Turkish Journal of Earth Sciences (Turkish J. Earth Sci.), Vol. **15**, 2006, pp. 379–384. *Copyright ©TÜBİTAK*

Reply to Comment on 'Petrography and Petrology of the Calc-Alkaline Sarıhan Granitoid (NE Turkey): An Example of Magma Mingling and Mixing'

ZAFER ASLAN

Karadeniz Teknik Üniversitesi, Gümüşhane Mühendislik Fakültesi,
Jeoloji Mühendisliği Bölümü, Bağlarbaşı, TR–29000 Gümüşhane, Turkey
(E-mail: aslant@ktu.edu.tr)

Preamble: Topuz and Okay comment in discussion that the geology, petrography and petrology of the Sarıhan granitoid described in Aslan (2005) are inconsistent with previously published data. The major criticisms are explained below.

Geological Setting

The first detailed geological study (Ağar 1997) was succeeded by many others (Korkmaz & Baki 1984; Tanyolu 1988; Keskin *et al.* 1989; Güven 1993; Okay 1996; Okay *et al.* 1996; Okay & Şahintürk 1997; Şen & Kaygusuz 1998; Aslan 1998, 1999, 2000; Aslan & Aslaner 1998; Akdeniz 1998; Topuz 2000; Çapkınoğlu 2003). Although the first study merely described general geology, subsequent studies are relevant to both geology and petrology in the area.

A close examination of previously published articles shows that the maps used by previous workers are all based on the same map prepared by Okay *et al.* (1997). Moreover the study made by Çapkınoğlu (2003), who also used the map of Okay *et al.* (1997), is not at all relevant to this paper. Briefly, the map used by previous workers and in discussion is the map prepared by Okay *et al.* (1997). Several studies (Ağar 1977; Korkmaz & Baki 1984; Tanyolu 1988; Keskin *et al.* 1989) made in the area are coherent with the Aslan's (2005) study.

Although the Sarıhan granitoid was termed the Sarıhan granodiorite in previous studies, it was correctly defined as the Sarıhan granitoid in this study, because it is composed mainly of quartz-monzodiorite, granodiorite and quartz-diorite. Two hundred samples were collected from the pluton and fifty thin-sections were made for petrographic observations. The modal mineralogy of selected samples was determined by point counting with a Swift automatic counter fitted to a polarizing microscope. On each thin-section a total of 500 to 650 points were counted and modes are normalized to 100%. Results of the modal mineralogy (Table 1) show that the pluton is a granitoid and not granodiorite as claimed in the discussion. Hence the commentators are confused in naming granitoid as granodiorite.

Eocene flysch, studied by several workers (Korkmaz & Baki 1984; Keskin *et al.* 1989), occurs approximately 1.5 km south of the Sarıhan granitoid and is out of the investigated area.

Although the age of the Saraycık granodiorite was previously defined as Permian (e.g. Tanyolu 1988), it was determined as Eocene by Topuz *et al.* (2005). But his geochemical data is in conflict with field data and further discussion is needed to solve the problem of the age of the Saraycık granodiorite.

Topuz proposed in the discussion that the Sarıhan granitoid is in contact with the ophiolitic mélange, although in this area granitoid has no contact with the Otlukbeli mélange, which is far from the intrusion. In fact a body of limestone or marble exists between the granitoid and mélange, and the granitoid is in contact with limestone in this area. The existence of a mineral assemblage such as magnetite, hematite, goethite and malachite along with crystallized limestone or marble confirms definite skarn occurrences, on the west margin of the intrusion. There are several old adits and mine around this skarn zone. Briefly, the Sarıhan granitoid does not contact the Otlukbeli mélange, as previously

Table 1. Modal mineralogy (normalized to 100%) of samples from Sarıhan granitoid. GD – granodiorite; QD – quartzdiorite; QMD – quartzmonzodiorite

Sample No	S1	S2	S3	S4	S5	S6	S7	S8	6	29	33	34	193	203	209	232	238	254	261	262	264	266	268	226
Plagioclase	64	59	55	64	49	43	50	51	47	43	46	55	46	52	40	55	53	50	48	51	41	46	52	47
Orthoclase	8	6	5	7	18	18	13	14	13	13	10	7	15	6	8	7	9	10	14	12	8	15	5	16
Quartz	10	16	14	12	15	17	16	13	17	13	17	11	17	24	40	16	11	13	11	11	29	23	15	15
Hornblende	14	13	17	9	10	11	11	10	5	12	10	7	9	1	1	8	15	20	14	11	4	6	17	9
Biotite	2	1	3	4	3	5	3	7	8	4	4	7	5	1	1	8	1	1	2	3	1	1	7	6
Zircon	1	0.3	1	1	0.3	0.2	0.5	0.2	1	1	-	-	1	1	1	1	0.7	0.8	-	1	1	1.2	-	-
Sphene	-	-	-	-	-	0.2	1	-	-	4	6	2	-	-	-	-	-	0.8	1	-	-	-	-	-
Apatite	0.3	0.5	0.4	0.2	0.2	0.5	0.6	0.2	0.4	1	1	0.7	0.5	0.4	0.8	0.6	0.3	0.4	0.5	0.3	0.2	0.3	0.1	-
Chlorite	-	0.5	0.6	0.8	0.2	1	0.4	0.4	1	4	1	2	1	1.2	4	0.7	-	1	0.5	8	1.8	1.5	-	3
Sericite	-	1.7	2	1	0.3	0.1	0.5	0.2	1.6	2	1	2	2.5	3.4	3.2	0.7	5	1	2	1.7	1	3	-	-
Calcite	-	-	1	-	-	-	-	-	-	-	1	1	-	5	-	-	-	-	-	-	9	-	-	-
Opaques	0.7	2	1	1	4	4	4	4	6	3	3	2	3	5	2	3	5	2	7	8	4	4	4	4
	QMD	QD	QD	QD	QMD	GD	GD	QMD	GD	GD	GD	QMD	GD	GD	GD	GD	QMD	QMD	QMD	QMD	GD	GD	GD	QMD

defined by Korkmaz & Baki (1984). Besides, Aslan (2005) emphasized that Sarıhan granitoid is younger than Otlutbeli mélange and verified it by dating the Sarıhan granitoid. Hence, the claim by Topuz and Okay that pluton and mélange are in contact in the investigated area is simply invalid.

Although the large Pulur Massif occurs in the region, our study area includes only a small part of the massif, and the mineral paragenesis of the metamorphic rocks in this area indicates that intensity of metamorphism gradually increases from southeast to northwest (Keskin *et al.* 1989; Aslan 2005).

Age of the intrusion

Aslan (2005) undertook Rb-Sr whole-rock isotopic studies on three selected samples and results established the age of the intrusion to be 66–63.4±2 Ma using both isochrons and the formula devised by Faure (1986).

Petrography and Petrology

Aslan (2005) analysed nineteen samples from the Sarıhan granitoid for major and trace element and these analyses were given by Aslan (2005). Results of these analyses were interpreted using minpet and an igneous geological computer program. The critical ratio of A/CNK and Mg# were reviewed but the results were unchanged. The pluton is I-type, metaluminous and has characteristics of cafemic-group granitoids. At the southern and northern parts of the eastern Pontides, when trace element contents of the other plutons are compared with those of Sarıhan granitoid, they show that the ratio of the Ba is comparable but the Sr ratio is increasing compared with other plutons (Şen & Kaygusuz 1998; Aslan 1998; Kaygusuz 2000; Boztuğ *et al.* 2004; Arslan &Aslan 2006).

Fe_2O_3 and FeO have been determined by the titration method (Aslan 1988) at the Karadeniz Technical University.

It is asserted at the discussion that the totals of some hornblende and biotite analyses are unacceptably low. But these values vary between 94.72–98.20% and are similar to the data presented by Topuz *et al.* (2005). Also, approximately 300 point microprobe analyses were made from plagioclase, orthoclase, hornblende and biotite, and some of them were given in Aslan's (2005) paper.

Compared with the host rock, mafic microgranular enclaves (MME) are more mafic than the felsic host, and geochemical data of them are given (Table3). MME are produced by a mingling process between mafic and felsic magma (Yılmaz & Boztuğ 1994). MME is fine-grained due to rapid cooling of the mafic magma which mixed with felsic magma (Barbarin & Didier 1991). While felsic magma initially displaying Newtonian behavior and mafic magma initially displaying visco-plastic behavior intermingled, both of them eventually display Newtonian behavior as magma mixing progresses (Fernandez & Barbarin 1991) and details of process are given in Table 2. Magma mixing is only identified by textural features summarized by Hibbard (1991) namely rapakivi texture, antirapakivi texture, poikilitic quartz/K-feldspar texture, titanite ocellar texture, quartz-hornblende ocellar texture, hornblende/biotite zones in K-felsdpar, blade cellular plagioclase, spongy cellular plagioclase. In addition, Aslan (2005) tried to explain the process whereby biotite is

Table 2. Products of magma mixing (from Yılmaz & Boztuğ 1994). MME – microgranular enclaves.

Mafic Magma	Felsic Magma	Type of Mix	Product
Newtonian	Newtonian	Magma Mixing	Microscopic textures
Visco-plastic	Newtonian	Magma Mingling	MME
Newtonian	Visco-plastic	Magma Mingling	Synplutonic dykes
Newtonian	Plastic	-	Mafic dykes
Plastic	Newtonian	-	Felsic dykes

Table 3. Whole-rock geochemistry data for enclave in the Sarıhan granitoid.

Sample No	AS2	AS4	AS7	AS21	AS31	AS8	AS41	AS71
				major oxides (wt%)				
SiO_2	59.06	59.05	58.06	59.08	59.3	59	60.1	58.03
TiO_2	0.89	0.8	0.92	0.86	0.91	0.93	0.8	0.92
Al_2O_3	16.01	16.44	15.42	16.04	16.07	15.44	16.02	15.47
Fe_2O_3	2.8	2	2.48	3.06	1.52	3.48	2.03	2.4
FeO	3.12	2.23	3.02	3.55	1.79	4.05	2.36	2.83
MnO	0.08	0.1	0.13	0.09	0.07	0.11	0.09	0.13
MgO	4.92	6.33	7.46	4.39	6.02	5.07	5.81	7.2
CaO	4.36	5.29	6.25	4.62	5.03	5.01	5.29	6.05
Na_2O	6.2	5.08	4.02	4.62	4.22	3.09	4.57	4.03
K_2O	1.24	2.1	1.4	2.06	3.04	3.1	2.11	1.2
P_2O_5	0.46	0.57	0.54	0.45	0.71	0.41	0.47	0.54
LOI	0.54	1.03	1.57	2.41	2.35	1.15	0.04	2.62
Total	99.68	100.13	101.27	101.23	101.03	100.84	100.69	101.42
				trace elements (ppm)				
Rb	31	89	59	104	203	117	89	61
Sr	968	914	663	702	796	606	918	663
Zr	138	180	123	138	185	132	182	121
Y	19	23	22	21	31	15	24	22
Ba	490	818	586	686	953	1579	820	581
Ce	-	43	14	5	88	-	50	-
Nb	34	17	22	22	18	18	17	23
Th	38	42	52	36	40	36	40	54
Cr	9	22	117	55	31	162	26	129
Ni	32	26	51	27	26	14	25	50
Cu	35	74	140	70	80	96	70	137
Pb	230	278	113	86	91	111	259	107
Zn	57	108	88	81	67	1131	109	86

mantled by hornblende. It is known that intrusions in the eastern Pontides were emplaced in the Palaeozoic, or Cretaceous and Eocene periods. While Palaeozoic granites have no MME (Güven 1993; Çoğulu 1995), Cretaceous and Eocene granites have ample MME (Keskin *et al.* 1989; Yılmaz & Boztuğ 1994; Aslan 1998; Arslan *et al.* 1999; Kaygusuz 2000) and these textural features are seen in the Maastrichtian Sarıhan granitoid. In Aslan’s paper (2005), Figures 5 and 9 are supported by previous publications. K-feldspar forms porphyroblasts in Figure 5b and d; small plagioclase inclusions occur within large plagioclases in Figure 5c; there is an arrangement of hornblende and biotite inclusions in K-feldspar in Figure 5e. The presence of MME and some microscopic textures in the rock may indicate magma mixing and mingling processes (Hibbard 1991; Pitcher 1993; Yılmaz & Boztuğ 1994). Also, supporting data is the irregular composition of %An in the plagioclase. Plagioclase crystals with oscillatory zoning have an irregular range in composition from An_{33} in cores to An_{18} at rims (Figure 1), (Aslan 1999). These irregular compositional changes may

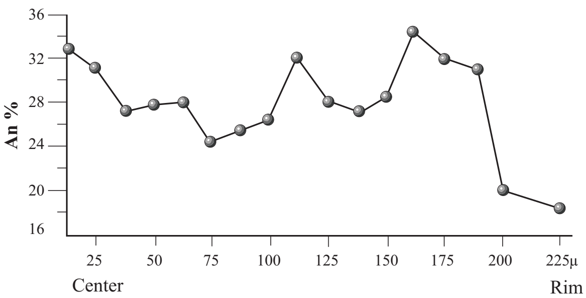

Figure 1. Irregular range composition of the %An in the oscillatory zoning plagioclase at the Sarıhan granitoid.

indicate either magma mixing, or unstable crystallization or both of them (Stamatelopoulou-Seymour *et al.* 1990; Shelley 1993). A %An change in the profile of the oscillatory zoning in the plagioclase may result from magma mixing and an unstable crystallization process (Nixon & Pearce 1987; Loomis 1982). In addition, the granitoid has A/CNK<1.1, FeO_t/ (FeO_t+MgO) <0.8 and $^{87}Sr/^{86}Sr$ initial ratio 0.705 (Aslan 2000) which are characteristic of hybrid continental arc granitoids (e.g., Barbarin 1990). All these characteristics indicate significant magma mixing and mingling processes during the evolutional history of the pluton.

As discussed, MME may record distinct origins, although all of them have been researched and interpreted. In this interpretation, geochemical data of the MME in the Sarıhan granitoid (given in Table 3) were taking into consideration. For example, the ratio of melt and restite in the granitic rock is changeable. Fundamental melt granite is separated from fundamental restite granite on a SiO_2 versus K/Rb variation diagram (Wyborn 1992). Samples of the Sarıhan granitoid plotted on the diagram (Figure 2) indicated that a negative relationship exists between SiO_2 and K/Rb.

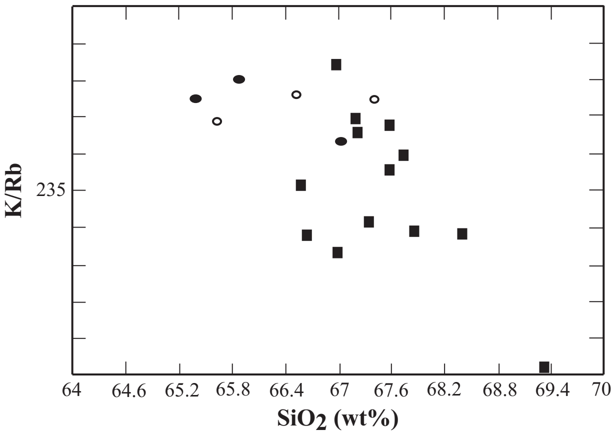

Figure 2. SiO_2 versus K/Rb diagram (after Wyborn 1992). (■: granodiorite; ✿: quartz-monzodiorite; O: quartz-diorite).

Conclusion

Topuz and Okay insisted that most of the data presented in our paper are inconsistent with previous ones. Re-examination and presentation of this work has showed that Topuz and Okay claims are irrelevant and that they have done insufficient field studies before publishing. But we hope that we can mutually collaborate to find a solution.

References

Ağar, Ü. 1977. *Demirözü (Bayburt) ve Köse (Kelkit) Bölgesinin Jeolojisi [Geology of Demirözü (Bayburt) and Köse (Kelkit) Region]*. PhD. Thesis, Karadeniz Technical University, Trabzon [in Turkish with English abstract].

Akdeniz, N. 1988. Permian and Carboniferous of Demirözü and their significance in the regional structure. *Geological Society of Turkey Bulletin* 31,71–80.

Arslan, M. & Aslan Z. 2006. Mineralogy, petrography and whole-rock geochemistry of the Tertiary granitic intrusions in the Eastern Pontides, Turkey. *Journal of Asian Earth Sciences* **27**, 177–193.

Arslan, M., Aslan, Z. & Şen, C. 1999. Post-collision granitic intrusions of Eastern Pontides, NE Turkey: Implications to Pontide arc evolution during Tertiary time. *In*: Barbarin, B. (ed), *The Origin of Granites and Related Rocks.* 4th Hutton Symposium, Clermont-Ferrand, France, p. 124.

Aslan, Z. 1998. *Saraycık-Sarıhan Granitoyidleri (Bayburt) ve Çevre Kayaçlarının Petrolojisi, Jeokimyası ve Sarıhan Granitoyidinin Jeokronolojik İncelenmesi [Petrology-Geochemistry of Saraycık-Sarıhan Granitoids and Their Country Rocks, and Geochronology of Sarıhan Granitoid]*. PhD Thesis, Karadeniz Technical University, Trabzon [in Turkish with English abstract].

Aslan, Z. 1999. Sarıhan (Bayburt) Granitoyidinin petrografisi ve mineral kimyası: Doğu Pontid güney zonu, KD Türkiye [Petrography and mineral chemistry of Sarıhan (Bayburt) granitoid: southern zone of eastern Pontides, NE Turkey]. *Proceedings of the 52nd Geological Congress of Turkey*, 231–238.

Aslan, Z. 2000. Rb-Sr dating and petrogenesis of the calc-alkaline Sarıhan Granitoid (Bayburt), NE Turkey. Implication for a hybrid source. *IESCA 2000 Abstracts*, p. 214.

Aslan, Z. 2005. Petrography and petrology of the calc-alkaline Sarıhan Granitoid (NE Turkey): an example of magma mingling and mixing. *Turkish Journal of Earth Sciences* 14,185–207.

Aslan, Z. & Aslaner, M. 1998. Saraycık (Bayburt) Granodiyoriti ve çevre kayaçlarla olan ilişkisi: Çarpışma eşzamanlı, kalk-alkalen, volkanik yay granitoyidi, Doğu Pontid güney zonu, KD Türkiye [Saraycık (Bayburt) Granodiorite and its contact with the country rocks: syn-collisional, calc-alkaline, volcanic-arc granitoid, southern zone of eastern Pontides, NE Turkey]. *Fırat Üniversitesi Jeoloji Mühendisliği Eğitiminin 20. Yılı Sempozyumu Bildiriler Kitabı*, 331–343.

Barbarin, B. 1990. Granitoids: main petrogenetic classifications in relation to origin and tectonic setting. *Geological Journal* **25**, 227–238.

BARBARIN, B. & 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.

BOZTUĞ, D., JONCKHEERE, R., WAGNER, G.A. & YEĞINGIL, Z. 2004. Slow Senonian and fast Palaeocene–Early Eocene uplift of the granitoids in the central eastern Pontides, Turkey: apatite fission-track results. *Tectonophysics* **382**, 213–228.

ÇAPKINOĞLU, S. 2003. First records of conodonts from the Permo-Carboniferous of Demirözü (Bayburt), Eastern Pontides, NE Turkey. *Turkish Journal of Earth Sciences* **12**, 199–207.

ÇOĞULU, E. 1975. *Gümüşhane ve Rize Granitik Plutonlarının Mukayeseli Petrojeolojik ve Jeokronolojik Etüdü* [*Petrogeologic and Geochronologic Investigation of Gümüşhane and Rize Granitic Plutons and Their Comparison*]. Dissertation Thesis, İstanbul Technical University [in Turkish with English abstract unpublished].

FAURE, G. 1986. *Principles of Isotope Geology* (2nd Edition). John Wiley & Sons, New York.

FERNANDEZ, A.N. & BARBARIN, B. 1991. Relative rheology of coeval mafic and felsic magmas: nature of resulting interaction processes – shape and mineral fabric of mafic microgranular enclaves. *In*: DIDIER, J. & BARBARIN, B. (eds), *Enclaves and Granite Petrology.* Development in Petrology 13, Elsevier, 263–275.

GÜVEN, İ. H. 1993. *1/250,000-Scale Geological and Metallogenical Map of the Eastern Black Sea Region*. Publications of Mineral Research and Exploration Institute of Turkey (MTA) of Turkey, Trabzon.

HIBBARD, M.J. 1991. Textural anatomy of twelve magma mixed granitoid systems. *In*: DIDIER, J. & BARBARIN, B. (eds), *Enclaves and Granite Petrology*. Development in Petrology 13, Elsevier, 431–444.

KAYGUSUZ, A. 2000. *Torul ve Çevresinde Yüzeylenen Kayaçların Petrografik ve Jeokimyasal İncelenmesi [Petrography and Geochemistry of Rocks Exposed in Torul and its Surroundings].* PhD. Thesis, Karadeniz Technical University, Trabzon [in Turkish with English abstract, unpublished].

KESKİN, İ., KORKMAZ, S., GEDİK, İ., ATEŞ, M., GÖK, L., KÜÇÜMEN, Ö. & ERKAL, T. 1989. *Bayburt Dolayının Jeolojisi [Geology of Bayburt Region].* Mineral Research and Exploration Institute of Turkey (MTA) of Turkey Project Report [unpublished, in Turkish].

KORKMAZ, S. & BAKİ, Z., 1984. Demirözü (Bayburt) güneyinin stratigrafisi [Stratigraphy of south of Demirözü (Bayburt)]. *Geological Society of Turkey Bulletin* **5**, 107–115 [in Turkish with English abstract].

LOOMIS, T.P. 1982, Numerical simulations of crystallization processes of plagioclase in complex melts: the origin of major and oscillatory zoning in plagioclase. *Contributions to Mineralogy and Petrology* **88**, 219–229.

NIXON, G.T. & Pearce, T.H. 1987. Laser-Interforemetry study of oscillatory zoning in plagioclase: The record of magma mixing and phenocryst recycling in calc-alkaline magma chambers, Iztaccihuatl Volcano. *American Mineralogist* **72**,1144–1162.

OKAY, A.İ. 1996. Granulite facies gneisses from the Pulur region, Eastern Pontides. *Turkish Journal of Earth Sciences* **5**, 55–61.

OKAY, A.İ. & ŞAHİNTÜRK, Ö. 1997. Geology of the eastern Pontides. *In*: ROBINSON, A.G. (ed), *Regional and Petroleum Geology of the Black Sea and Surrounding Region.* AAPG Memoir 68, 291–311.

OKAY, A.İ., ŞAHİNTÜRK, Ö. & YAKAR, H. 1997. Stratigraphy and tectonics of the Pulur (Bayburt) region in the eastern Pontides. *Bulletin of the Mineral Research and Exploration Institute (MTA) of Turkey* **119**, 1–22.

PITCHER, W.S. 1993. *The Nature and Origin of Granite.* Chapman & Hall, London.

SHELLEY, D. 1993. *Igneous and Metamorphic Rocks under the Microscope.* Chapman and Hall, London.

STAMATELOPOULOU-SEYMOUR, K., VLASSOPOULOS, D., PEARCE, T.H. & RICE, C. 1990. The record of magma chamber processes in plagioclase phenocrysts at Thera Volcano, Aegean volcanic arc, Greece. *Contributions to Mineralogy and Petrology* **104**, 73–84.

ŞEN, C. & KAYGUSUZ, A. 1998. Doğu Pontid adayayı granitoyidlerin karşılaştırılmalı petrografik ve kimyasal özellikleri, KD Türkiye [Petrography and geochemical characteristics of eastern Pontide granitoids, NE Turkey]. *Fırat Üniversitesi Jeoloji Mühendisliği Eğitiminin 20. Yılı Sempozyumu Bildiri Özleri Kitabı, Elazığ,* 12–13.

TANYOLU, E. 1988. Pulur Masifi (Bayburt) doğu kesiminin jeolojisi [Geology of eastern part of Pulur Massif (Bayburt). *Bulletin of the Mineral Research and Exploration Institute (MTA) of Turkey* **108**, 1–18 [in Turkish with English abstract].

TOPUZ, G. 2000. *Zur Petrologie der metamorphen Gesteine des Pulur Massivs (Östliche Pontiden, Türkei.* PhD Thesis, Ruprecht Karls Universitaet, Heidelberg, Germany [unpublished].

TOPUZ, G., ALTHERR, R., SCHWARZ, W.H., SIEBEL, W.,SATIR, M. & DOKUZ, A. 2005. Post-collisional plutonism with adakite-like signatures: the Eocene Saraycık granodiorite (Eastern Pontides, Turkey). *Contribution to Mineralogy and Petrology* **150**, 441–455.

WYBORN, L.A.I. 1992. Proterozoicgranite Types in Australia Implications for Lower Crust Composition, Structure and Evolution. *Transactions of the Royal Society of Edinburgh: Earth Sciences* **83**, 201–209.

YILMAZ, S. & BOZTUĞ, D. 1994. Granitoyid petrojenezinde magma mingling/mixing kavramı [Magma mingling/mixing processes in granitoid petrogenesis]. *Jeoloji Mühendisliği Dergisi* **44/45**, 1–20 [in Turkish with English abstract].

Received 12 May 2006; revised typescript accepted 04 August 2006