Available online at www.sciencedirect.com

SCIENCE DIRECT®

Journal of Asian Earth Sciences 27 (2006) 177–193

Journal of Asian Earth Sciences

www.elsevier.com/locate/jaes

Mineralogy, petrography and whole-rock geochemistry of the Tertiary granitic intrusions in the Eastern Pontides, Turkey

M. Arslan[a,*], Z. Aslan[b]

[a]*Department of Geological Engineering, Engineering & Architecture Faculty, Karadeniz Technical University, 61080 Trabzon, Turkey*
[b]*Department of Geological Engineering, Gümüşhane Engineering Faculty, Karadeniz Technical University, Gümüşhane, Turkey*

Received 12 August 2003; revised 8 March 2005; accepted 10 March 2005

Abstract

Granitic intrusions in Eocene and post-Eocene volcanic rocks outcrop in the Northern and Southern Zones of the Eastern Pontides, NE Turkey. Intrusions in the Northern Zone extend NW–SE whereas those in the Southern Zone are nearly E–W orientated. The contacts of the intrusions with the volcanic rocks are sharp, epidotized and include volcanic xenoliths. The margins of Southern Zone intrusions often contain abundant angular mafic microgranular enclaves of diorite to quartz diorite composition. The rocks also show evidence of mingling and mixing between coeval mafic and felsic magmas. Field observations suggest a stopping type of ascent and emplacement style for the intrusions. Petrographically, intrusions show variations in both colour and mineralogy with fine to medium granular, monzonitic, poikilitic, rapakivi, anti-rapakivi and graphic textures. Based on modal mineralogy, the Northern rocks are monzonite, quartz monzonite, monzodiorite and quartz monzodiorite whereas the Southern samples are monzogranite and granodiorite. The rocks are generally calc-alkaline to mildly alkaline transitional and metaluminous, and show a CAFEMIC trend. The Northern Zone intrusions form a post-collisional, A-type, alkaline monzonitic association and Southern Zone intrusions form a post-collisional, I-type, granodioritic calc-alkaline-transitional association. Whole-rock compositional data indicate that differentiation occurred via fractional crystallisation with or without magma mixing. Incompatible and rare earth element patterns indicate that both the Northern and the Southern Zone intrusions were derived from melting of a mantle region enriched by subduction-related fluids but evolved differently during ascent and emplacement. U–Pb zircon dating in the Southern Zone yields an intrusion age of 44.4 ± 0.3 Ma. Regional geodynamics indicates post-collisional extensional tectonics in the region. Crustal involvement and the level of emplacement may have been important for magmatic evolution, especially for the Southern Zone intrusions, after the cessation of subduction and subsequent crustal thickening.

Keywords: Granite; U–Pb zircon age; Post-collisional granitoids; Magmatic evolution; Geochemistry; Petrology; Eastern Pontide; Turkey

1. Introduction

The Eastern Pontides (Ketin, 1966) form the northern margin of Anatolia, straddling the North Anatolian Transform Fault, and rising steeply inland from the Black Sea coast (Fig. 1). The Eastern Pontide terrane is an example of paleo-island arc generation and long-term crustal evolution from pre-subduction rifting, through arc volcanism and plutonism to post-subduction alkaline volcanism (e.g. Akın, 1978; Şengör and Yılmaz, 1981; Akıncı, 1984). Three main groups of volcanic rocks are distinguished (e.g. Adamia et al., 1977; Eğin et al., 1979; Kazmin et al., 1986; Çamur et al., 1996; Arslan et al., 1997), that are broadly grouped into three age intervals: Liassic, Upper Cretaceous and Eocene, although the age boundaries are poorly constrained. Recent field and geochemical investigations describe differences in terms of compositional, spatial and temporal relationships with regard to the Neo-Tethyan convergence system among the three volcanic groupings (Tokel, 1977; Akın, 1978; Şengör and Yılmaz, 1981; Yılmaz, 1981; Ercan and Gedik, 1983; Robinson et al., 1995; Genç and Yılmaz, 1995; Çamur et al., 1996; Yılmaz et al., 1997; Okay and Şahintürk, 1997; Arslan et al., 1997; Şen et al., 1998; Arslan et al., 2000a,b; Arslan and Aliyazıoğlu, 2001).

---

* Corresponding author. Tel.: +90 462 377 2072; fax: +90 462 325 7405.
E-mail address: marslan@ktu.edu.tr (M. Arslan).

1367-9120/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jseaes.2005.03.002

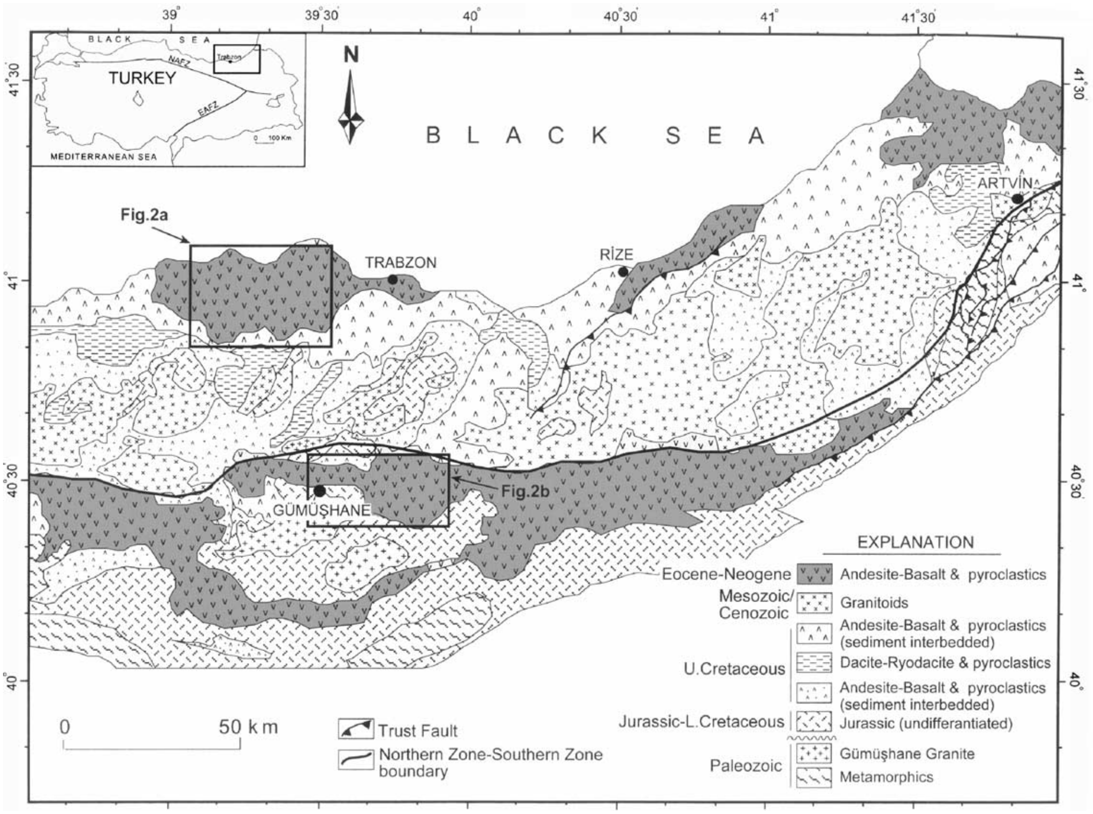

Fig. 1. Generalized geological map of the Eastern Pontides, NE Turkey (modified from Güven, 1993). Inset indicates location of the study area, NAFZ: North Anatolian Fault Zone; and EAFZ: East Anatolian Fault Zone. Northern Zone–Southern Zone boundary after Bektaş and Çapkınoğlu (1997).

In the region, plutonic rocks have a range of ages and compositions, and were probably emplaced into a variety of geodynamic environments. Ages range from Permo-Carboniferous (Gümüşhane Granitoid; Çoğulu, 1975), through Cretaceous, to Eocene (Delaloye et al., 1972; Giles, 1974; Taner, 1977; Gedikoğlu, 1979; Kamitani and Akıncı, 1979; Moor et al., 1980; JICA, 1986; Şen, 1987; Terashima et al., 1988; Okay and Şahintürk, 1997; Yılmaz et al., 1997; Aslan and Aslaner, 1998; Kaygusuz, 2000; Boztuğ et al., 2002, 2003, 2005; Arslan et al., 2004). Whole-rock compositions range from low-K tholeiitic (sometimes high-K) through calc-alkaline metaluminous granitoids and peraluminous leucogranites to silica-oversaturated alkaline syenites and monzonites (Yılmaz and Boztuğ, 1996; Boztuğ et al., 2001, 2002, 2005). The geodynamic environments of emplacement include arc-collision, syn-collisional crustal thickening and post-collisional extensional regimes (Yılmaz and Boztuğ, 1996; Okay and Şahintürk, 1997; Yılmaz et al., 1997; Boztuğ et al., 2001, 2002, 2004, 2005).

Plutons within Eocene and post-Eocene volcanic rocks occur as narrow E–W oriented bodies that crosscut all pre-Eocene units in the Eastern Pontides. Age relations among plutons are unclear and radiometric dating is limited (Delaloye et al., 1972; Giles, 1974; Kalkancı, 1974; Çoğulu, 1975; Yılmaz, 1977; Taner, 1977; Gedikoğlu, 1979; Moor et al., 1980; JICA, 1986; Bergougnan, 1987; Aslan and Aslaner, 1998; Boztuğ et al., 2002). The emplacement ages of most intrusives are inferred from contact relations and stratigraphic criteria. These are, however, obscured by deformation or overlying rocks so that such inferred ages must continuously be reassessed in light of new isotopic data, as discussed by Boztuğ et al. (2004). Nevertheless, available geochemical and radiometric studies indicate that most of the plutons were emplaced during multiple phases of activity, forming zoned plutons where each zone corresponds to a different intrusive episode (e.g. Yılmaz and Boztuğ, 1996; Boztuğ et al., 2001, 2002, 2004, 2005).

In this study, Tertiary intrusions (Aslan et al., 1999) have been studied. Six separate bodies were selected. They outcrop around the Sisdağı and Kuruçam plains (near the City of Trabzon) in the Northern Zone, and near the villages of Kaletaş and Akhisar (near the City of Gümüşhane) in the Southern Zone (Figs. 1 and 2). Although these bodies are grouped within the Late Eocene aged Kaçkar Granitoid II in previous studies (Güven, 1993), their stratigraphic position remains uncertain. To date, there are no geochemical and petrologic data for these rocks. The petrographic, compositional and petrologic characteristics of these bodies are described and compared here, and the implications discussed in terms of petrogenesis and regional tectonics.

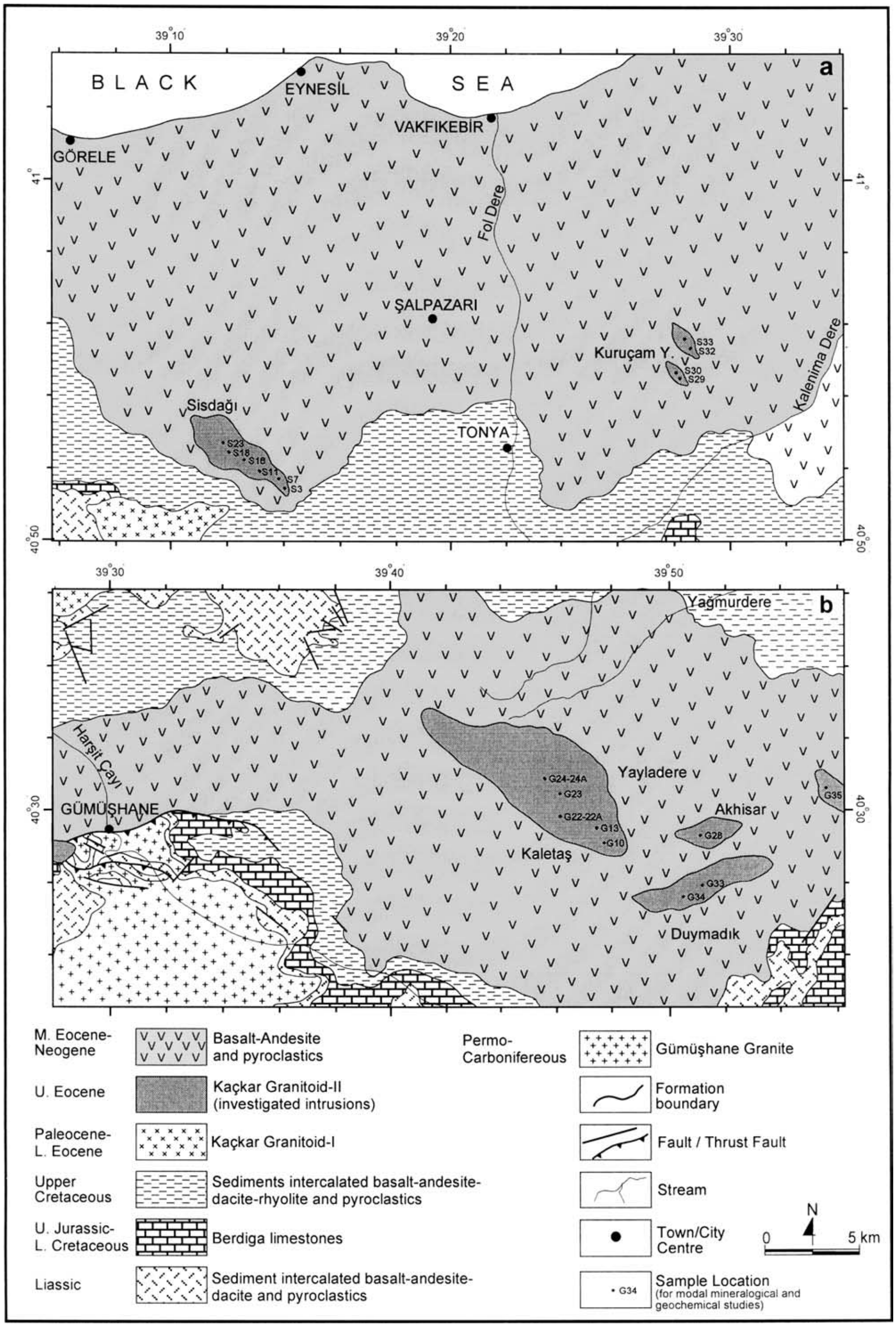

Fig. 2. Geological maps of (a) the Northern Zone and (b) Southern Zone intrusions and surrounding rocks in the Eastern Pontides (modified from Güven, 1993).

2. Geological setting

The Eastern Pontides, as a paleo-island arc, is commonly subdivided into Northern and Southern Zones on the basis of structural and lithological differences (Fig. 1) (Akın, 1978; Gedikoğlu, 1979; Özsayar et al., 1981; Bektaş et al., 1995). The Northern Zone is dominated by Late Cretaceous and Middle Eocene volcanic and volcaniclastic rocks, whereas pre-Late Cretaceous rocks are widely exposed in the Southern Zone. The volcanic rocks of the Eastern Pontides lie unconformably on a Palaeozoic heterogeneous crystalline basement, the Pulur Massif. The basement consists of metamorphic sequences of varying metamorphic grades, and is crosscut by granitoids of Permian age (Yılmaz, 1972; Çoğulu, 1975; Okay and Şahintürk, 1997; Topuz et al., 2001; Topuz, 2002). An Upper Palaeozoic sequence has been studied by several workers with conflicting views of the stratigraphy and age (e.g. Ağar, 1977; Robinson et al., 1995; Okay and Şahintürk, 1997; Yılmaz et al., 1997). Volcanic, volcano-sedimentary rocks and local sediments of Liassic-Dogger age (Ağar, 1977; Robinson et al., 1995) lie unconformably on the basement. They are overlain conformably by Dogger-Malm-Cretaceous aged neritic and pelagic carbonates. The Upper Cretaceous series, unconformably overlying the carbonate rocks, is dominated by sediments and volcanic rocks in the Southern and Northern parts of the Eastern Pontides, respectively (Robinson et al., 1995; Yılmaz and Korkmaz, 1999). Some plutonic rocks were emplaced between Jurassic and Palaeocene time (Okay and Şahintürk, 1997; Yılmaz et al., 1997).

Subduction-related arc magmatism is recorded by Senonian (ca. 84 Ma) submarine volcano-sedimentary units and associated plutonic rocks (Fig. 1). The Eocene rocks, mainly volcanics and rarely volcaniclastics and sediments, unconformably overlie the Upper Cretaceous series (e.g. Güven, 1993; Yılmaz and Korkmaz, 1999), indicating that the Eastern Pontides was above sea-level during the Palaeocene–Early Eocene, presumably due to collision between the Eastern Pontides and the Anatolide–Tauride basement along the İzmir-Ankara-Erzincan Suture Zone (Okay and Şahintürk, 1997). The timing and mechanism of the collision are interpreted differently by different researchers, based on structural considerations and the composition and timing of igneous activity. Şengör and Yılmaz (1981), Yılmaz et al. (1997), Okay and Şahintürk (1997) and Boztuğ et al. (2004) propose a Palaeocene–Early Eocene (ca. 55 Ma) collision, resulting in crustal thickening, characterized by a telescoping of the continental margin into a stack of north-vergent thrust slices, resulting in regional uplift of the Eastern Pontides. Tokel (1977), Akın (1978) and Robinson et al. (1995) interpret the Middle Eocene volcanic rocks as related to northward subduction of the Eastern Pontides and propose that collision occurred in the Oligocene (ca. 30 Ma). The contrasting interpretations for timing and the mechanism of collision in the Eastern Pontides largely results from considerations of Tertiary magmatism in this region. The Eocene–Neogene volcanic rocks are calc-alkaline to alkaline in composition, although there are lithological and chemical variations between the rocks exposed in the Northern Zone relative to those exposed in the Southern Zone (Arslan et al., 1997; Şen et al., 1998; Arslan et al., 2000a,b). Several granitoids belonging to this magmatic episode intrude the Eocene volcanic and volcaniclastic rocks (e.g. Çoğulu, 1975; Moor et al., 1980; Arslan et al., 1999). Post-Eocene uplift and subsequent erosion have maintained the clastic inputs into locally developed basins (Korkmaz et al., 1995). From the end of the Middle Eocene onward, the region remained largely above sea level, with minor volcanism and terrigeneous sedimentation continuing until the present (Okay and Şahintürk, 1997).

3. Methods

Petrographic observations of 50 thin-sections were made. 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 400–500 points were counted. Modes were normalized to 100% (Table 1). Selected samples were analysed for whole-rock major-, trace- and rare earth element compositions by using ICP-emission spectrometry and ICP-Mass spectrometry using natural rock standards as reference samples for calibration at ACME Analytical Laboratories Ltd, Vancouver, Canada. Major and trace elements were analysed by ICP on pulps after 0.2 g of rock-powder was fused with 1.5 g $LiBO_2$ and then dissolved in 100 mL 5% HNO_3. Loss on ignition (LOI) is by weigh difference after ignition at 1000 °C. Rare earth elements were performed by ICP-MS on pulps after 0.25 g rock-powder was dissolved with four acid digestions. Detection limits range 0.01–0.1 wt% for major oxides, 0.1–10 ppm for trace elements and 0.01–0.5 ppm for the rare earth elements.

U–Pb dating on sample G24 taken from one of the Southern Zone intrusions was carried out by isotope dilution, thermal-ionization mass spectrometer (ID-TIMS) at Geochron Laboratories and MIT Geochronology Laboratory, Massachusetts, USA. The sample for U–Pb dating was first hand sledged, jaw crushed, and pulverized into monomineralic sand-sized fragments, and was passed over

Table 1
Modal mineralogy (normalized to 100%) of selected samples from Northern and Southern Zone intrusions

Sample no.	Northern zone										Southern zone					
	S3	S7	S11	S16	S18	S23	S29	S30	S32	S33	G10	G13	G22	G24	G33	G34
Plag.	41.3	25.7	37.1	33.2	54.1	56.6	47.4	43.1	34.7	33.9	39.3	33.1	42.5	46.4	31.1	29.2
Orthoc.	23.9	37.7	19.9	35.0	8.5	8.5	7.4	16.1	30.7	29.4	7.3	15.9	2.2	4.2	23.5	19.6
Quartz	6.7	5.1	2.3	2.1	2.4	4.4	4.3	4.4	2.3	2.4	21.1	16.7	23.5	17.3	19.9	20.8
Hornbl.	13.6	3.4	25.6	1.0	1.0	4.4	16.3	6.1	2.7	4.5	–	–	–	–	7.5	5.8
Biotite	–	3.8	–	1.0	–	–	4.9	–	6.2	7.8	10.0	13.6	17.6	16.7	6.4	10.6
Augite	–	14.7	–	8.8	4.0	9.3	9.2	18.1	14.4	15.9	13.4	–	8.1	7.4	2.5	6.8
Chlorite	7.6	5.2	9.7	14.1	17.2	10.1	4.3	4.0	4.6	3.6	5.1	8.1	4.3	3.8	5.8	4.7
Epidote	2.0	–	4.0	–	3.4	1.3	0.1	0.2	1.1	0.3	–	0.3	1.0	1.3	0.8	0.6
Opaques	4.9	4.4	1.4	4.8	9.4	5.4	6.1	8.0	3.3	2.2	3.8	12.3	0.8	2.9	2.5	1.9

a Wilfley table, followed by heavy liquid and Frantz magnetic separation in order to obtain zircon concentrates. U–Pb zircon analyses are performed using a mixed ^{205}Pb–^{235}U–^{233}U spike, with total procedural blanks that are routinely 0.4–1.5 pg for Pb and less than 0.1 pg for U. The isotopic ratios were measured on a VG Sector 54 thermal ionization mass spectrometer with seven independently adjustable Faraday collectors and a Daly collector for the measurement of small ion beams. The age was calculated from data from two separate measurements of two multi-grain separates. The mean age is the weighted ^{206}Pb/^{238}U value for the two samples.

4. Results

4.1. Field observations and petrography

Intrusions in the Northern Zone extend NW–SE whereas those in the Southern Zone are nearly E–W (see Fig. 2a and b), which conforms with the main fracture directions in the Eastern Pontides. The contacts of the intrusions are sharp with the country rocks, mainly alkaline basaltic and pyroclastic rocks in the Northern Zone and calc-alkaline basaltic-andesitic and pyroclastic rocks in the Southern Zone (Fig. 3), and are locally epidotized. The intrusions, particularly at the outer zones, may host 1–10 cm, ellipsoidal-angular shaped volcanic xenoliths. Plutons of the Southern Zone commonly contain 2–15 cm, angular shaped mafic microgranular enclaves. The Kaletaş intrusion in the Southern Zone exhibits schlieren at its outer zone, possibly representing gravity settling of mafic phases. All intrusions are cut by aplite dykes of a few centimetre thickness.

The modal mineralogy of selected samples from the Northern and Southern intrusions are given in Table 1. The modal mineralogy is mainly 30–56% plagioclase (An_{28-49}, optically), 3–35% orthoclase, 2–21% quartz, 1–25% hornblende, 3–18% augite, 1–17% biotite, 1–8% opaques, with accessory apatite, titanite, and zircon. Chlorite, sericite, epidote and calcite are secondary. Petrographically, intrusions show variations in terms of colour, texture and mineralogy. They range from fine to medium-coarse grained rocks (Fig. 4). Generally, they have monzonitic, poikilitic, rapakivi, anti-rapakivi, graphic and rarely myrmekitic textures (Fig. 5).

Plagioclase occurs as euhedral to subhedral crystals, and its composition is mainly andesine and rarely oligoclase with An_{28-49} (optically). Plagioclase in Southern Zone samples is commonly oscillatory zoned and has a spongy-cellular texture (Fig. 5). This is not seen in Northern Zone samples. A myrmekitic texture is observed at the contact between orthoclase and plagioclase. A monzonitic texture also occurs between these minerals. Plagioclase may include small acicular apatite crystals, probably due to local saturation of apatite or magma mixing and quenching (Wyllie et al., 1962; Frost and Mahood, 1987; Hibbard, 1991; Salonsaari, 1995). Some large plagioclase crystals are alterated to sericite and clay. Orthoclase may include plagioclase, biotite, hornblende and augite, which may also indicate magma mixing. Orthoclase mainly occurs as subhedral large crystals, and its alteration to clay is more common than for plagioclase. Northern samples may

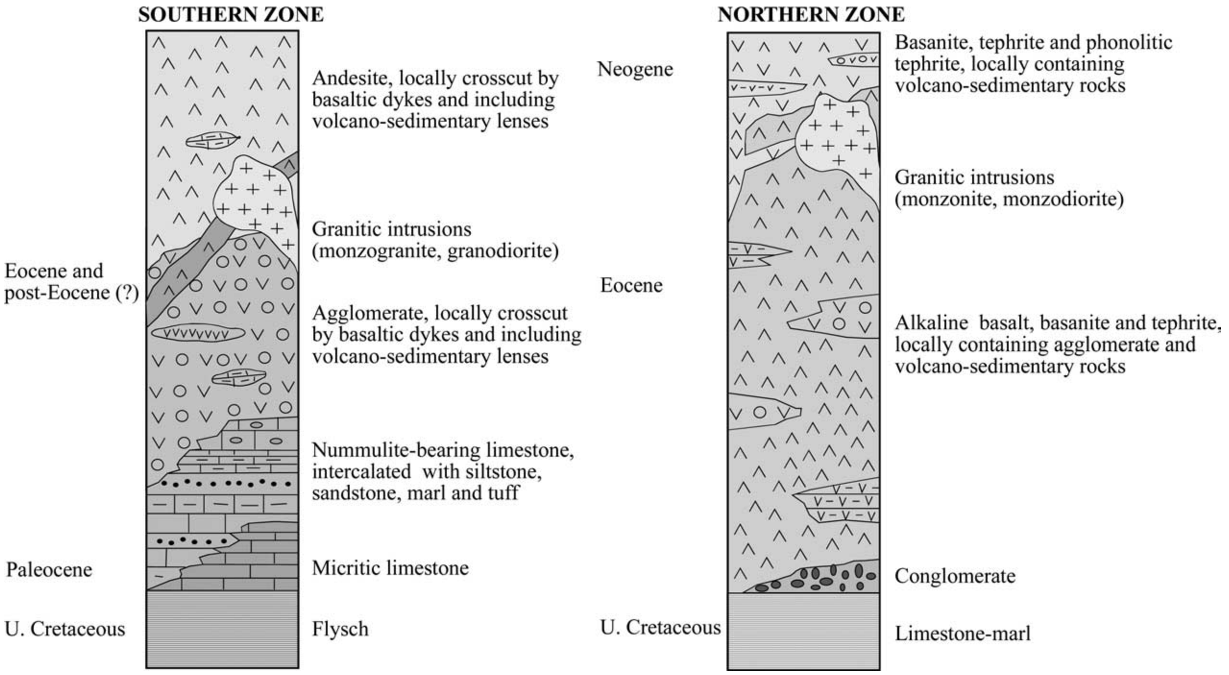

Fig. 3. Simplified comparative stratigraphic sections of the Tertiary units of Southern and Northern Zones in the Eastern Pontides (modified from Arslan et al., 2000b).

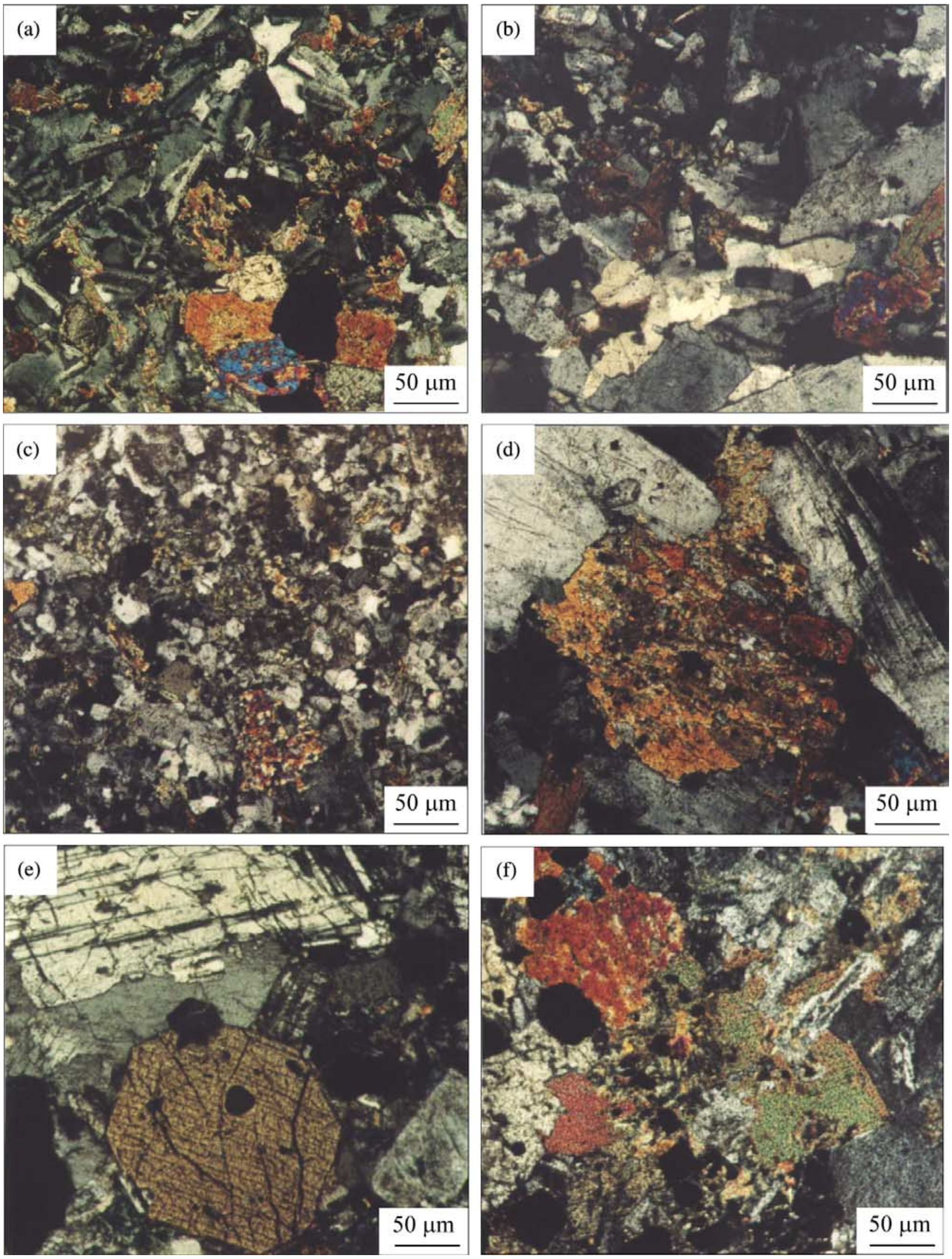

Fig. 4. Microphotographs of (a) fine grained mafic enclave (sample G26), (b) enclave-host granite contact (sample G23A), (c) aplite (sample G4), (d) intergrowth of hornblende and biotite (sample G24) in Southern Zone intrusions, (e) euhedral augite and plagioclase (sample S17), (f) augite and biotite (sample S32) in Northern Zone intrusions (crossed polars).

contain abundant medium-fine grained plagioclase, biotite, hornblende and opaques, forming poikilitic textures (Fig. 5); also evidence for magma mixing. In some samples of both zones, orthoclase is mantled by plagioclase, forming a rapakivi texture (Fig. 5) which is a significant texture indicating magma mixing (Didier and Barbarin, 1991; Fernandez and Barbarin, 1991; Barbarin and Didier, 1992; Hibbard, 1995). Samples from Akhisar village in the Southern Zone have orthoclase and plagioclase intergrowths in a graphic texture (Fig. 5). Orthoclase in some samples shows perthitic features. Quartz is subhedral to anhedral with irregular internal cracks and commonly exhibits undulose extinction.

Hornblende is the main mafic phase in Northern samples whereas it is biotite in the Southern Zone. Hornblende occurs as euhedral to subhedral crystals with h′(100) twinning. It shows characteristic pleochroism with X = pale yellow, Z = yellowish green to pale green. It may be locally altered to chlorite, especially in samples close to the outer contacts of intrusions. Augite occurs as euhedral to subhedral crystals, being especially abundant in Kuruçam Yayla samples. Some augites may exhibit sector zoning and h′(100) twinning.

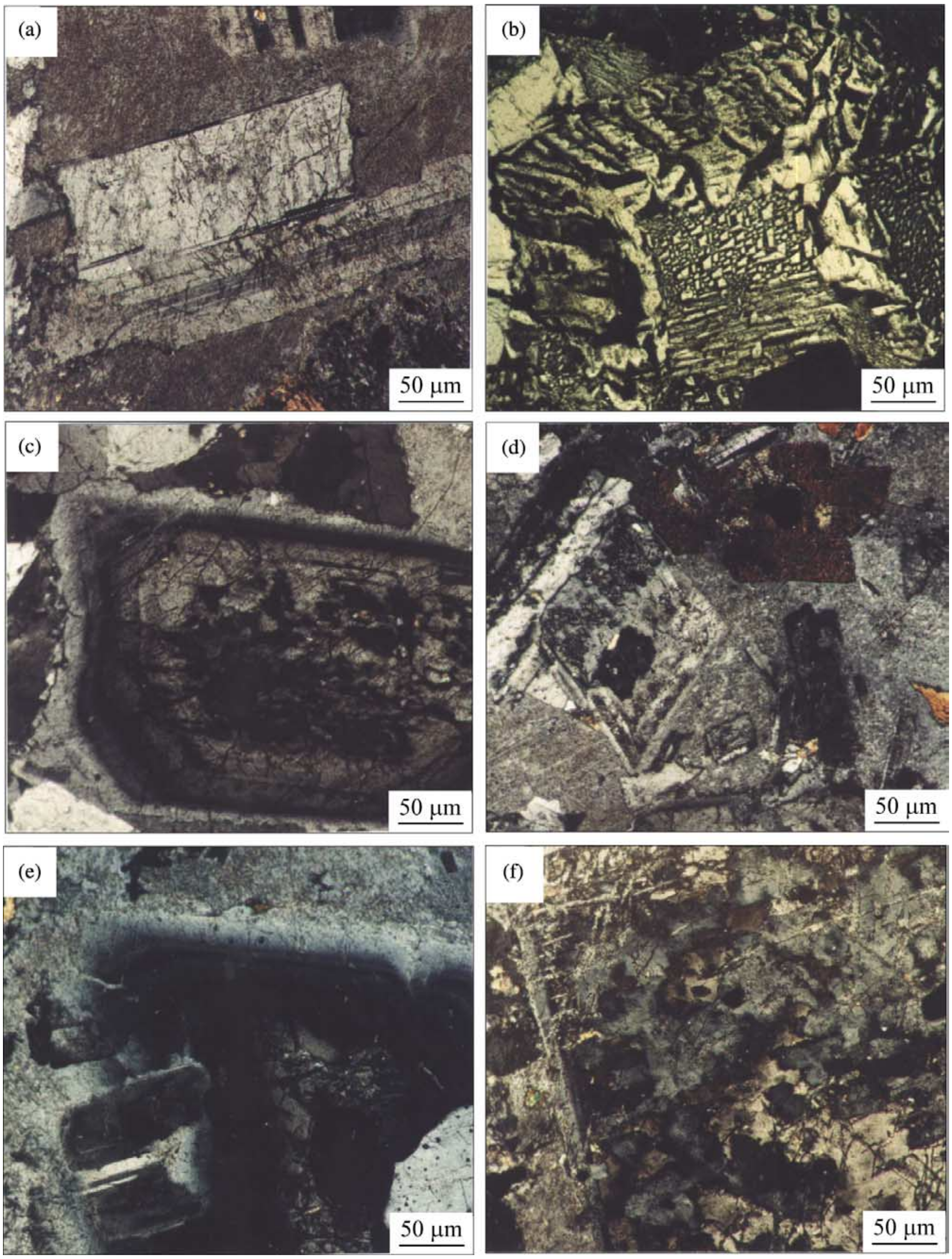

Fig. 5. Microphotographs of disequilibrium textures in the studied intrusions; (a) anti-rapakivi texture (sample G16), (b) graphic texture (sample G34), (c) oscillatory zoned and cellular plagioclase (sample G10), (d) poikilitic orthoclase (sample S6), (e) oscillatory zoned plagioclase (sample G36), (f) spongy-cellular plagioclase (sample G16) (crossed polars).

It may include small grains of opaques, and be rarely altered to uralite and chlorite. Biotite occurs as subhedral crystals with characteristic pleochroism, X = pale yellow, Z = brown, reddish brown. It may rarely show chloritic alteration. In some Southern Zone samples, biotite shows intergrowth with or mantled by hornblende. This intergrowth is seen especially at the border zone of mafic granular enclaves, which is interpreted to be evidence of magma mixing (e.g. Didier and Barbarin, 1991; Barbarin and Didier, 1992).

Mafic microgranular enclaves (MMEs) are angular in shape and very fine-grained compared to the host rock. They have diorite and quartz diorite compositions. MMEs have similar textural and mineralogical features as their host rocks. They consist of plagioclase, orthoclase ($<1\%$), quartz (2%), biotite and augite. Plagioclase is subhedral, andesine (An_{38-48}, optically) in composition, and has oscillatory zoning and albite-law twinning. Biotite is abundant at contacts between enclave and host rock, and may show chloritization.

Quartz-Alkali Feldspar-Plagioclase (QAP) modal classification (Streckeisen, 1976) is used widely to determine the nature of a main magma series (Lameyre and Bowden,

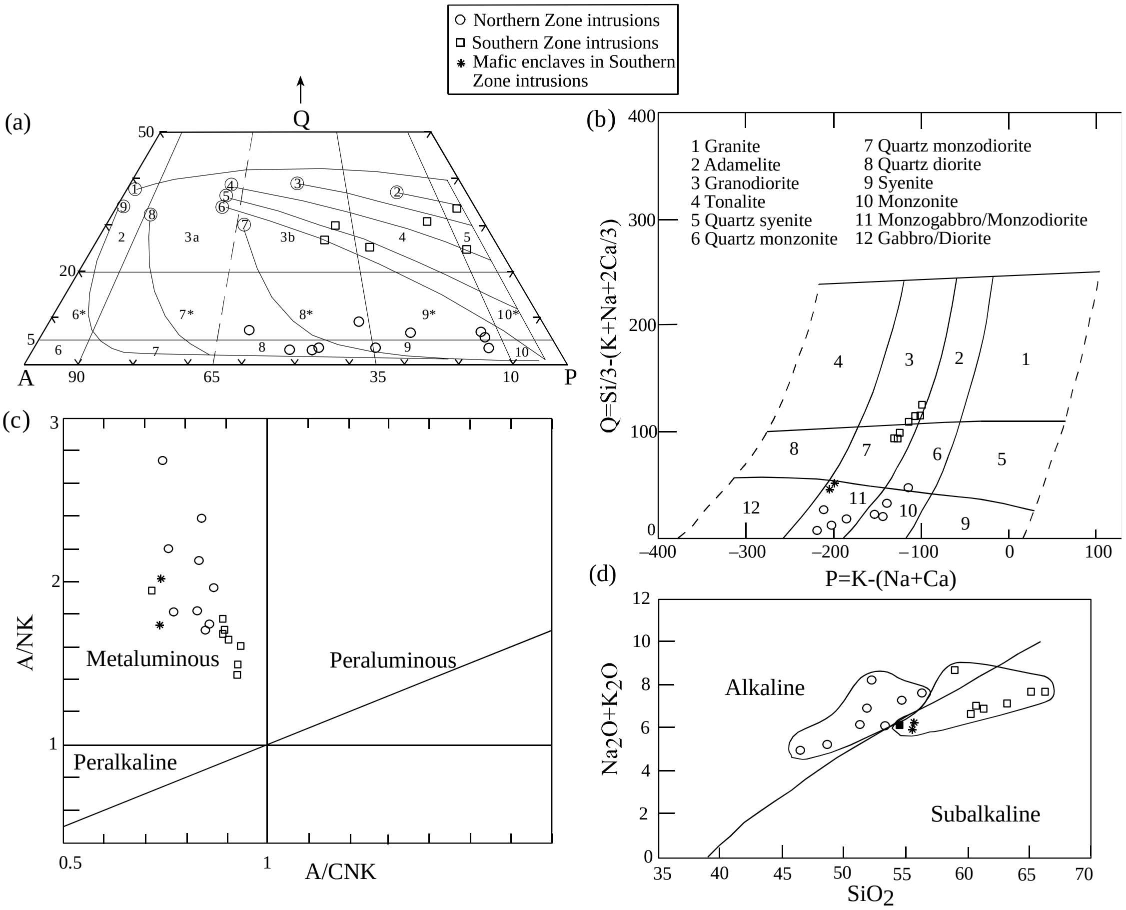

Fig. 6. (a) Main trends of plutonic type series based on QAP modal mineralogy. Trends with circled numbers are 1-tholeiitic series, 2-calc-alkaline trondhjemitic series, 3-6-various calc-alkaline granodiorite series, 7-monzonitic series, 8-9-various alkaline series (Lameyre and Bowden, 1982; Lameyre and Bonin, 1991). Field names with numbers are 2-alkali feldspar granite, 3a-syenogranite, 3b-monzogranite, 4-granodiorite, 5-tonalite, 6*-quartz-alkali feldspar syenite, 7*-quartz syenite, 8*-quartz monzonite, 9*-quartz monzodiorite/quartz monzogabbro, 10*-quartz diorite/quartz gabbro/quartz anorthosite, 6-alkali feldspar syenite, 7-syenite, 8-monzonite, 9-monzodiorite/monzogabbro, 10-diorite/gabbro/anorthosite (after Streckeisen, 1976). (b) Q-P chemical nomenclature diagram (Debon and Le Fort, 1983). (c) A/CNK versus A/NK Shand index diagram (Maniar and Piccolli, 1989). (d) Total alkali versus SiO_2 diagram (Irvine and Baragar, 1971) for the studied intrusions.

1982; Lameyre and Bonin, 1991). In magmatic arcs, the calc-alkaline series trend of intrusive rocks is subdivided into tonalitic-trondjemitic calc-alkaline series, granodioritic calc-alkaline series and monzonitic calc-alkaline series (Lameyre and Bowden, 1982). Based on modal mineralogy, the intrusions of this present study form two main groups (Fig. 6a); the Northern intrusions are monzonite, quartz monzonite, monzodiorite and quartz monzodiorite with a monzonitic series trend whereas the Southern intrusions are monzogranite, granodiorite and tonalite with a calc-alkaline granodiorite series trend.

4.2. Whole-rock composition and classification

Major, trace and rare earth element analyses of representative samples from the Northern and Southern Zone intrusions are given in Tables 2 and 3. The chemical nomenclature of samples based on major oxides of plutonic rocks (Debon and Le Fort, 1983) shows that Northern Zone samples are monzonite, monzodiorite and quartz monzonite whereas Southern Zone samples are quartz-monzodiorite and granodiorite (Fig. 6b). The chemical and mineralogical based classifications of Southern Zone rocks are self-consistent.

The intrusions show slight differences in composition. The rocks have generally metaluminous character, I-type calc-alkaline–transitional in the Southern Zone, and A-type alkaline in the Northern Zone (Fig. 6c and d) as well as having high-K (>3 wt% K_2O). Northern Zone samples have high MgO (3–5 wt%), Sr (500–800 ppm) and Y (22–30 ppm) whereas those of Southern Zone have high Ba (500–1000 ppm) and Zr (150–200 ppm) contents (see Table 2; Fig. 7).

In Harker variation plots (Fig. 7), both Northern and Southern Zone samples exhibit a linear-like trend for most major and some trace elements. The Northern Zone samples lie at the silica-undersaturated end, but the Southern samples lie on the silica-saturated end of this linear trend. In all rocks, Al_2O_3, Fe_2O_3, MgO, CaO and Sr show negative correlations with silica, whereas Na_2O, K_2O and Ba are positively correlated (Fig. 7). These chemical variations

Table 2
Whole-rock major (wt%) and trace element (ppm) ICP analyses of samples from the studied intrusions

	Southern zone samples										Northern zone samples									
	G10	G13	G22A	G23A (MME)	G24	G24A (MME)	G28	G33	G34	G35	S3	S7	S11	S16	S18	S23	S29	S30	S32	S33
SiO_2	62.42	59.00	60.86	55.60	61.28	55.60	60.09	63.27	65.37	64.05	53.49	56.63	51.89	54.45	48.53	52.39	46.68	51.33	51.12	54.39
TiO_2	0.64	0.65	0.66	0.90	0.63	0.83	0.69	0.65	0.58	0.67	0.70	0.78	0.95	0.57	0.86	0.60	1.30	1.03	0.72	0.85
Al_2O_3	15.94	17.11	16.06	16.86	15.83	15.56	16.13	15.47	14.86	15.36	17.67	17.17	18.96	18.78	21.56	20.17	18.17	18.05	19.78	17.67
tFe_2O_3	6.45	6.80	6.94	8.44	6.38	8.68	7.58	6.43	5.32	5.66	8.34	8.14	8.75	6.20	8.93	6.06	11.48	10.33	7.85	8.62
MnO	0.09	0.12	0.09	0.20	0.09	0.14	0.10	0.09	0.06	0.09	0.14	0.21	0.17	0.13	0.18	0.13	0.22	0.24	0.23	0.23
MgO	2.00	3.24	2.23	4.05	2.22	3.80	2.88	2.31	1.67	1.93	5.15	2.64	3.17	3.61	2.73	4.73	4.62	3.19	5.07	3.03
CaO	4.34	3.03	4.67	8.03	4.58	6.67	4.95	3.73	3.09	3.40	6.40	5.58	7.65	6.63	10.24	8.51	9.77	8.61	6.42	7.21
Na_2O	3.49	4.17	3.53	3.47	3.51	3.92	3.41	3.56	3.81	3.75	3.32	3.30	2.81	3.23	2.69	3.49	2.42	2.97	4.49	3.33
K_2O	3.66	4.38	3.39	2.47	3.36	2.27	3.22	3.55	3.81	3.86	3.93	4.30	3.94	3.98	2.41	2.53	2.45	3.06	3.69	3.96
P_2O_5	0.20	0.23	0.20	0.18	0.21	0.33	0.23	0.19	0.17	0.18	0.43	0.23	0.36	0.46	0.47	0.61	0.33	0.45	0.45	0.30
LOI	1.30	1.50	2.00	0.40	1.70	1.70	1.50	1.00	1.80	1.70	1.00	0.90	2.00	1.20	1.90	1.70	3.00	1.30	0.90	0.80
Total	100.53	100.23	100.63	100.60	99.79	99.50	100.78	100.25	100.54	100.65	100.57	99.88	100.65	99.24	100.50	100.92	100.44	100.56	100.72	100.39
Cr	17	14	21	<10	17	12	23	25	11	<10	33	13	12	10	<10	10	<10	<10	10	11
Ni	<10	9	11	29	<10	13	<10	<10	<10	<10	<10	30	28	<10	21	11	30	26	13	32
Cu	12	77	42	41	<10	51	<10	11	<10	11	318	35	23	45	40	87	88	93	55	75
Pb	82	102	65	80	60	65	57	53	39	40	135	126	100	86	87	73	127	104	96	76
Zn	73	110	70	97	61	89	60	53	27	41	67	153	73	70	53	49	72	73	64	66
Rb	120	135	99	64	96	55	91	106	134	120	164	179	129	177	81	100	58	86	121	135
Ba	691	1106	812	509	688	551	869	744	809	1079	315	422	407	456	368	422	287	445	408	397
Sr	281	313	294	392	313	405	322	275	288	255	494	527	577	570	816	684	849	816	588	717
Nb	11	<10	<10	<10	<10	<10	10	<10	12	11	11	<10	10	10	<10	<10	<10	<10	17	10
Zr	187	186	204	153	98	190	202	204	185	100	183	142	156	185	127	143	124	150	152	134
Y	20	21	18	31	25	21	19	24	21	18	27	23	22	27	29	28	20	23	28	22
Th	20	<10	20	<10	<10	25	18	<10	21	15	47	17	12	26	29	29	43	34	36	12
K/Y	1830	2086	1883	797	1344	1081	1695	1479	1814	2144	1456	1870	1791	1474	831	904	1225	1330	1318	1800
K/Rb	305	324	342	386	350	413	354	335	284	322	240	240	305	225	298	253	422	356	305	293
Sr/Y	14	15	16	13	13	19	17	11	14	14	18	23	26	21	28	24	42	35	21	33
Mg#	24	32	24	32	26	30	28	26	24	25	38	24	27	37	23	44	29	24	39	26

MME is mafic microgranular enclave. tFe_2O_3 is total iron as Fe_2O_3. LOI is loss on ignition. Mg# (Mg-number) $= 100 \times MgO/(MgO + tFe_2O_3)$.

Table 3
Whole-rock rare earth element (ppm) ICP-MS analyses of samples from the studied intrusions

	Southern zone samples				Northern zone samples		
	G13	G23A	G24	G33	S7	S11	S33
La	20.70	25.20	28.80	28.80	27.50	29.00	28.50
Ce	44.20	53.90	57.50	57.50	57.50	58.00	57.70
Pr	5.34	6.59	6.66	6.82	6.94	7.20	7.22
Nd	20.50	25.70	24.50	24.10	27.80	28.30	27.70
Sm	3.80	5.80	4.70	4.80	5.40	5.40	5.70
Eu	0.78	1.35	1.08	0.90	1.23	1.32	1.55
Gd	4.81	6.32	5.28	5.34	5.36	5.53	5.68
Tb	0.68	1.11	0.86	0.83	0.84	0.84	0.84
Dy	3.42	5.37	4.16	4.12	4.13	3.80	4.11
Ho	0.74	1.23	0.91	0.95	0.91	0.83	0.83
Er	2.46	3.65	2.72	2.92	2.83	2.68	2.54
Tm	0.34	0.51	0.39	0.38	0.41	0.38	0.35
Yb	2.43	3.40	2.65	2.75	2.71	2.57	2.27
Lu	0.33	0.46	0.38	0.36	0.41	0.38	0.35
La_N/Lu_N	7.16	5.23	7.47	7.47	7.13	7.53	7.39
Eu_N/Eu^*	0.57	0.70	0.67	0.54	0.67	0.72	0.85

$Eu^* = (Sm_N + Gd_N)/2$.

indicate the importance of fractional crystallisation in the magmatic evolution of both zones. The fractionating phases are mainly plagioclase, pyroxene and hornblende. Southern Zone samples are more fractionated. Furthermore, the behaviour of Ba in Southern Zone samples may be related to high-T feldspar fractionation. Fractional crystallization is also indicated by the behaviour of Ba and Zr with respect to K, because Ba and Zr behave incompatibly during crystallisation of magmatic liquid, so they are enriched in late-stage liquids (Fig. 8).

All samples from both zones show a CAFEMIC trend on the mineral diagram of Debon and Le Fort (1983) indicating a hybrid magma source (Fig. 9a). Northern Zone samples have total (Fe + Mg + Ti) higher (> 170) than Southern

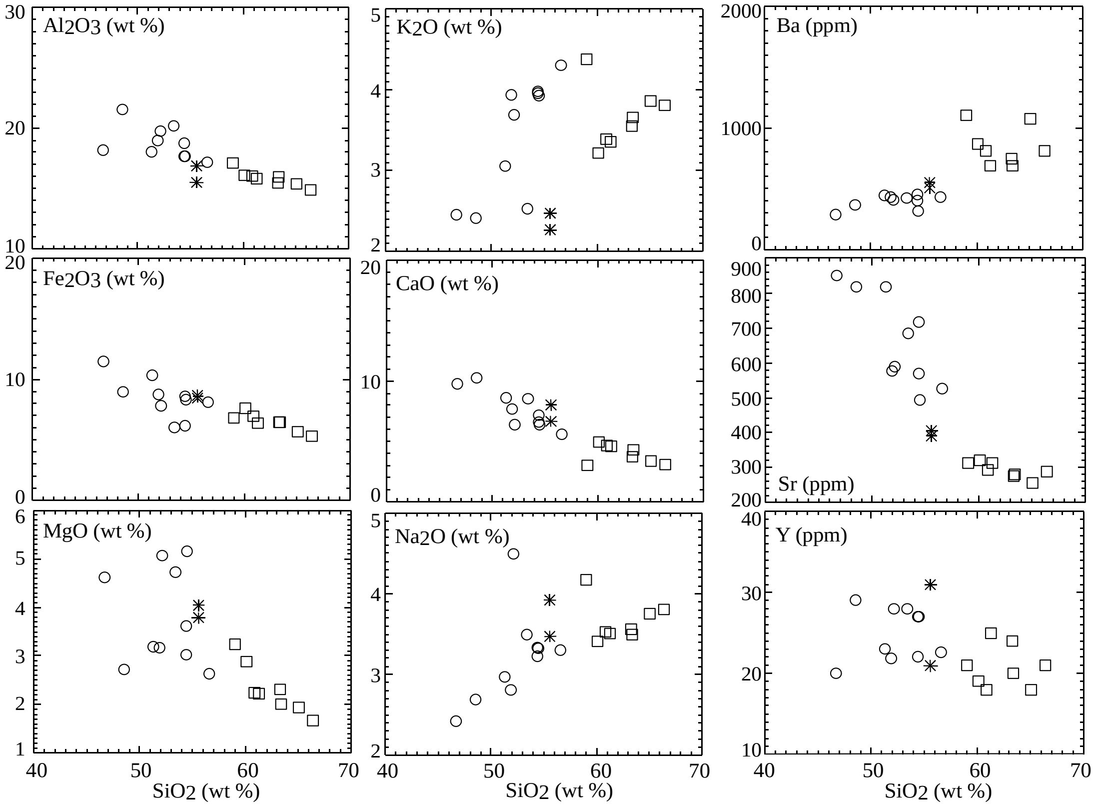

Fig. 7. Selected SiO_2 versus major oxide and trace element plots for the studied intrusions. Symbols are the same as for Fig. 6.

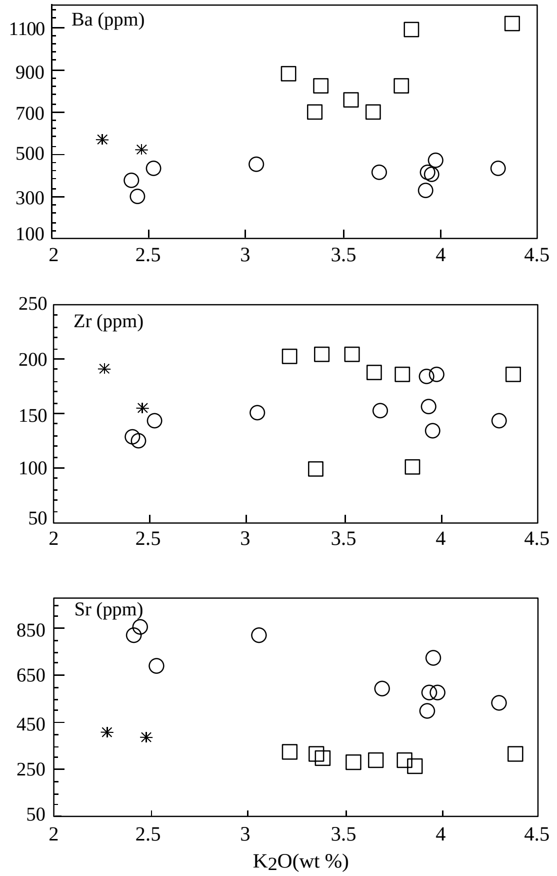

Fig. 8. K_2O versus incompatible Ba, Zr and Sr plots for the studied intrusions. Symbols are the same as for Fig. 6.

Zone samples (<170), and the main magma type is represented by a dark-subalkaline (SALKD) character for the Northern Zone and a calc-alkaline (CALC) character for the Southern Zone on the QBF diagram (Fig. 9b) of Debon and Le Fort (1983).

On the geotectonic discrimination diagram of Batchelor and Bowden (1985) based on the $R1=4Si-11(Na+K)-2(Fe+Ti)$ and $R2=6Ca+2Mg+Al$ parameters (De la Roche et al., 1980), the Southern Zone samples plot in the post-collision uplift field whereas Northern Zone samples fall mainly outside of this field (Fig. 9c), because of higher Al_2O_3, CaO and MgO contents than Southern samples. Using a Rb−Y+Nb trace element tectonic discrimination plot (Pearce et al., 1984), all samples from the studied intrusions fall within the field of volcanic arc granitoids (VAG) (Fig. 9d). However, most of the samples plot close to the triple junction point of VAG, WPG and syn-COLG subfields. As pointed out by Pearce et al. (1984), such a geodynamic setting is typical for post-collisional rocks that are already indicated for Southern samples in the R1–R2 diagram of Batchelor and Bowden (1985).

The chondrite (Sun and McDonough, 1989) normalized REE patterns of both the Northern and Southern Zone samples are similar, having LREE fractionated patterns with $(La/Lu)_N=5$–7 (Fig. 10a). For all samples, negative Eu anomalies are characteristic with more pronounced anomalies in Northern samples, implying that feldspars were either an important phase in the unmelted residue or that they were involved in fractionation. In addition, the Northern Zone rocks seem to be enriched in the LREE and MREE relative to those of the Southern Zone, possibly due to the more mafic and alkaline nature of the Northern Zone intrusions. The rocks also display almost unfractionated HREE abundances (Fig. 10a) with low $(La/Yb)_N$ and $(Tb/Yb)_N$ ratios, and they have low abundances of Y and low ratios of Sr/Y which range from 12–14 in Southern Zone samples to 18–42 in Northern Zone samples. ORG (Pearce et al., 1984) and MORB (Sun and McDonough, 1989) normalised trace element patterns with negative Ba and Nb anomalies, and positive Rb, Th and Ce anomalies (Fig. 10b and c), resemble the collisional and post-collisional granitoids of Pearce et al. (1984). The negative Ba anomalies may indicate feldspar fractionation. The negative Nb anomalies reveal an arc signature in the evolution of the magmas.

Barium readily substitutes for K in feldspar, hornblende and biotite, so that the negative Ba anomaly may be related to high temperature feldspar fractionation rather than hornblende and biotite (Rollinson, 1993). Furthermore, the correlation of Ba with Sr reflects possible fractionation paths of main mineral phases such as plagioclase and hornblende in the granitic suites (Fig. 11). Based on Rayleigh fractionation, calculated fractionation vectors suggest that plagioclase fractionation played a significant role in both Northern and Southern Zone samples. Similarly Zr and Y could have been consumed by some early phases such as zircon and hornblende (Wilson, 1989). All these features could also be related to source characteristics, excluding the involvement of significant quantities of garnet either in the residue during partial melting and final re-equilibration, or as part of the fractionating assemblage in the deep crust. The rocks have low values of Eu_N/Eu^* (0.54–0.85) and Sr/Nd (11–25) and low abundances of Sr, suggesting a significant amount of plagioclase in their residues during magma segregation.

5. Discussion

5.1. Petrogenesis

It is believed by some that Eocene igneous rocks of the Eastern Pontides, NE Turkey, are arc derived (Tokel, 1977; Akın, 1978; Yılmaz, 1981; Ercan and Gedik, 1983; Robinson et al., 1995). Others suggest that they are products of a post-collisional extensional regime. This suggestion is based on structural data which show that subduction had long ceased in this region prior to the Eocene (Şengör and Yılmaz, 1981; Genç and Yılmaz, 1995; Yılmaz and Boztuğ, 1996; Yılmaz et al., 1997; Okay and Şahintürk, 1997; Boztuğ et al., 2001, 2002, 2003, 2004). These rocks do have a subduction signature, which may have been inherited from

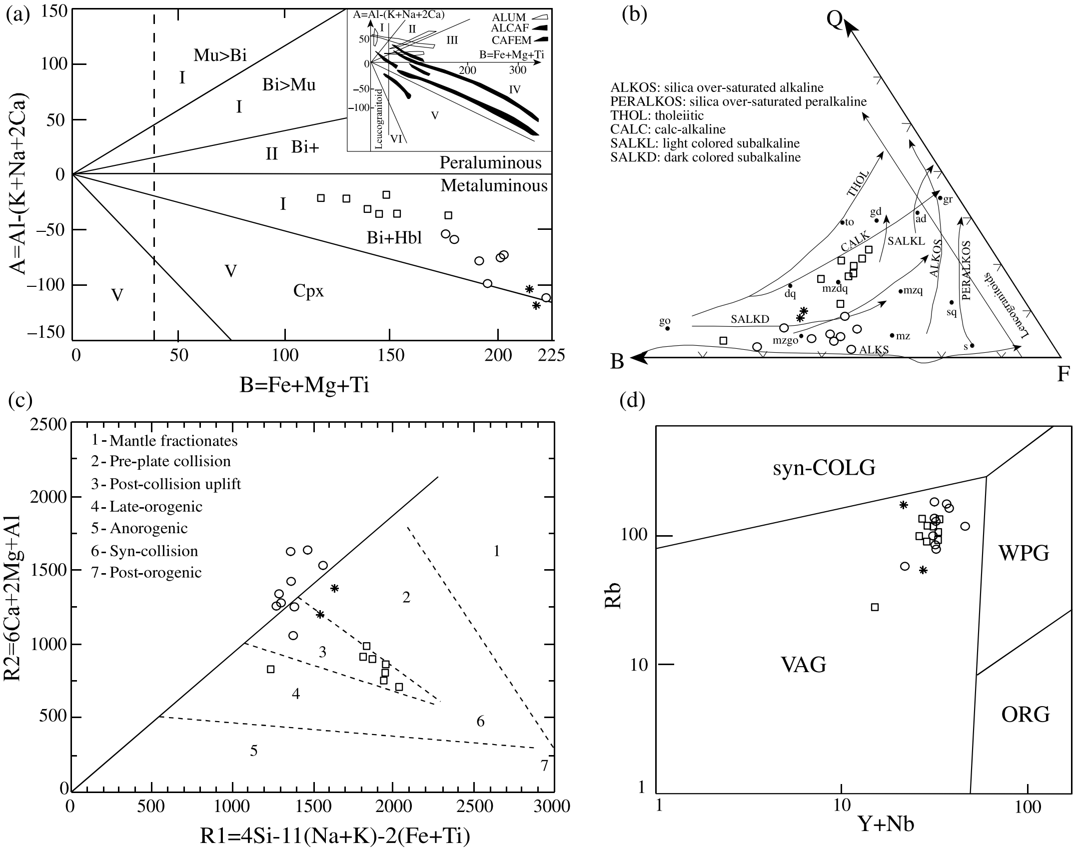

Fig. 9. (a) A-B characteristic mineral plot (Debon and Le Fort, 1983), (b) Q-B-F ternary plot (Debon and Le Fort, 1983), (c) R1–R2 major element plot (Batchelor and Bowden, 1985), (d) Rb-(Y + Nb) tectonic discrimination plot (Pearce et al., 1984) for the studied intrusions. Symbols are the same as for Fig. 6.

a mantle which was previously enriched by subduction-related fluids, possibly during Late Mesozoic subduction (Yılmaz et al., 1997, p. 216). In addition, the timing and mechanism of collision between the Pontides and Anatolide-Tauride basement along the İzmir-Ankara-Erzincan (IAE) Suture Zone suggests that a post-collisional extensional tectonic regime was extensive in NE Turkey, which in turn may have accelerated the opening of the Eastern Black Sea Basin during the Middle Eocene (Okay et al., 1994; Okay and Şahintürk, 1997; Kazmin et al., 2000; Yılmaz et al., 2000; Boztuğ et al., 2004).

In the Northern Zone, the studied intrusions crosscut Eocene and younger alkaline volcanic rocks, and in the Southern Zone they cut Eocene and younger calc-alkaline volcanic rocks. Northern Zone plutons are elongated NW–SE whereas those in the Southern Zone extend in a near E–W direction (see Fig. 2). These directions conform with two main fracture directions in the Eastern Pontides as defined by Bektaş and Çapkınoğlu (1997), suggesting a role for fractures during pluton emplacement. However, the intrusions examined in this study exhibit features of structurally undisturbed country rocks and thermal aureole with epidotization at the exocontact, sharp intrusive contacts and abundant country rock xenoliths at the endocontact, suggesting a stopping type of ascent and diaparic emplacement style.

The intrusions have textures that may indicate significant magma mixing and mingling processes. The MMEs may represent mingling of coeval mafic and felsic magmas (e.g Didier, 1973; Vernon, 1990; Didier and Barbarin, 1991; Barbarin and Didier, 1992). Interaction (or hybridization) between mafic (enclave) and surrounding felsic (granitic) magma is also clearly viewed in the host rocks between close enclaves, where biotite crystals develop so as to define lineaments as a result of reaction with the host granitic magma. Furthermore, Hibbard (1991) suggested that chemical and mechanical exchanges produce compositions closer to quartz diorite by hybridisation of MMEs, possibly prior to the mafic magma batch dispersion by magma flow, producing the MMEs. The angular shape of MMEs is probably due to the fact that they were not transported far.

The variation of large ion lithophile elements, especially Ba, in the studied intrusions reveals magma mixing processes in the genesis of the rocks. On the K_2O versus Ba and Zr plots (see Fig. 8), Southern Zone and Northern Zone samples follow distinct trends but enclave samples lie almost at the intersection of these trends. Therefore, Northern Zone intrusions, poor in Ba and Zr, may have evolved without mixing/mingling but the Southern Zone intrusions fractionated with mixing/mingling of a more mafic magma until their Ba contents reached higher levels.

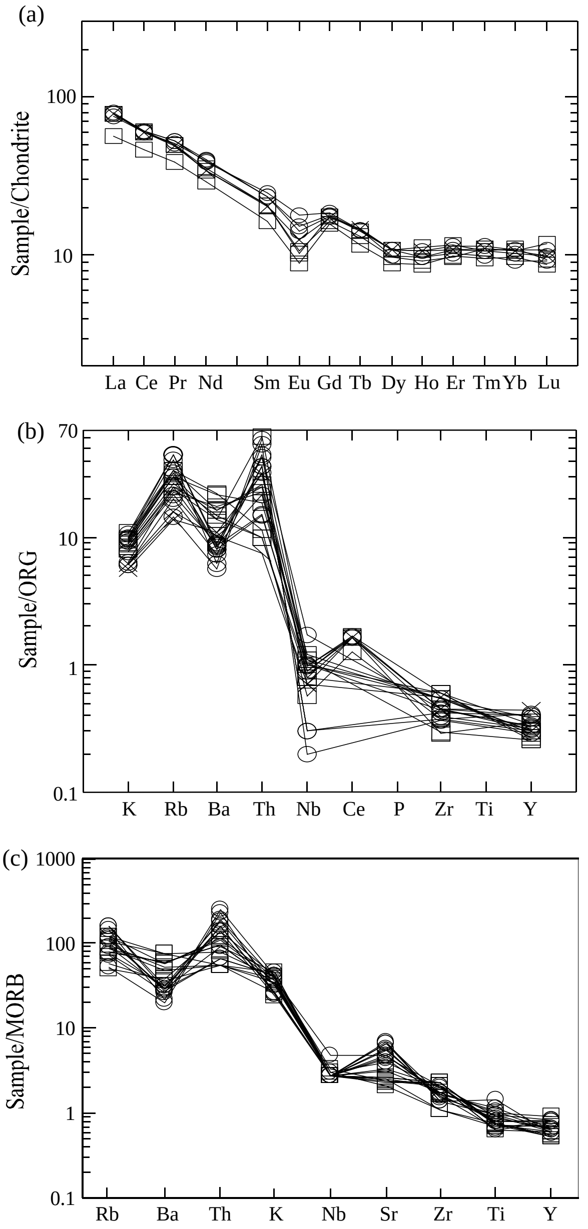

Fig. 10. (a) Chondrite (Sun and McDonough, 1989) normalised rare earth element plot, (b) Ocean Ridge Granite (ORG) (Pearce et al., 1984) normalised trace element plot, (c) Mid-Ocean Ridge Basalt (MORB) (Sun and McDonough, 1989) normalised trace element plot for the studied intrusions. Symbols are the same as for Fig. 6.

In almost all diagrams, the enclave samples lie on a similar trend with their hosts, implying a genetic link with the Southern Zone intrusions.

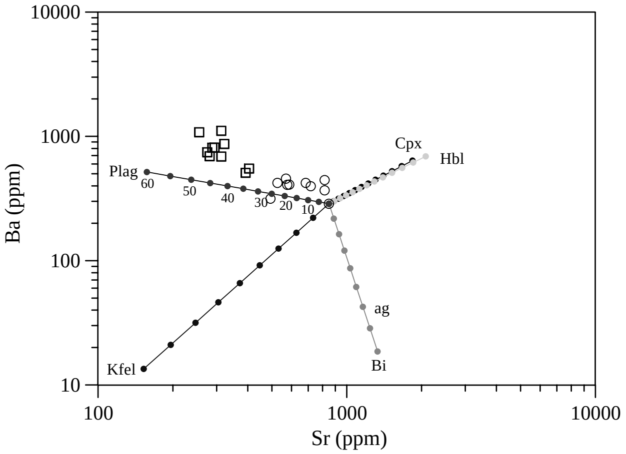

Fig. 11. Possible fractionation paths of main mineral phases in the studied granitic suites. Fractionation paths were calculated according to Rayleigh fractionation. K_d values are from Rollinson (1993). Symbols are the same as for Fig. 6.

In this region of Turkey there are very few isotopic age constraints. The age of the volcanic country rocks is thought, however, to range from Eocene to Late Miocene (e.g. Arslan et al., 2000a); ages of the intrusions of both the Northern and Southern Zones, which cut the volcanic country rocks, are younger than at least Late Eocene and possibly much younger. U–Pb dating of zircon mineral separates from the Kaletaş granitic stock of the Southern Zone gave an intrusion age of 44.4 ± 0.3 Ma. (Fig. 12), providing an upper age constraint for the emplacement of this stock. This age cannot be compared with Northern Zone stocks because there are no available age data for them. Moreover, U–Pb ages on titanite and zircon from the Northern Zone volcanic country rocks indicate that volcanism continued into the Miocene (Arslan et al., 2001). These may reflect differential crustal responses to thickening across the Eastern Pontides prior to and after cessation of subduction (Arslan et al., 2001).

The monzonitic (in the Northern Zone) and granodioritic (in the Southern Zone) intrusive suites investigated are related to variations in the processes which generate magmas and modify the compositions of primary magmas. In the presence of enough water in a partial melting zone of the upper mantle or lower crust, partial melting produces calc-alkaline and hybrid magmas whereas water deficiency and low-degrees of partial melting of an upper mantle source produces primary alkaline magmas (Bonin, 1990).

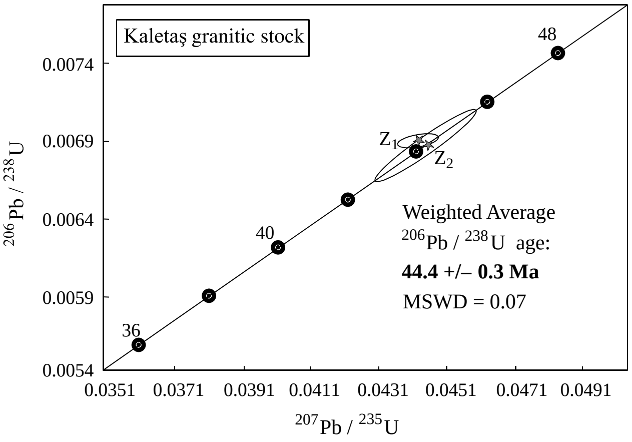

Fig. 12. ^{207}Pb/^{235}U versus ^{206}Pb/^{238}U plot for zircon of the Kaletaş granitic stock (sample G24), the Southern Zone.

As such, diversification between the Northern and Southern intrusions of the Eastern Pontides may be related to H_2O deficiency in the magma chambers during solidification. In this situation, the silica oversaturated calc-alkaline trend in the Southern Zone intrusions can be induced by hornblende fractionation whereas the silica-undersaturated alkaline trend in Northern Zone intrusions can be formed under solidification conditions in which there was insufficient water activity.

Major, trace and rare earth element variations between the intrusions indicate the importance of differentiation (via fractional crystallisation and magma mixing and mingling) in the evolution of these rocks. Incompatible and rare earth element patterns indicate that both the Northern and Southern Zone intrusions in the Eastern Pontides were derived from similar sources but evolved differently at shallower levels. Crustal involvement may have been important, especially in the evolution of the Southern Zone intrusions.

5.2. Tectonic implications

The studied intrusions may represent post-collisional, extensional-related Eocene igneous activity. This style of activity has been previously recognized in the Eastern Pontides (Şengör and Yılmaz, 1981; Genç and Yılmaz, 1995; Yılmaz and Boztuğ, 1996; Yılmaz et al., 1997; Okay and Şahintürk, 1997; Boztuğ et al., 2001, 2002, 2003, 2004). Whole-rock trace element patterns of the studied granitic rocks indicate that they are post-collisional extensional intrusions that were derived from a subduction-inherited and enriched mantle source. Given this, an absolute age determination for these rocks may give a minimum age for the Eocene volcanic episode. These granitic intrusions may be differentiates of the mafic rocks they crosscut, or may be unrelated. If they are unrelated, they might indicate crustal melting due to advective heating of the crust by deep-seated magma chambers (that would have generated widespread volcanism in both Northern and Southern Zones) and, therefore, provide evidence of long-term magmatic activity in the Eastern Pontide region after cessation of subduction and crustal thickening. The Eocene volcanic rocks surrounding the intrusions and present in other areas in the region, reveal an arc origin in their composition (Tokel, 1977; Akın, 1978; Yılmaz, 1981; Ercan and Gedik, 1983; Robinson et al., 1995; Arslan et al., 1997; Arslan and Aliyazıoğlu, 2001). However, the structural evidence indicates that subduction had long ceased in this region by Eocene time (Şengör and Yılmaz, 1981; Genç and Yılmaz, 1995; Yılmaz et al., 1997; Okay and Şahintürk, 1997; Boztuğ et al., 2004). The Eocene volcanic rocks and intrusions are therefore not related to subduction, but rather are products of ongoing extension. As to the arc geochemical signature, Yılmaz et al. (1997) suggest that it could be inherited from a mantle source which was previously enriched by subduction fluids, possibly during a Late Mesozoic subduction event. Furthermore, recent studies in the Eastern Pontides suggest that the Middle Eocene volcanic rocks are part of a different volcano-sedimentary episode related to regional extension (Yılmaz and Boztuğ, 1996; Arslan and Aliyazıoğlu, 2001; Boztuğ et al., 2001, 2002, 2004, 2005).

6. Conclusions

The studied Eastern Pontide Eocene intrusions in NE Turkey include monzonite, quartz monzonite, monzodiorite and quartz monzodiorite in the Northern Zone, and monzogranite and granodiorite in the Southern Zone. The plutons have textures that indicate significant magma mixing and mingling processes. Poikilitic, rapakivi, anti-rapakivi textures and oscillatory zoned plagioclase and hornblende-biotite intergrowths possibly record the mixing of coexisting mafic and felsic magmas. Mafic microgranular enclaves indicate the interaction between mafic and felsic magmas in the evolution of the studied intrusions.

The whole-rock geochemistry of the intrusions yields imprints of a volcanic arc along with post-collisional extensional granitoids. The field and geochemical-mineralogical studies show that the hybrid magma source of the granodioritic-monzonitic association was derived from mixing between coexisting felsic and mafic magmas. On the other hand, fractional crystallisation processes operated during solidification of this hybrid magma.

The Northern Zone intrusions form a post-collisional, A-type, alkaline monzonitic association while the Southern Zone intrusions form a post-collisional, I-type, granodioritic calc-alkaline-transitional association. U–Pb dating of zircon from the Kaletaş granitic stock of the Southern Zone yields an intrusion age of 44.4 ± 0.3 Ma. The data presented here support a post-collisional, extensional tectonic framework in the Eocene for the Eastern Pontides.

Acknowledgements

This study has been supported in part by Karadeniz Technical University Scientific Research Fund (Project No: 98.112.005.2). Authors thank staff at ACME Analytical Laboratories Ltd (Canada) for compositional data and Dr Richard Reesman at Geochron Laboratories and MIT Geochronology Laboratory, Massachusetts (USA) for zircon U–Pb isotopic data, and Prof. K. Burke and J. Lytwyn for their editorial helps. Constructive comments and helpful suggestions from Prof. Dr D. Boztuğ and Dr P.W.O. Hoskin are greatly appreciated.

References

Adamia, S.A., Lordkipanidze, M.B., Zakariadze, G.S., 1977. Evolution of an active continental margin as exemplified by the Alpine history of the Caucasus. Tectonophysics 40, 183–199.

Ağar, U., 1977. Demirözü (Bayburt) ve Köse (Kelkit) bölgesinin jeolojisi. PhD Thesis, İstanbul University, İstanbul, 59p.

Akın, H., 1978. Geologie, Magmatismus und Lager-staettenbidung im ostpontischen Gebirge-Turkei aus der Sicht der Plattentektonik. Geologische Rundschau 68, 253–283.

Akıncı, Ö.T., 1984. The Eastern Pontide volcano-sedimentary belt and associated massive sulphide deposits. In: Dixon, J.E., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean Geological Society of London Special Publication 17, pp. 415–428.

Arslan, M., Aliyazıoğlu, İ., 2001. Geochemical and petrochemical characteristics of the Kale (Gümüşhane) volcanic rocks: implications for the Eocene evolution of Eastern Pontide arc volcanism, Northeast Turkey. International Geology Review 43 (7), 595–610.

Arslan, M., Tüysüz, N., Korkmaz, S., Kurt, H., 1997. Geochemistry and petrogenesis of the eastern Pontide volcanic rocks, Northeast Turkey. Chemie Der Erde, Geochemistry 57, 157–187.

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, p. 124.

Arslan, M., Aslan, Z., Şen, C., Hoskin, P.W.O., 2000a. Constraints on petrology and petrogenesis of Tertiary volcanism in the Eastern Pontide paleo-arc system, NE Turkey. 10th V.M. Goldschmidt Conference. Journal of Conference Abstracts 5 (2), 157–158.

Arslan, M., Şen, C., Aliyazıcıoğlu, İ., Kaygusuz, A., Aslan, Z., 2000b. Trabzon ve Gümüşhane yörelerinde (KD, Türkiye) yüzeylenen Eosen (?) volkanitlerinin karşılaştırmalı jeolojisi, mineralojisi ve petrolojisi. Yerbilimleri ve Madencilik Kongresi Bildiriler Kitabı I, 39–53.

Arslan, M., Hoskin, P.W.O., Aslan, Z., 2001. Continental crust formation and thermal consequences of Cenozoic thickening of the Eastern Pontides Tectonic unit: preliminary temporal constraints and implications, Fourth International Turkish Geology Symposium Abstracts, Adana, Turkey 2001 p. 121.

Arslan, M., Temizel, İ., Abdioğlu, E., 2002. Subduction input versus source enrichment and role of crustal thickening in the generation of Tertiary magmatism in the Pontid Paleo-Arc setting, NE Turkey. In: De Vivo, B., Bodgar, R.J. (Eds.), Workshop-Short Course on Volcanic Systems, Geochemical and Geophysical Monitoring, Melt Inclusions: Methods, Applications and Problems, Napoli, Italy, pp. 13–16.

Arslan, M., Kolaylı, H., Temizel, İ., 2004. Petrographical, geochemical and petrological characteristics of the Güre (Giresun, NE Turkey) Granitoid. Bulletin of Earth Sciences Application and Research Centre of Hacettepe University 30, 1–21.

Aslan, Z., Aslaner, M., 1998. Evidence of magma mixing and hybrid source on calc-alkaline Sarıhan (Bayburt) Granitoid, NE Turkey. Mineralogical Magazine 62A 1–3, 79–80.

Aslan, Z., Arslan, M., Şen, C., 1999. Comparative geological, petrographical and geochemical features of Eocene aged granitic intrusives in the Northern and Southern Zones of the Eastern Pontides, Proceedings of the 52nd Geological Congress of Turkey 1999 pp. 223–230.

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.

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

Bektaş, O., Çapkınoğlu, Ş., 1997. Doğu Pontid magmatik arkında (KD Türkiye) neptüniyen dayklar ve blok tektoniği, Mesozoyik havzaların kinematiği ile ilgili bulgular. ÇÜ 20.Yıl Sempozyumu, Adana, Bildiri Özleri, pp. 187–189.

Bektaş, O., Yılmaz, C., Taslı, K., Akdağ, K., Özgür, S., 1995. Cretaceous rifting of the eastern Pontides carbonate platform (NE Turkey): the formation of the carbonate breccias and turbidites as evidence of a drowned platform. Giornale di Geologia 57, 233–244.

Bergougnan, H., 1987. Etudes ge'ologiques dans l'est Anatolien. These de Doctorat D'Etat, Academie de Paris Univ. Pierre et Marie Curie, Me'm. des Sci. de la Terre. 606 pp.

Bonin, B., 1990. From orogenic to anorogenic settings: evolution of granitoid suites after a major orogenesis. Geological Journal 25, 261–270.

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

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

Boztuğ, D., Kuşçu, İ., Erçin, A.İ., Avcı, N., Şahin, S.Y., 2003. Mineral deposits associated with the pre-, syn- and postcollisional granitoids of the Neo-Tethyan convergence system between the Eurasian and Anatolian plates in NE and Central Turkey. In: Eliopoulops, D. et al. (Ed.), Mineral Exploration and Sustainable Development. Millpress, Rotterdam, pp. 1141–1144.

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.

Boztuğ, D., Erçin, A.İ., Kuruçelik, M.K., Göç, D., Kömür, İ., İskenderoğlu, A., 2005. Main geochemical characteristics of the composite Kaçkar batholith derived from the subduction through collision to extensional stages of the Neo-Tethyan convergence system in the Eastern Pontides, Turkey. Journal of Asian Earth Sciences 2005; in review.

Çamur, M.Z., Güven, İ.H., Er, M., 1996. Geochemical characteristics of the Eastern Pontide volcanics: an example of multiple volcanic episodes in arc evolution. Turkish Journal of Earth Science 5, 123–144.

Çoğulu, E., 1975. Petrologic and Geochronologic Studies in the Gümüşhane-Rize region, İstanbul Technical University Publication 1034 1975. 112p..

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

Delaloye, M., Çoğulu, E., Chessex, R., 1972. Etude ge'ochronometrique des massifs cristallins de Rize et de Gümüşhane, Pontides Orientales (Turquie), CR des Sciences, vol. 7/2–3. SPHN, Geneve pp. 43–52.

De la Roche, H., Letterier, J., Grandclaude, P., Marchal, M., 1980. A classification of volcanic rocks using R1–R2 diagram and major element analyses. Its relationships with current nomenclature. Chemical Geology 29, 183–210.

Didier, J., 1973. Granites and their Enclaves. Elsevier, London. 393p.

Didier, J., Barbarin, B., 1991. The different types of enclaves in granites—nomenclature. In: Didier, J., Barbarin, B. (Eds.), Enclaves and Granite Petrology, Developments in Petrology, vol. 13. Elseiver, Amsterdam, pp. 19–24.

Eğin, D., Hirst, D.M., Phillips, R., 1979. The petrology and geochemistry of volcanic rocks from the northern Harşit river area, Pontide volcanic province, northeast Turkey. Journal of Volcanology and Geothermal Research 6, 105–123.

Ercan, T., Gedik, A., 1983. Pontidlerdeki volkanizma. Jeoloji Mühendisliği 18, 3–22.

Fernandez, A.N., Barbarin, B., 1991. Relative rheology of coeval mafic and felsic magmas. In: Didier, J., Barbarin, B. (Eds.), Enclaves and Granite Petrology Developments in Petrology, vol. 13. Elsevier, Amsterdam, pp. 263–275.

Frost, T.P., Mahood, G.A., 1987. Field, chemical, and physical constraints on mafic—felsic magma interaction in the Lamarck Granodiorite, Sierra Nevada, California. Geological Society of America Bulletin 99, 272–291.

Gedikoğlu, A., 1979. Harşit (Giresun–Doğankent) granit karmaşığının jeokronolojik etüdü. Türkiye Jeoloji Bilimsel ve Teknik Kurultayı Bildiri Özleri Kitabı 33, 59–60.

Genç, Ş.C., Yılmaz, Y., 1995. Postcollisional Eocene magmatic activity of NW Anatolia: EUG VII, Strasbourg, Terra Abstracts, Terra Nova, vol. 7 1995 p. 181.

Giles, D.L., 1974. Geology and mineralization of the Ulutaş copper–molybdenum prospect, mineral exploration in two areas. UNDP Technical Report, 6, MTA, Ankara (unpublished).

Güven, İ.H., 1993. 1/250 000 scaled geological and metallogenical map of the Eastern Black Sea Region. General Directorate of Mineral Research and Exploration, Ankara (unpublished).

Hibbard, M.J., 1991. Textural anatomy of twelve magma-mixed granitoid systems. In: Didier, J., Barbarin, B. (Eds.), Enclaves and Granite Petrology. Elsevier, Amsterdam, pp. 431–444.

Hibbard, M.J., 1995. Petrography to petrogenesis. Prentice Hall, New Jersey p. 587.

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

JICA, 1986. The Republic of Turkey report on the cooperative mineral exploration of Gümüşhane area, consolidated report. Japanese International Cooperation Agency, Metal Mining Agency of Japan.

Kalkancı, Ş., 1974. Etude ge'ologique et pe'trochimique de sud de la region de Suşehri: ge'ochronologie du massif syenitique de Kösedağ (NE de Sivas-Turquie). These Doctorate 3 eme cycle, Univ. de Grenoble. 135 pp. (unpublished).

Kamitani, M., Akıncı, Ö., 1979. Alpine granitoids and related tungsten-molybdenum deposits in Turkey. Mining Geology 29, 341–350.

Kaygusuz, 2000. Torul ve çevresinde yüzeyleyen kayaçların petrografik ve jeokimyasal incelenmesi. PhD Thesis Karadeniz Techical University, Trabzon, 250p. (unpublished).

Kazmin, V.G., Sbortshikov, I.M., Ricou, L.E., Zonenshain, L.P., Boulin, J., Knipper, A.L., 1986. Volcanic belts as markers of the Mesozoic–Cenozoic evolution of Tethys. Tectonophysics 123, 123–152.

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

Ketin, İ., 1966. Anadolu'nun Tektonik Birlikleri: Maden Tetkik ve Arama Dergisi 66, 23–34.

Korkmaz, S., Tüysüz, N., Er, M., Musaoğlu, A., Keskin, İ., 1995. Stratigraphy of the eastern Pontides NE Turkey. In: Erler, A., Ercan, T., Bingöl, E., Örçen, S. (Eds.), Geology of the Black Sea Region. General Directorate of Mineral Research and Exploration, and Chamber of Geological Engineers, Ankara, pp. 59–69.

Lameyre, J., Bonin, B., 1991. Granites in the main plutonic series. In: Didier, J., Barbarin, B. (Eds.), Enclaves and Granite Petrology Developments in Petrology, vol. 13. Elsevier, Amsterdam, pp. 3–17.

Lameyre, J., Bowden, P., 1982. Plutonic rock type series: discrimination of various granitoids series and related rocks. Journal of Volcanology and Geothermal Research 14, 169–186.

Maniar, P.D., Piccolli, P.M., 1989. Tectonic discrimination of granitoids. Geological Society of America Bulletin 101, 635–643.

Moor, W.J., Mckee, E.H., Akıncı, Ö., 1980. Chemistry and chronology of plutonic rocks in the Pontid mountains, northern Turkey. Symposium of European Copper Deposits, Belgrade 1980;, 209–216.

Okay, A.İ., Şahintürk, 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, pp. 291–311.

Okay, A.İ., Şengör, A.M.C., Görür, N., 1994. Kinematic history of the opening of the Black Sea and its effect on the surrounding regions. Geology 22, 267–270.

Özsayar, T., Pelin, S., Gedikoğlu, A., 1981. Doğu Pontidler'de Kretase. KTÜ Yer Bilimleri Dergisi 1, 65–114.

Pearce, J.A., Harris, N.B.W., Tindle, A.G.W., 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. Journal of Petrology 25, 956–983.

Robinson, A.G., Banks, C.J., Rutherford, M.M., Hirst, J.P.P., 1995. Stratigraphic and structural development of the Eastern Pontides, Turkey. Journal of Geological Society London 152, 861–872.

Rollinson, H.R., 1993. Using Geochemical Data: Evaluation, Presentation, Interpretation. Longman, New York. 352p.

Salonsaari, P.T., 1995. Hybridization in the subvolcanic Jaala–Iitti complex and its petrogenetic relation to rapakivi granites and associated mafic rocks of southeastern Finland. Geological Society of Finland Bulletin 67 (1b), 104.

Şen, C., 1987. Dağbaşı (Trabzon) Bölgesinde yüzeylenen Alt Bazik (Jura)-Granitoyid (Üst Kretase) formasyonlarının petrografik-kimyasal özellikleri. M.Sc. Thesis, KTÜ Fen Bilimleri Enstitüsü, Trabzon, 80s.

Şen, C., Arslan, M., Van, A., 1998. Geochemical and petrological characteristics of the Pontide Eocene (?) Alkaline Volcanic Province, NE Turkey. Turkish Journal of Earth Science 7–3, 231–239.

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

Streckeisen, A.L., 1976. To each plutonic rock its proper name. Earth Science Reviews 12, 1–33.

Sun, S.S., McDonough, W.F., 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In: Saunders, A.D., Norry, M.J. (Eds.), Magmatism in Ocean Basins Geological Society of London Special Publication 42, pp. 313–345.

Taner, M.F., 1977. Etuda géologique et pétrographique de la région de Güneyce-İkizdere, située au sud de Rize (Pontides orientales, Turquie). PhD Thesis, Universite de Geneve, 180p. (unpublished).

Terashima, S., Taner, M.F., Yajima, J., Ishihara, S., 1988. Geochemistry of the Pontides granitoids in Turkey. Bulletin of the Geological Survey of Japan 39 (4), 251–268.

Tokel, S., 1977. Eocene calc-alkaline andesites and geotectonism in the Eastern Black Sea region (in Turkish). Türkiye Jeoloji Kurumu Bülteni 20, 49–54.

Topuz, G., 2002. Retrograde P–T path of anatectic migmatites from the Pulur Massif, Eastern Pontides, NE Turkey: petrological and microtextural constraints, First International Symposium of the Faculty of Mines (İTÜ) on Earth Sciences and Engineering Abstracts, Istanbul, Turkey 2002 p. 110.

Topuz, G., Altherr, R., Satır, M., Schwarz, W., 2001. Age and metamorphic conditions of low-grade metamorphism in the Pulur Massif, NE Turkey, Fourth International Turkish Geology Symposium Abstracts, Adana, Turkey 2001 p. 215.

Vernon, R.H., 1990. Crystallization and hybridism in microgranitoid enclave magmas: microstructural evidence. Journal of Geophysical Research 95, 17849–17859.

Wilson, M., 1989. Igneous Petrogenesis. Unwin Hyman, London. 456p.

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.

Yılmaz, Y., 1972. Petrology and structure of the Gümüşhane granite and surrounding rocks, North-eastern Anatolia. PhD Thesis, University of London, 260p.

Yılmaz, İ., 1977. Çaykara granitlerinin petrojenetik ve jeokronometrik etüdü. Tübitak Doğa Bilim Dergisi 8, 29–35.

Yılmaz, Y., 1981. Sakarya kıtası güney kenarının tektonik evrimi. İstanbul Yerbilimleri 1 (1–2), 33–52.

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

Yılmaz, C., Korkmaz S., 1999. Basin development in the eastern Pontides, Jurassic to Cretaceous, NE Turkey. Zentralblatt für Geologie und Paläontologie, Teil I, 10–12, 1485–1494.

Yılmaz, Y., Tüysüz, O., Yiğitbaş, E., Genç, Ş.C., Şengör, A.M.C., 1997. Geology and tectonic evolution of the Pontides. In: Robinson, A.G. (Ed.), Regional and Petroleum Geology of the Black Sea and Surrounding Region AAPG Memoir 68, pp. 183–226.

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