümü, Bornova, İzmir–TURKEY

Received: 10.06.1998

Abstract: Enclaves which are relicts of initial basic magma give important information on the origin and evolution of granitic magmas. The mafic microgranular enclaves from the I–type Kozak pluton are less than 1 m that are located at the margin of pluton and mostly less than 15 cm and are generally in sharp contact with the surrounding granodiorite. In some cases, several enclaves may occur close to each other, but they are not closely clustered to form swarms. Most of the enclaves are ellipsoidal in shape. The largest enclaves are less ellipsoidal with curved boundaries. The mafic microgranular enclaves contain same mineral species as the host granodiorite; however the proportions are different. In the mafic micragranular enclaves plagioclase, K–feldspar and hornblende are more abundant, quartz and biotite are less abundant. In some equigranular enclaves clinopyroxene and orthopyroxene are accessory minerals. The mafic microgranular enclaves are mostly intermediate in composition all contain more than 46% SiO_2. The femic oxides (Fe_2O_3t, MgO and MnO) decrease systematically relative to SiO_2; most of mafic microgranular enclaves compositions cluster near the granodiorite trend line. Many trace elements do not show clear linear correlation with SiO_2; are scattered off the trends defined by related granodiorite. The petrographic and geochemical characteristics of the mafic enclaves and their host granodiorite indicate that the Kozak granodiorite is a product of partial melting and fractional crystallization of basic magma, and enclaves are trapped blobs of basic initial magma. Petrographic properties indicate that during magmatic evolution, the granodiorite and enclaves are effected by magma mingling and mixing processes.

Kazak Granoclioritindeki Mafik Mikrogranular Anklavlar, Batı Anadolu

Özet: İlksel bazik magmaya ait kalıntılar olan anklavlar granitik magmanın kökeni ve evrimi hakkında önemli bilgiler vermektedir. Kozak granodioriti içinde saçınmış olarak gözlenen anklavlar, belirli bir gruplaşma sunmamaktadırlar. I–tip Kozak plütonu içinde yeralan anklavaların maksimum boyutu genelde 1 metreden az olup özellikle plütonun sınır kesimlerinde daha az elipsoidal şekillerle gözlenmektedirler, ortalama 15 cm boyutundaki anklavlar yankaya ile keskin dokanaklı ve elipsoidal yapıları ile belirgindirler. Mafik mikrogranular anklavlar, granodiyorit ile benzer mineralojik bileşime sahiptirler ancak mineralojik oranlarında farklılıklar gözlenmektedir. Mafik anklavlarda plajioklas, ortoklas ve hornblend mineral bileşeni daha fazla olmasına karşın kuvars ve biotit miktarı daha azdır. Genelde eş tane boylu anklavlarda klinopiroksen ve ortopiroksen aksesuar oranda bulunmaktadır. Mafik mikrogranular anklavların % 46 dan biraz fazla SiO_2 oranı ile nötür özelliktedirler. SiO_2 oranına bağlı olarak toplam Fe_2O_3, MgO ve MnO oranlarında sistematik bir azalma sunan anklavlar çoğunlukla granodiyorite ait değerlerin oluşturduğu eğri hattı üstünde gruplaşmalar sunmaktadırlar. İz element değerlerinin SiO_2 değerine göre karşılaştırılan diagramlarda anklavlar lineer bir gidiş sunmamakla beraber granodiorite ait eğri üzerinde gelişi güzel saçınmışlardır. Petrografik ve jeokimyasal özellikler, mafik mikrogranular anklavların ilksel bir bazik magmanın bölümsel ergimesi ve fraksiyonal kristalleşmesiyle meydana gelen asidik magma içinde kapanımlanmış ilksel bazik magmaya ait parçalar olduğunu göstermektedir. Petrografik özellikler magmatik evrim boyunca granodiyorit ve anklavlar magma mixing ve minglin olaylarından etkilenmişlerdir.

Introduction

Mafic enclaves are common in igneous rocks and especially in I–type calc–alkaline igneous rocks (Didier, 1973). Detailed studies on mafic enclaves, provide information on the nature of source rocks, the mechanism of production of granitic melt (White and Chappell, 1977).

In recent years, the mafic enclaves have been studied by several researchers in Anatolia. The investigations are focused on the granitoid rocks which are located in Central Anatolia (e.g. Kadıoğlu and Güleç, 1993, 1996). However, several granitoid outcrops are widely exposed in northwestern part of Anatolia, many of them contain enclaves. Kozak granodiorite is one of them that is contain the mafic enclaves.

The aim of this paper is to present the whole rock chemistry, mineralogy and textural properties of mafic mikrogranular enclaves and to discuss the relation between mafic microgrunalar enclove and granodiorite in terms of their rock chemistries.

Geological setting of Kozak granodiorite

The granitic intrusions or norhwestern Anatolia are classified into three groups based on similarities in age and petrology (Bingöl et al., 1982). These three groups, from north to south, are given as follow:

– Paleozoic to late Cretaceous granites are located north of North Anatolian Fault.

– Pre-Liassic granites are found between the North Anatolian Fault and the Eskişehir-Bursa-Edremit line.

– Miocene granites are found south of the Eskişehir-Bursa-Edremit line

Bingöl et al. (1982) suggested that K_2O abundances are increases from north to south. Thus it is also possible to divide the granites into three groups due to K_2O contents. The Kozak granodiorite, which was emplaced into Paleozoic metamorphic and unmetamorphic rocks is in the third group (Figure 1). The Kozak granodiorite has sharp contacts with the country rocks which comprise the low grade metamorphic groups of the Late Triassic Çavdartepe Formation and Kınık Formation (Akyürek, 1989). Contact metamorphic effects are observed in the Late Triassic country rocks. The contact metamophic zones formed near the granodioritic porphyry dikes, ranging from K–feldsar–cordierite–hornfels facies, hornblende–hornfels facies down to albite–epidote–hornfels facies (İzdar, 1968). The intrusive and country rocks are covered by volcanic rocks known as the Yuntdağı volcanics (Akyürek and Soysal 1983). The Yuntdağı volcanic rocks are comprise andesite, latite–andesite, dacite, rhyodacite and their pyroclastic rocks. According to Borsi et al. (1972), K–Ar ages for the volcanics are 16.7–18.5 my Most of the published data on granodiorite indicate the age younger then late Cretaceous. The first age dates were done by Bürküt (1966), and determined to be 79.8 my from zircon using the radiogenic Pb method. Ataman (1975) found 13–16 and 23 my from biotite and whole–rock Rb–Sr methods. Bingöl et al. (1982) determined 20.3–24.6 and 24.2–37.6 my ages respectively, using the K–Ar method on biotite and orthoclase. The latest radiometric ages obtained from the Kozak granodiorite as the 20 my old, and from volcanic rocks as range between 20 and 15 my by Altunkaynak and Yılmaz (1995).

Petrography

The Kozak granodiorite is a fine to medium–grained hypidiomorphic equigranular granitoid. Microgranodiorites crop out around Çamavlu village. The mineralogical composition and the texture are the same as the medium grained rocks but the further group is more felsic. Aplitic veins having varying orientation and thicknesses are common. In the marginal zones of the intrusion aplitic veins and small pegmatitic dikes have developed irregularly. Rare basic dikes are also observed near the margin of the intrusion. Large pegmatitic veins consisting of K–feldspar, biotite, quartz, epidote, topaz, pyrite usually occur at the contacts of aplites and granodiorite or within the aplitic veins. Nodular pegmatites, which have same mineralogical composition as the pegmatitic veins, are present around Aşağıcumalı village. Their minerals are euhedral and vary in size between 2 and 3 cm. The main minerals of The Kozak granodiorite are quartz, plagioclase, orthoclase, hornblende, titanite, allanite, apatite, zircon and opaque minerals. Quartz crystals are anhedral. Orthoclases are characterized by anhedral crystals and display poikilitic texture with biotite, hornblende and plagioclase inclusions. Biotites occurs as anhedral and euhedral crystals; some anhedral grains of biotite contain small plagioclase inclusions. The poikilitic texture can be recognized in large hornblende crytals, where biotite grains are enclosed by hornblend. Another type of the hornblendes are is fine grained which occur as cumulate crystals in the granodiorite. Some plagioclases display different textural properties. Zoned plagioclases have generally spongy cellular texture. According to Hibbard (1995) spongy cellular texture is result a of dissolution or direct melting attendant to reheating of plagioclase of the more felsic composition. Some of the large, non spongy cellular plagioclases trap lath–shaped small primary plagioclases, orientated parallel to the zoning, small plagioclase crystals were formed during the early stage of crystallization on the granitic magma, in the late stage crystallization, the small crystals are mantled by late–stage plagioclase crystals.

Geochemistry

Results of the chemical analysis of the Kozak granodiorite are given in Table 1. It may be seen from the Table 1 that the chemical composition of the granodiorite is rather homogeneous, showing no chemical zonation. SiO_2 and K_2O are generally higher in the aplitic rock, while MgO, Ca_2O and Al_2O_3 are lower. Increase and decrease of all oxides as a function of SiO_2 show a linear trend from granodiorite to aplite.

According to Debon and Le Fort (1982) diagram (Figure 2) the granitoid rocks fall into granodiorite (3), adamellite (2), quartzmonzodiorite (7) fields. The majority plots within the granodiorite field.

In the A–P diagram of Debon and Le Fort (1982) (Figure 3) most of the samples are cluster in the fourth section of metaluminous field. According to Debon and Le Fort (1982) this cafemic association inticates a mantle–derived source.

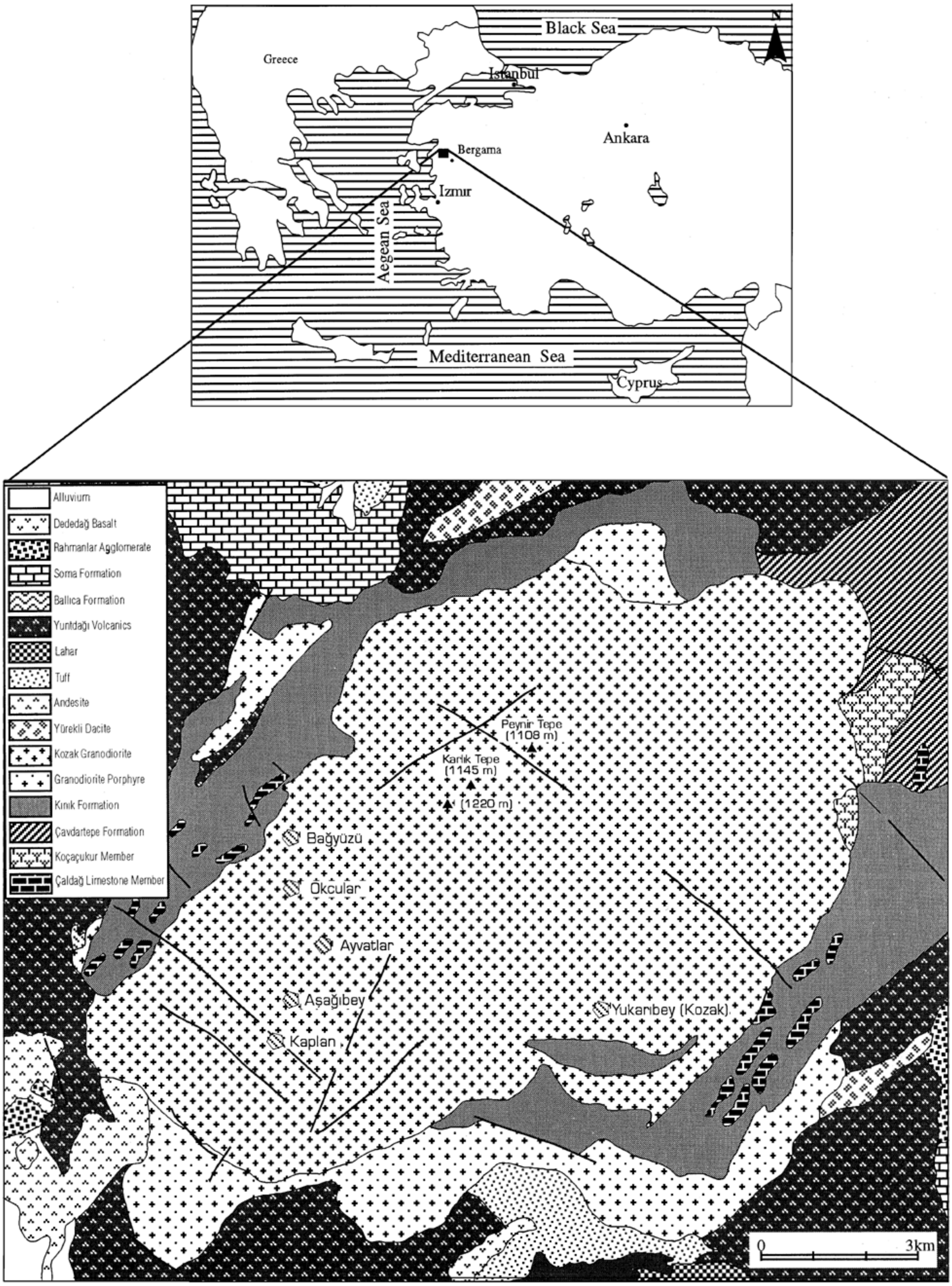

Figure 1. Location and geological map of the Kozak pluton after Akyürek, 1989.

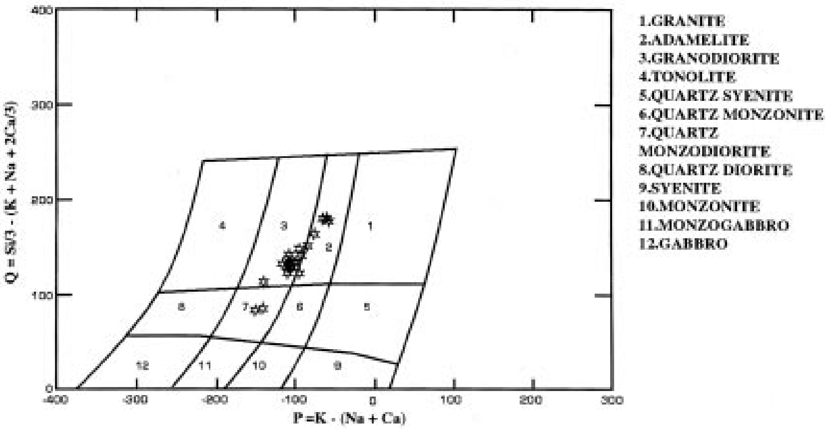

Figure 2. Nomenclature diagram after Debon and Le Fort (1982) for the Kozak pluton.

In the Q–B–F triangular diagram of Debon and Le Fort (1982), (Figure 4) the Kozak samples display the calc–alkaline trend.

The calc–alkaline Kozak granodiorite samples fall in the I–type granite field in the Zr/SiO_2, Y/SiO_2, Nb/SiO_2, diagrams of Collins et al. (1982) (Figure 5). When plotted on log–log (Y/Nb and Rb/Y+Nb) for discrimination diagram of Pearce et al. (1984), all samples plot in the field of subduction–related volcanic arc granites (Figure 6).

Field occurrence and petrography of mafic microgranular enclaves

Mafic microgranular enclaves in the granodiorite are not restricted the margin or to any specific part of the pluton. Although in some areas, several mafic microgranular enclaves are closely spaced, they do not form "swarms". Most of the mafic microgranular enclaves are elliptical, though they range widely in size; the vast majority are small, with maximum dimensions of less than 100 cm. The smallest are 2–5 cm across (Figure 7). Along the margin of pluton, occur generally, the largest enclaves, their shapes less ellipsoidal and have curved boundaries.

Most of the mafic microgranular enclaves have sharp contacts with the immediate surrounding granodiorite host. The enclaves are darker and finer–grained. The sizes of crystals vary the range have 0.2 to 4.8 mm, compared to 0.9–8 mm of the granodiorite (Figure 8). Some mafic microgranular enclaves are equigranular whereas others are porphyritic; plagioclases are phenocrysts and the matrix grains consist of small quartz plagioclase, hornblende and rarely biotite in most

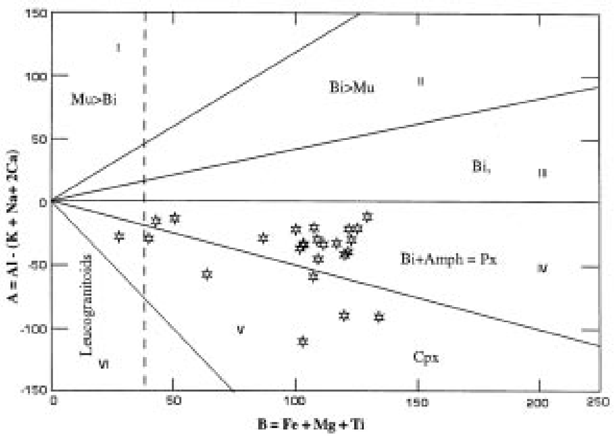

Figure 3. Place of the Kozak granodiorite on the A–P multicationic plot of Debon and Le Fort (1982) Sectors I, II, III and IV, V, IV represent the peraluminous and meta–aluminous domains, respectively.

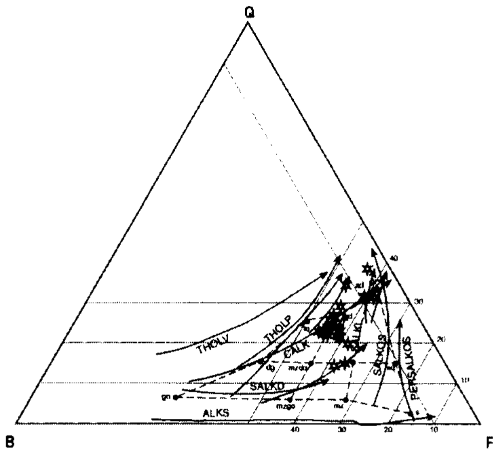

Figure 4. Distrubution of the Kozak granodiorite in the Q–B–F diagram of Debon and Le Fort (1982).

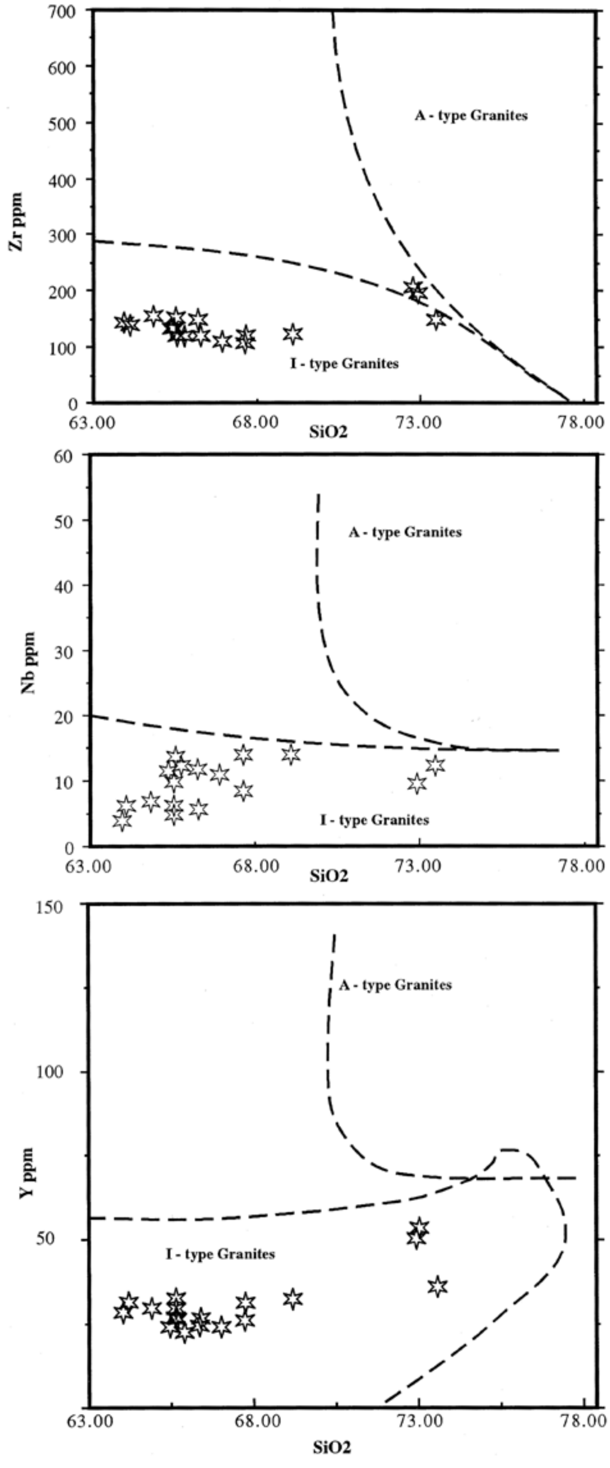

Figure 5. Plot of the Kozak granodiorite on the I/A–type diagram of Collins et al. (1982).

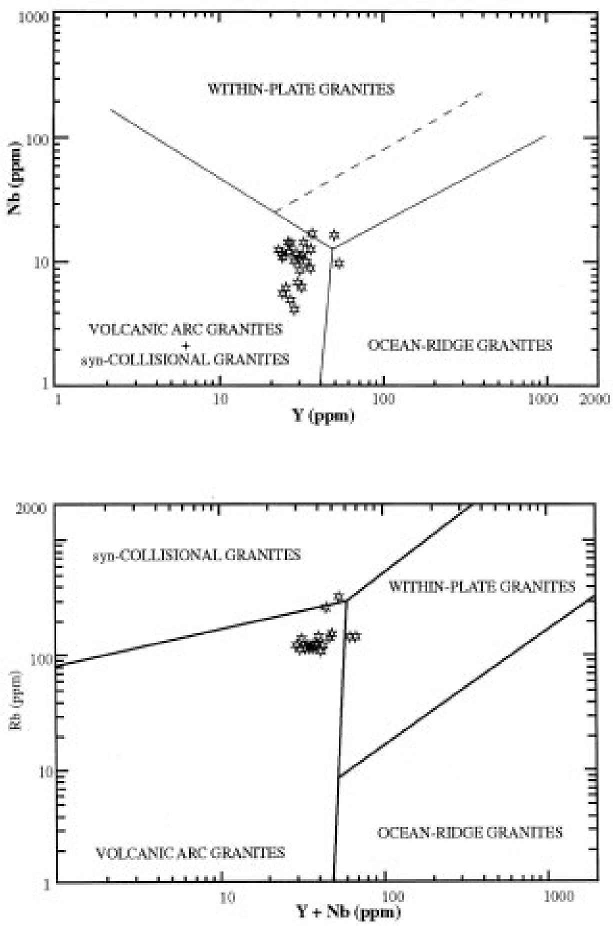

Figure 6. Y/Nb and Rb/Y+Nb tectonic discrimination diagrams after Pearce et al. (1984) classify the Kozak granodiorite as a subduction–related volcanic arc granite.

enclaves. These enclaves are similar to the microgranular enclaves of Didier (1973). Mafic microgranular enclaves are identical in mineralogy to the host granodiorite; only the proportions of minerals are different. Plagioclase and hornblende are invariably dominant minerals in the enclaves.

K–feldspar crytals are much lower in the mafic micrognular enclaves. Commonly, K–feldspars are present as large irregular, poikilitic patches. They enclose fine–grained plagioclase, hornblende, biotite and accessory minerals, especially acicular apatite (Figure 9a). Rarely, hornblende–biotite rims can observed on K. feldspor (Figure 9b).

Two types of plagioclase occur in the mafic microgranular enclaves: as phenocrysts and as matrix plagioclase. The size of plagioclase crystals ranges from 1 mm to 5 mm. Small plagioclase crystals, herein termed matrix plagioclase, are generally present as tabular crystals. Some crystals show normal zoning; oscillatory zoning is scarce. Large subhedral plagioclase crystals have

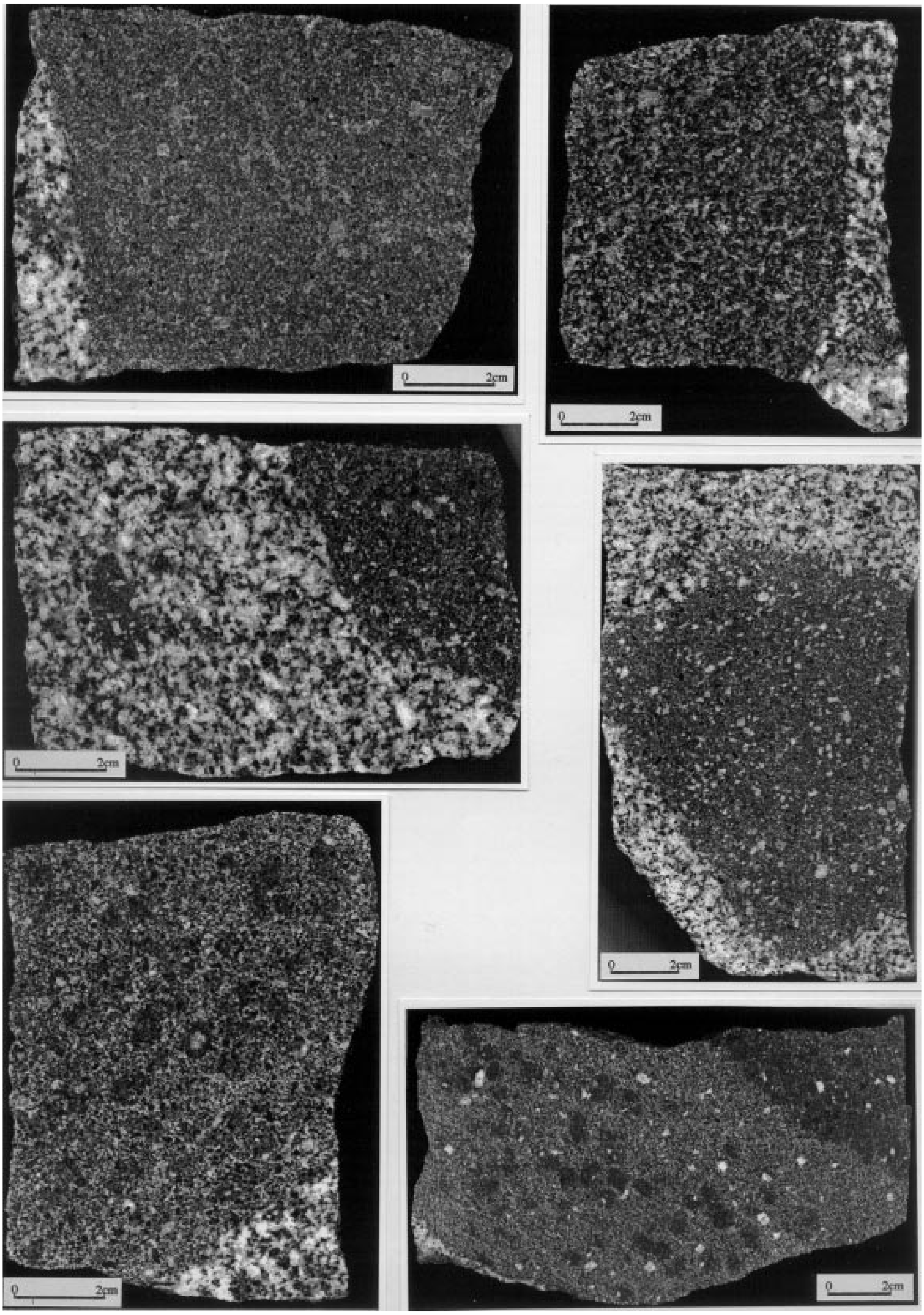

Figure 7. The various type of mafic microgranular enclaves of the calc–alkaline Kozak Granodiorit.

Figure 8. Photomicrograph of mafic mikrogranular enclaves (0.2–4.8) mm and its host rock (0.9–8 mm).

oscillatory zoning and alteration rims (Figure 9c) or hornblende–biotite zones (Figure 9d). Some large plagioclase crystals contain relict cores. These cores occur as isolated patches (Figure 9e) or skeletal relics of initial plagioclase (Figure 9f).

Two types of quartz can be distinguished; anhedral patches and large crystals. The anhedral quartz patches (2–3 mm across) show poikilitic texture containing fine–grained plagioclase, hornblende, biotite and acicular apatite (Figure 9g). The mineral inclusions in the anhedral quartz patches indicate that they were formed at a late stage during the cristallization. The second type large quartz crystals which have fine–grained hornblende–biotite rims are irregular in shape. These large quartz ocelli in the enclaves can be interpreted xenorysts of granitic origin (Figure 9h).

Three kinds of hornblende crystals are distinguished according to their size and shape. Fine–grained, anhedral and cumulate hornblende crystals make up the first group (Figure 9i). The second group comprises single, small stubby prismatic hornblende crystals (Figure 9b). These two types are herein termed matrix hornblende. Third group, large hornblende crytals are commonly present. In some cases, they enclose fine–grained biotite, plagioclase, titanite, anhedral zircon and opaque minerals, suggesting that these large hornblende crystals grew later than the enclosed minerals. The clinopyroxene and orthopyroxene crystals that are relic minerals of initial basic magma (maximum 1.2 mm) are accessories amount. The crystals have been partly or completely altered to hornblende (Figure 9j).

Biotite crystals in the mafic microgranular enclaves are common. Biotite reaches up to 2 mm but is mostly less than 1 mm. It occurs as both subhedral flakes and as irregular crystals with ragged ends. Some mafic microgranular enclaves contain blade–shaped biotite which are usually located near the contact of plagioclases, their lengths greatly exceeding the widths. Some relatively large biotite flakes contain plagioclase, hornblende and zircon grains as inclusions. The large and partly greenish biotites are replaced by chlorite along grain boundaries and cleavages.

Apatite occurs mainly as acicular crystals (Figure 9k,l). Some mafic microgranular enclaves contain less abundant stubby crystals. The length ranges from 0.1 to 1 mm but most are less than 0.4 mm. These acicular apatites occur as continuous crystals or are broken into several segments along their long axes. Acicular crystals occur in a radial or a parallel pattern are randomly scattered. Apatites are present in quartz, plagioclase and K–feldspar, but they are more concentrated in K–feldspar and quartz than in plagioclase. Wyllie et al. (1962) suggested that acicular apatites are characteristic of rapidly cooling magmas.

Allanite is present in some mafic microgranular enclaves, as fine–grained subhedral crystals. Titanite in the mafic microgranular enclaves occurs as both perfect wedge–shaped crystals and as irregular crystals (<0.5 mm) interstitial to matrix hornblende, plagioclase and biotite. The perfect crystals appear to have formed at a early stage whereas the irregular crystals formed at a late stage. Zircons are mainly present as fine, rounded grains. Some prismatic and stubby zircon crystals are present in K–feldspar.

In summary, the crystal habit, twinning and oscillatory zoning shown by the plagioclase crystals are suggestive of an igneous texture. The irregular poikilitic patches of quartz and K–feldspar seem to have crystallized within the enclaves at a very late stage. The quartz ocellars in

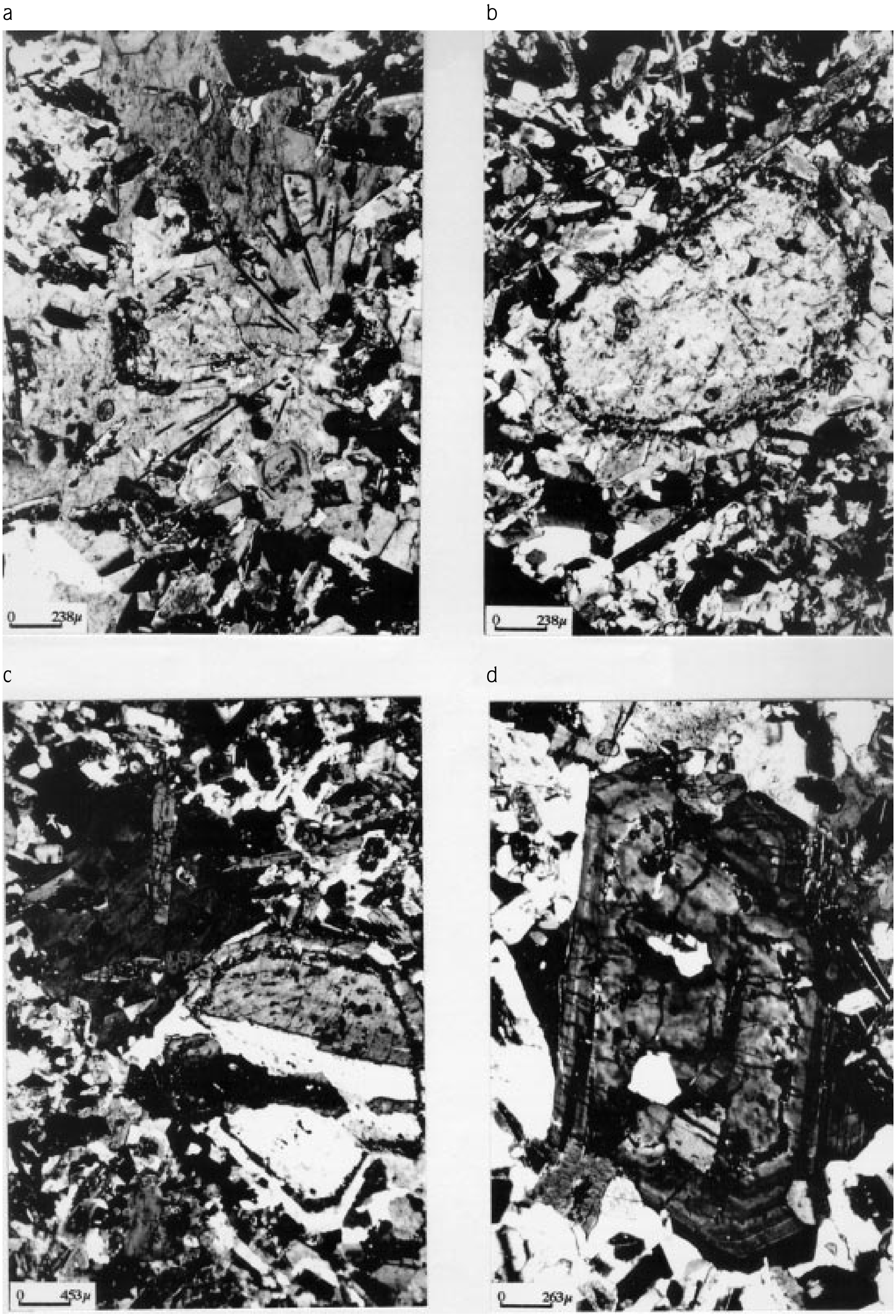

Figure 9. a. Poikilitic K–feldspar with fine–grained plagioclase, hornblende, biotite and acicular apatite b. hornblende–biotite rims on K–feldispar, c. alteration rims, on large plagioclase, d. hornblende–biotite zone in plagioclase phenocryst.

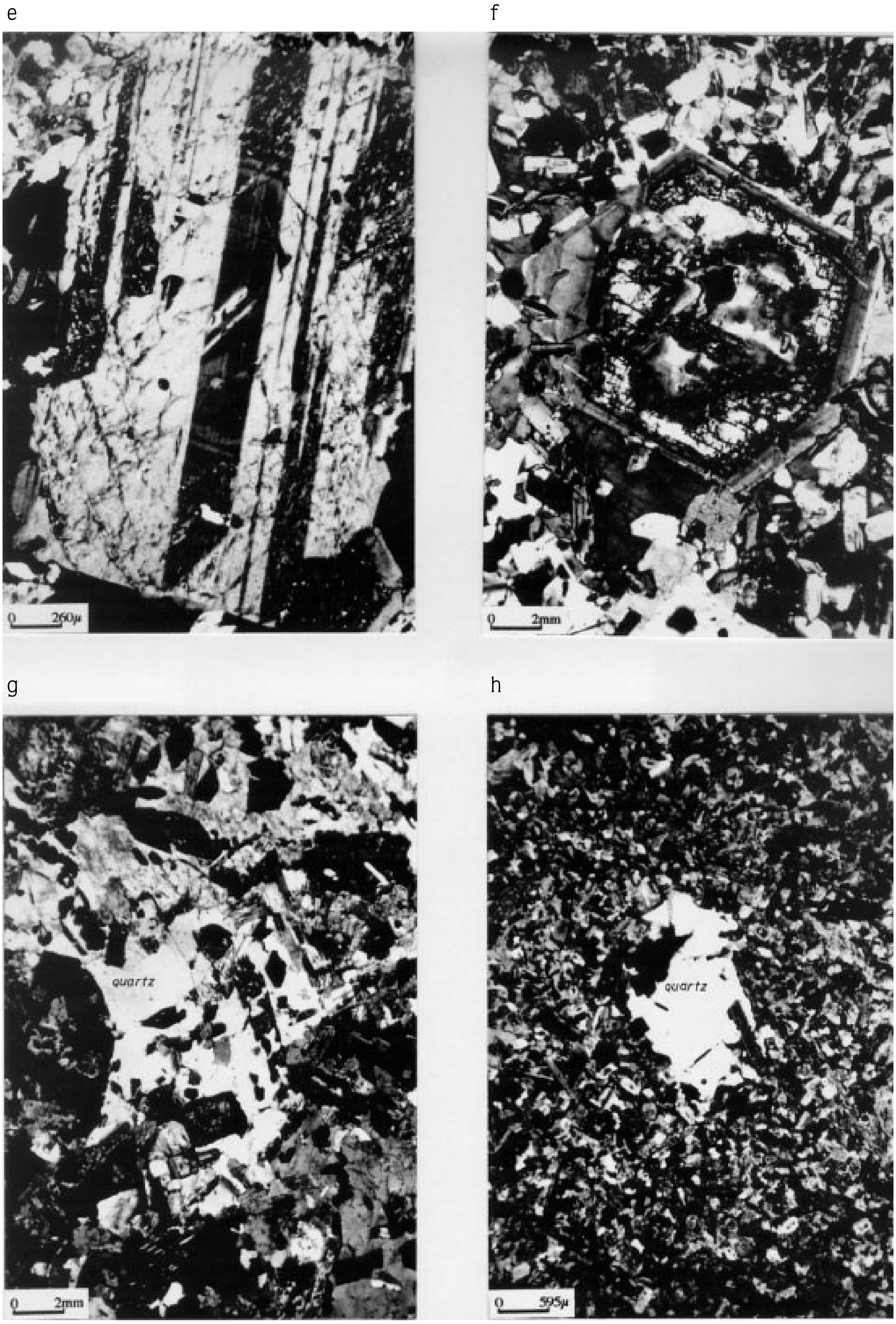

Figure 9. e. Isolated fine–grained plagioclase crystals in large plagioclase, f. skeletal relict plagioclase crystal in plagioclase, g. irregular quartz patch showing poikilitic texture, h. primary quartz crystal, resulting from mechanical transfer from acidic magma.

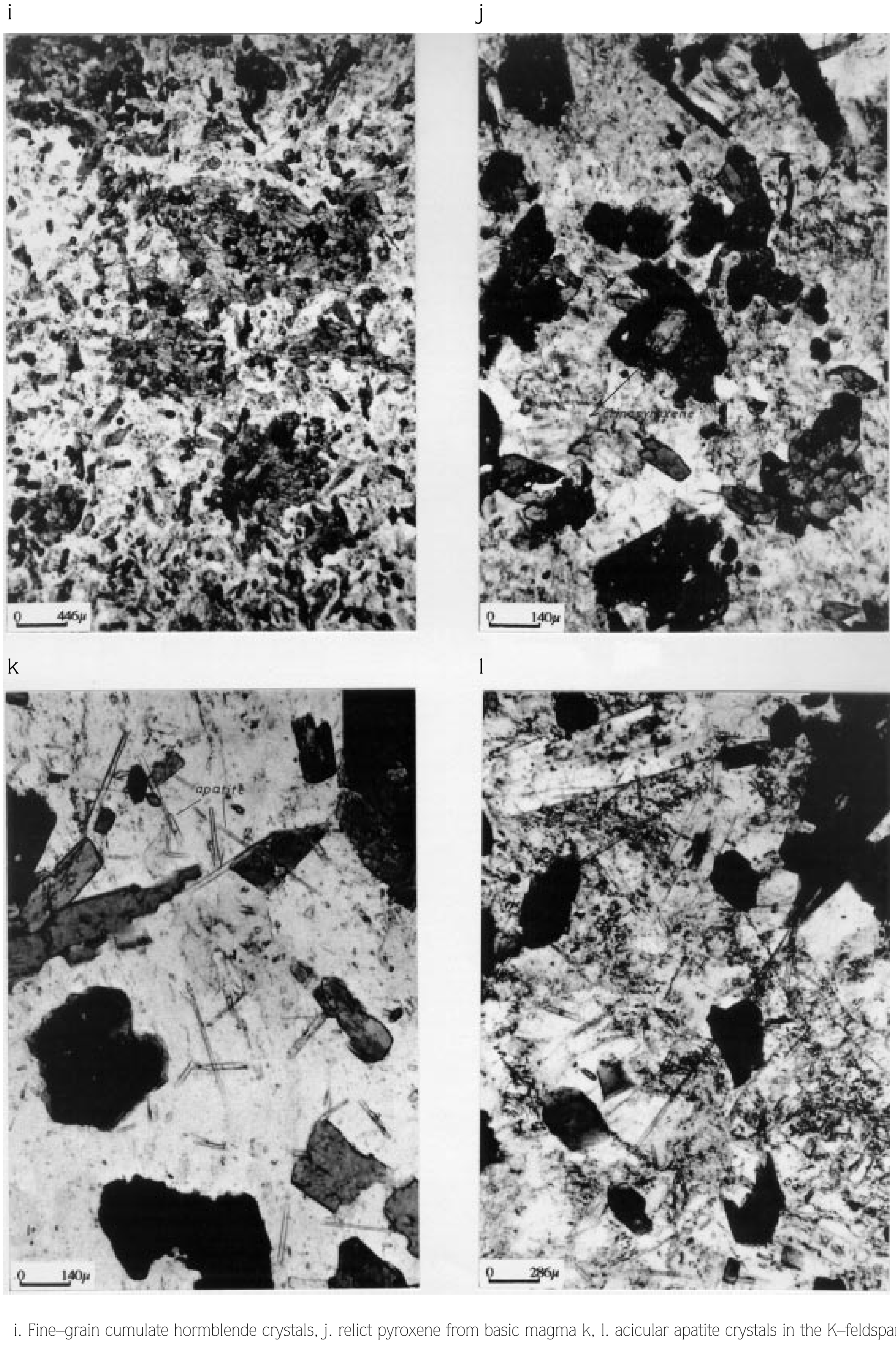

Figure 9. i. Fine–grain cumulate hormblende crystals, j. relict pyroxene from basic magma k, l. acicular apatite crystals in the K–feldspar.

Table 1. Chemical analysis of mafic microgranular enclaves and their host granodiorites.

Analysis of the most granodiorite	3	6–A	7	8	9	11	12–A	13	14–A	15–A
SiO_2	65.54	66.25	67.67	65.54	65.54	64.82	69.10	67.67	65.54	64.11
Al_2O_3	15.26	14.86	14.86	14.86	14.66	15.46	13.66	14.26	15.06	15.86
tFe_2O_3	4.25	4.25	4.25	4.60	4.60	4.71	3.44	3.85	3.90	4.66
MgO	2.02	1.96	1.91	2.23	2.23	23.2	1.47	1.80	1.91	2.18
CaO	4.07	4.30	3.46	4.07	3.84	4.22	3.08	3.15	3.46	3.99
Na_2O	3.40	3.32	3.40	3.32	3.40	3.32	3.16	3.32	3.32	3.48
K_2O	3.63	3.60	3.68	3.77	3.74	3.53	3.96	3.87	3.81	3.69
TiO_2	0.51	0.51	0.54	0.56	0.56	0.59	0.46	0.48	0.51	0.59
MnO	0.07	0.07	0.07	0.08	0.08	0.08	0.06	0.08	0.07	0.07
LOI	0.58	0.74	0.66	0.55	0.76	0.96	0.69	0.59	0.85	0.59
TOTAL	99.33	99.57	100.3	99.58	99.41	99.20	99.80	99.07	98.43	100.66
Zr	151.0	151.0	123.7	141.8	160.6	158.1	126.6	115.5	124.6	149.6
Nb	6.0	11.7	8.4	10.9	11.2	6.7	13.9	13.8	4.7	9.9
Y	24.9	26.6	31.0	31.6	29.3	29.7	32.7	26.0	25.8	29.0
Sr	623.6	599.1	621.1	610.5	618.2	631.2	631.9	447.7	502.1	574.8
U	4.0	0.0	21.3	2.2	0.0	0.0	0.0	4.7	5.0	0.0
Rb	107.2	121.6	127.7	116.0	116.1	109.5	135.6	137.9	139.4	113.6
Th	1.3	3.5	19.0	0.0	6.4	0.0	0.0	28.9	14.1	11.1
Ba	622.5	538.6	607.1	685.1	713.1	648.0	537.7	586.3	655.4	644.9
Ga	13.4	16.6	16.5	17.9	12.2	18.1	16.2	16.2	13.1	15.0

	17	18	19	25	26	27–A	28	29	33	34	35
SiO_2	64.11	63.94	65.36	61.26	61.26	72.94	73.47	65.76	66.96	66.25	72.81
Al_2O_3	15.46	15.77	15.73	16.06	15.86	13.25	12.94	15.38	14.66	15.06	13.36
tFe_2O_3	5.12	4.87	4.27	5.06	4.60	2.03	1.86	4.01	3.96	5.12	2.04
MgO	2.23	2.22	2.08	2.50	2.12	0.50	0.50	1.82	1.80	1.85	0.79
CaO	3.61	4.07	4.03	6.13	5.90	1.96	2.05	4.22	3.84	3.91	1.97
Na_2O	3.40	3.39	3.34	3.48	3.40	3.53	3.55	3.45	3.48	3.48	3.59
K_2O	3.59	3.58	4.07	3.47	3.68	4.28	4.44	3.48	3.50	3.57	4.19
TiO_2	0.59	0.60	0.26	0.59	0.56	0.35	0.31	0.53	0.54	0.56	0.39
MnO	0.08	0.07	0.06	0.08	0.07	0.04	0.04	0.07	0.07	0.07	0.04
LOI	0.48	0.61	0.56	0.72	0.87	0.47	0.54	0.65	0.64	0.55	0.50
TOTAL	98.67	99.12	99.76	99.35	99.35	99.70	98.32	99.37	99.45	100.42	99.68
Zr	141.1	144.7	135.1	142.7	135.9	199.4	150.9	124.4	112.4	123.3	203.1
Nb	6.0	4.0	11.3	10.5	9.4	9.5	12.3	12.1	10.7	5.5	16.0
Y	31.3	28.2	24.0	30.6	33.0	53.6	36.1	22.7	24.0	24.3	50.8
Sr	623.3	633.4	632.8	601.9	635.0	191.5	202.0	532.6	508.2	493.0	181.9
U	3.7	6.1	13.9	0.0	5.6	16.7	12.9	0.0	14.2	11.9	0.2
Rb	118.5	114.0	115.4	103.5	112.9	139.3	146.9	110.6	119.5	119.1	139.8
Th	16.6	4.1	12.6	8.0	16.9	31.9	16.9	0.0	12.5	16.0	2.1
Ba	575.2	632.1	636.0	606.4	674.6	524.5	387.3	573.1	602.3	563.9	472.2
Ga	20.0	14.6	15.5	15.7	18.0	11.1	13.7	16.6	12.4	16.7	12.1

Analysis of the mafic microgranular enclaves

	1–1	1–2	1–3	1–4	1–5	1–6	1–7	1–10	
SiO_2	54.78	53.31	57.84	55.72	53.72	53.78	55.35	50.02	
Al_2O_3	16.84	14.07	16.96	16.61	16.67	17.07	15.49	17.34	
tFe_2O_3	6.45	7.58	5.95	5.91	6.85	5.76	8.85	7.34	
MgO	4.86	6.79	3.72	3.73	5.28	4.53	7.93	4.29	
CaO	6.37	7.65	5.96	5.96	8.12	7.11	9.03	6.23	
Na_2O	3.75	3.23	4.01	4.00	3.92	3.97	3.43	4.33	
K_2O	3.47	3.07	3.51	3.93	2.98	3.19	2.40	3.37	
TiO_2	0.83	0.75	0.69	0.80	0.81	0.65	1.01	0.97	
MnO	0.16	0.27	0.13	0.14	0.17	0.15	0.29	0.14	
LOI	1.80	1.09	1.09	2.05	1.36	1.82	0.97	1.78	
TOTAL	99.31	99.81	99.86	98.85	99.94	99.60	99.42	99.53	
Zr	147.7	150.4	154.8	172.6	204.7	128.5	243.5	196.2	
Nb	14.2	13.6	14.1	12.3	16.8	12.3	11.8	19.4	
Y	41.6	44.3	43.4	34.6	45.2	42.4	33.7	47.9	
Sr	405.4	388.9	614.5	477.4	450.9	559.5	468.1	474.1	
U	8.0	0.0	2.7	0.0	0.0	6.9	0.0	8.4	
Rb	128.1	97.4	110.0	148.2	112.0	98.0	97.4	146.4	
Th	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Ba	799.0	485.3	905.1	844.8	614.5	843.5	482.4	756.4	
Ga	16.9	15.4	17.1	16.9	17.1	19.6	18.7	20.4	
Cu	44.7	24.9	46.8	28.2	8.7	32.5	13.4	0.0	
Ni	21.6	111.0	16.9	17.3	37.1	28.0	89.8	20.9	
Zn	76.1	83.3	68.0	76.7	78.8	67.3	110.9	80.2	
	1–D	1–E	1–F	15–C	16–B	19–B	19–D	20–B	40–1
SiO_2	53.74	56.64	57.07	46.78	54.21	57.56	56.78	56.35	57.56
Al_2O_3	16.42	14.92	16.32	16.50	14.59	14.85	16.90	15.99	14.69
tFe_2O_3	6.53	4.86	9.36	5.40	4.86	5.81	4.15	6.52	6.22
MgO	4.44	4.86	9.39	5.36	4.86	5.81	4.15	5.40	5.96
CaO	5.66	7.09	7.12	6.71	5.54	6.39	5.60	6.55	6.98
Na_2O	4.07	3.92	2.72	4.02	2.90	3.27	4.14	3.64	3.65
K_2O	3.17	2.51	3.80	3.04	7.61	4.85	4.22	2.99	2.52
TiO_2	0.82	0.63	1.32	1.01	0.54	0.69	0.88	0.68	0.56
MnO	0.15	0.17	0.19	0.16	0.14	0.18	0.14	0.17	0.18
LOI	1.07	0.87	1.02	1.01	0.39	0.82	1.69	1.51	1.41
TOTAL	98.97	99.38	99.35	99.29	99.30	99.93	99.46	99.80	99.73
Zr	175.0	179.8	160.4	188.1	155.2	152.6	176.	73.5	91.7
Nb	17.8	13.6	16.1	14.7	11.7	14.3	20.8	10.9	9.0
Y	36.7	54.3	34.1	36.2	39.4	42.2	46.2	32.1	26.1
Sr	409.6	491.8	412.8	529.7	567.1	448.8	542.9	485.1	429.8
U	0.0	25.9	0.0	0.0	7.2	3.8	2.4	0.0	0.0
Rb	131.5	79.2	145.7	126.8	162.7	136.1	172.6	72.2	66.1
Th	5.7	11.4	1.7	1.7	10.0	0.0	0.0	2.4	0.0
Ba	641.6	418.9	590.2	590.6	2470.7	1522.9	696.2	694.3	601.2
Ga	15.5	15.6	14.9	18.5	11.9	15.2	18.2	14.9	16.5
Cu	38.5	16.4	50.9	14.1	11.5	39.6	33.1	23.0	13.0
Ni	23.6	27.6	159.4	24.3	67.4	55.6	22.0	37.8	41.7
Zn	75.8	71.4	129.5	82.0	59.4	82.3	77.8	71.8	74.5

Explanations:
– Major and trace elements are given weight % and ppm, respestively.
– tFe_2O_3 Total iron oxides as ferric iron.
– LOI, loss of ignition.

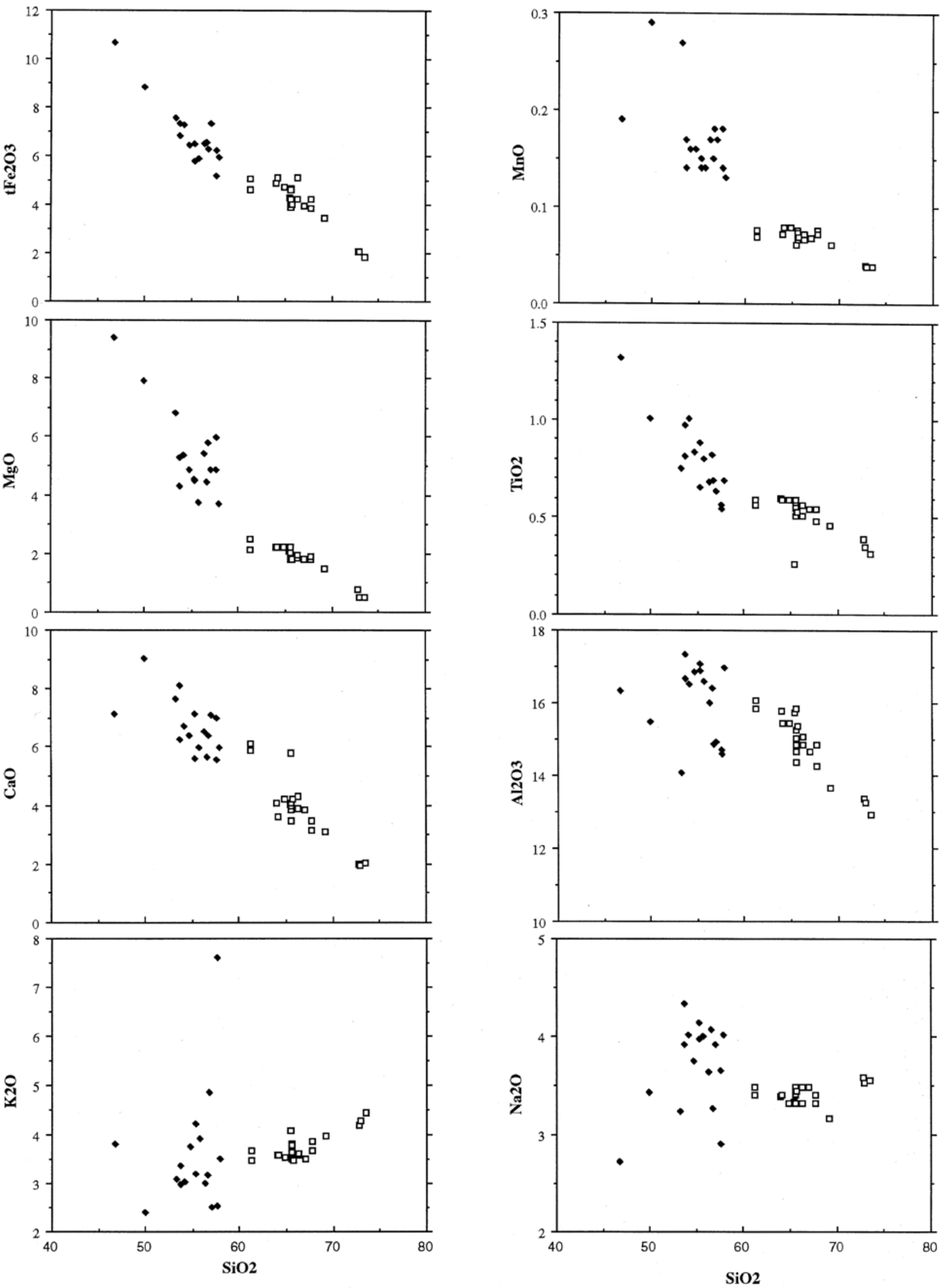

Figure 10. Major elements–SiO_2 Harker type diagrams for mafic microgranular enclaves and their host granodiorites. Solid symbols are enclaves, open symbols are granodiorite.

the matrix suggest mechanical transfer of quartz into the mafic microgranular enclaves during the crystallization stage of both basic and acidic magmas. Large crystals of horblende are seen to enclose other matrix minerals, suggesting that these hornblende crystals formed late. Also blade–shaped biotite crystals and matrix minerals which they enclose represent late–stage crystallization in the enclaves. Acicular apatites indicate rapid growth because of quick cooling of the basic magma in the acidic magma. The pyroexenes are relic crystals of initial basic magma.

Geochemistry of the Mafic Microgranular Enclaves

17 samples from mafic microgranular enclaves and 24 samples from the granodiorite have been analyzed for major and minor elements to investigate chemical differences between the enclaves and heir host rock. These samples were analysed at the geochemistry laboratory of Dokuz Eylül University, using a Philips x–ray fluorescense (XRF) with an Cr anode tube for minor elements and Pye Unicam 5pg atomic absorption spectrophotometer for oxides.

As seen from Table 1, the mafic micro granular enclaves are chemically distinct from the host granodiorite. The SiO_2 contents of the enclaves which are present intermediate composition are range from about 46 to 57 weight percent and lower than the SiO_2 contents of the host rock. Al_2O_3, CaO and Na_2O of the enclaves are higher and K_2O content is generally lower than granodiorite. Higher Al_2O_3 and Na_2O are effect of higher plagioclase content and higher CaO is effect of higher plagioclase and hornblende in the mafic microgranular enclaves. As the SiO_2 contents of the mafic microgranular enclaves tend to be distinct but contiguous with granodiorite, SiO_2 variation diagrams provide a means of observing overall chemical differences between two groups. On the diagrams, nearly linear trends are apparent for all the major element oxides of the enclaves and host granodiorite with the eception of Na_2O. In the diagrams; Al_2O_3 decreases relative to SiO_2 in both enclaves and host granodiorite. The femic oxides (Fe_2O_3t, MgO and MnO) show well–defined, continuous decreasing, linear trend relative to increasing SiO_2. CaO clearly shows a decresaing linear trend relative to SiO_2.K_2O abundances are scattered, although they do decrease with decreasing SiO_2 in the host rock and shows a near–linear trend. Na_2O in the granodiorite shows no clear trend relative to SiO_2, but Na_2O variation is within a narrow interval between about 3% and 3.5%. There is also a large amount of scatter of Na_2O relative to SiO_2 in the enclaves. A well–defined decreasing linear trend of TiO_2 relative to increasing SiO_2 is shown by the host rocks.

Figure 11, shows Harker type plots of nine trace elements of enclaves and their host rocks against SiO_2. Many trace elements do not show clear linear correlation with SiO_2 but are scattered off the trends defined by related granodiorite. The Rb plot displays notable scatter. Although a vague trend of decreasing Rb with decreasing SiO_2 is apparent for the granodiorite, Rb abudances in the enclaves and host rock, show no discernible trends. Nb abundances roughly increase relative to decreasing SiO_2, though in view of the scatter, the trend probably has little significance. Ga abundances in both enclaves and granodiorites are characterized as scatter. Usually Th and U abudances are lower than host granodiorite. They do not show linear trends. The enclaves have widely varying Y and Zr abundances but are relatively high. It is possible to say that the Y and Zr abundances increase relative to decreasing SiO_2 although the scatter of values has little linear trend. She Sr trend is markedly curved, and shows maximum at 60% SiO_2.

White and Chappell (1977) suggested that linear trends on variation diagrams have been interpreted as evidence either of magma mixing or of restite unmixing. However Wall et al. (1987) have shown that under certain conditions fractional crystallization can also generate linear trends. Dorais et al. (1990) indicate that if the compositional spectrum of enclave samples ranges from 46 to 57 wt% SiO_2 result from fractional crystallization.

Discussion and Conclusions

Enclaves are important features of granitic magmas and their origin is a complex problem. Various hypotheses have been advanced to explain the source of enclaves and their host granitic magma by several authers.

According to Bailey (1984), enclaves are fragments of earlier parental magma. The trapped basic magma involved in such mixtures in generally considered to have mantle origin, whereas the acidic magma may represent either products of crustal melting or residues from the differentiation of basic magma. Further, Bailey (1984) suggest also that dark microgranular enclaves and their host granites are hybrid rocks resulting from incomplete mixing or mingling of more acidic and basic components. Clarke (1992) indicated that continental arc metaluminous granitoids are partial melts of basaltic rocks that were previously partial melts of the mantle. It

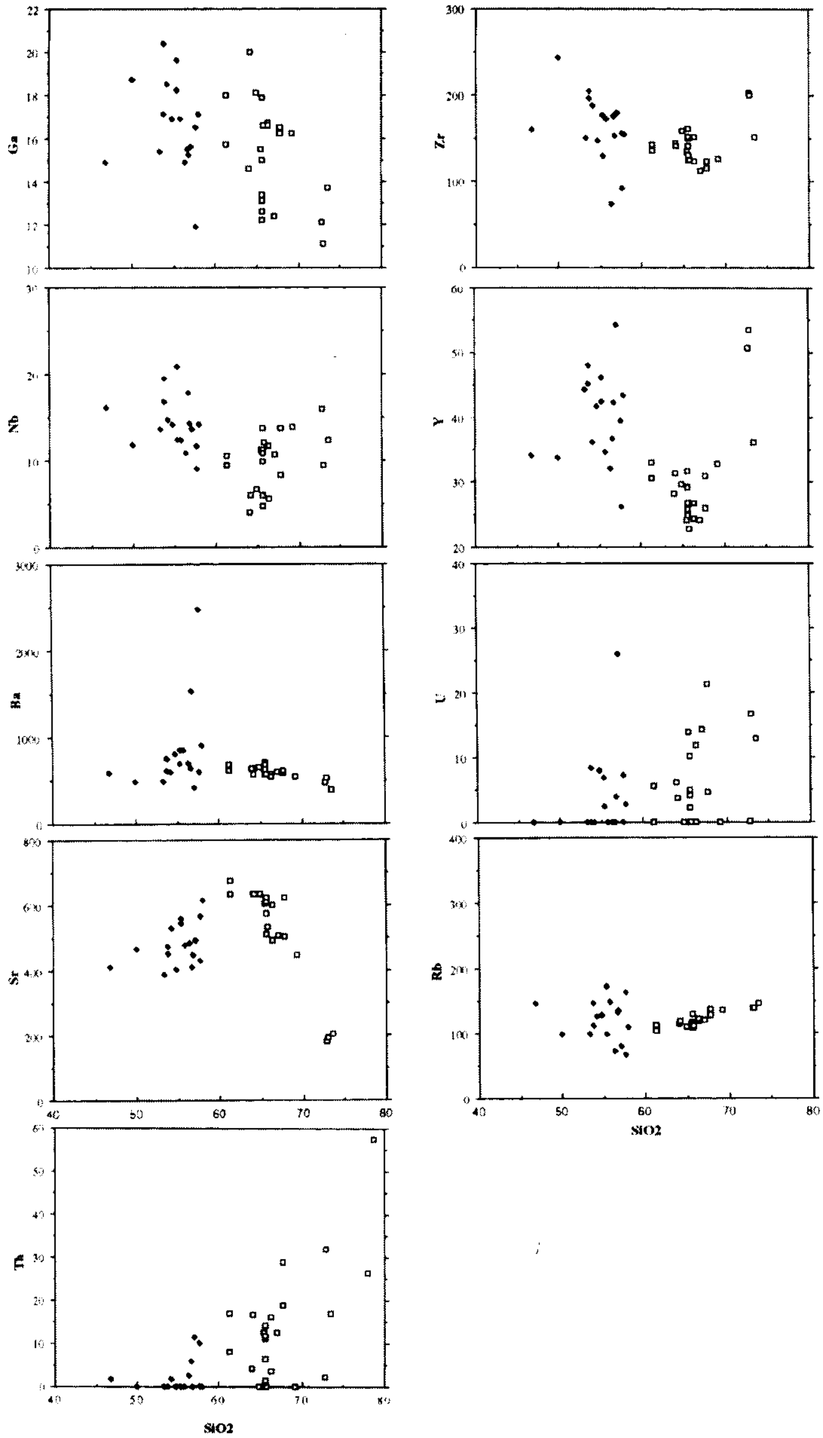

Figure 11. Minor elements–SiO_2 Harker type diagrams for mafic microgranular enclaves and their host granodiorites. Solid symbols are enclaves, open symbols are granodiorite.

is possible that the fragments of basic magma are trapped by acidic magmas. This period has been called magma mingling. Orsini et al. (1991) suggested that mixing involves thermal equilibration and various types of interactions between the two coeval magmas, such as material exchanges between the two components through either mechanical transfers of crystals or chemical transfers. During chemical transfer, the migration of alkali elements from the acid towards the basic components are recognized by chemical analyses. The Y and Nb contents of the enclaves are generally higher than those of the host rock; these high contents are similarly explained by a chemical transfer of trace and major elements out of the acid component. Bussy and Ayrton (1990) indicated that the quartz ocelli are result of the mechanical transfer of the quartz xenocrysts from the acid system into the more basic enviroment. The mingling process followed by mixing process. During the incomleted mixing process some textural characteristics developed in the enclaves (Hibbard, 1995).

The Kozak granodiorite represents metaluminous I–type calc alkaline character. The enclaves that are present intermediate composition are classified as mafic microgranular enclaves on the basis of their dark color, grain size and textural properties. The petrographic and geochemical relations of the mafic microgranular enclaves and the host granodiorite indicate that the Kozak pluton is product of partial melting and fractional crystallization of basic magma and the mafic microgranular enclaves are trapped blobs of basic magma in acidic magma. The mineralogical compositions of mafic microgranular enclaves are more or less same with the host granodiorite but in different proportions. The textural properties in the mafic microgranular enclaves such as poikilitic K–feldispars, irregular poikilitik quartz patchs, quartz ocelli rimmed by mafic minerals, skeletal relic plagioclase crystals, isolated small plagioclase crystal in large plagioclase, acicular apatite crystals are all consistent with magma mixing process between felsic (host) and mafic (enclave) magma. The relic pyroxenes in the enclaves are residue crystals of initial basic magma.

During magma mingling/mixing process, mechanical and chemical transfers developed from acidic to basic magma. The higher contents of oxides (except SiO_2 and K_2O) and Nb, Y ratios in the enclaves can be result of the chemical transfer or trace and major elements. The presence of quartz ocelli in the mafic microgranular enclaves are explained by mechanical transfer from acidic magma.

References

Akyürek, B., 1989.1/100 000 Ölçekli açınsama nitelikli Türkiye jeoloji haritaları serisi Balıkesir–G4 Paftası. MTA Genel Müdürlüğü, Jeoloji Etütleri Dairesi 12s. (Unpublished).

Akyürek, B., Soysal Y., 1983. Biga yarımadası güneyinin (Savaştepe–Kırkağaç–Bergama–Ayvalık) temel jeoloji özellikleri. MTA Dergisi, 95/96, I–12.

Altunkaynak, S. and Yılmaz, Y., 1995. Geology of the Kozak dağı magmatik complex. International Earth Sciences Congress on Aegean Region–Abstracts, Güllük, p.4.

Ataman, G., 1975. Plutonisme calco–alcolin d'age Alpin en Anatolie du Nordquest. C.R. Acad. Sc. Paris, D.280: 2065–2068.

Bailey, J.C., 1984. Geochemistry and origin of hornblende–bearing xenoliths in the I–type Petford Granite, north–eastern Queensland. Aust. J. Earth Sci., 31, 7–23.

Bingöl, E., Delaloye, M., Ataman, G., 1982. Granitic intrusions in western Anatolia, a contribution to the geodynamic study of this area. Eclogae Geol. Helv., 75/2, 437–446.

Bussy, F. and Ayrton, S., 1990. Quartz textures in dioritic rocks of hybrid origin. Schweiz. Mineral. Petrogr. Mitt. 70, 223–235.

Bürküt, Y., 1966. Kuzeybatı Anadolu'da yer alan plütonların mukayeseli jenetik etüdü. Doktora Tezi, İTÜ Maden Fak., İstanbul, 272.

Borsi, S., Ferrara, G., Innocenti, F., Mazzuoli, R. 1972. Geochronology and petrology of recent volcanics in the eastern Aegean Sea. Bull. Volcan., 36/I, 473–496.

Clarke, D.B., 1992. Granitoid Rocks. Chapman & Hall Publications, Hong Kong, 283 pp.

Collins, W.J., Beams, S.D., White, A.J.R., Chappell, B.M. 1982. Nature and origin of A–type granites with particular reference to Southeastern Australia. Contrib. Mineral. Petrol. 80, 189–200.

Debon, F., Le Fort, P., 1982. A chemical–mineralogical classification of common plutonic rocks and associations. Royal Soc. of Edinburg Transaction: 73: 135–149.

Didier, J., 1973. Granite and Their Enclaves: The Bearing of Enclave on the Origin of Granites, Development in Petrology, 3, Elsevier, Amstredam, 393 pp.

Dorais, M.J., whitney, J.A., and Roden, M.F., 1990. Origin of mafic enclaves in the Dinkey Creek Pluton, Central Sierra Nevada batholith, California. J. Petrol. 31, 853–881.

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

İzdar, E. 1968. Kozak intrüzif masifinin petrolojisi ve paleozoik çevre kayaçlarıyla jeolojik bağıntıları. Türkiye Jeoloji Kurumu Bülteni II 1–2, 140–19.

Kadıoğlu, Y.K. and Güleç, N., 1993. Granitoidler içindeki anklavların kökeni ve Türkiye'de örnekler. Türkiye Jeoloji Kurultayı Bülteni, 8, 113–118.

Kadıoğlu, Y.K. and Güleç, N., 1996. Mafic microgranular enclaves and interaction between felsic and mafic magmas in the Agacören intrusive suite: evidence from petrografic features and minenal chemistry. International Geology Review, 38, 854–867.

Orsini, J.B., Corcirta, C., Zorpi, M.J., 1991. Genesis of mafic microgranular envlaves through differentiation of basic magmas, mingling and chemical exchanges with their host granitoid magmas: Dider, J., ve Barbarian, B. (eds) Enclaves and Granite Petrology. Developments in Petrology, 13, Elsevier, 445–463.

Pearce, J.A., Harris, N.B.W., Tindle, A.G.W., 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. J. Petrol., 25, 56–983.

Wall, V.J., Clemens, J.D., Clarke, D.B., 1987. Models for granitoid evolution and source compositions. J. Geol., 95, 49–73.

White, A.R., Chappell, B.W., 1977. Ultrametamorphism and granitoid genesis. Tectonophysics, 43, 7–22.

Wyllie, P.J., Cox, K.G., Biggar, G.M., 1962. The habit of apatite in synthetic systems and igneous rocks. Journal of Petrology, 3, 238–243.