Stratigraphy and Geochemical Features of the Early Miocene Bimodal (Ultrapotassic and Calc-alkaline) Volcanic Activity Within the NE-trending Selendi Basin, Western Anatolia, Turkey

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Abstract: Western Anatolia has experienced thickening and orogenic collapse subsequent to the Eocene continent-arc collision. The early stage of the post-collisional volcanism in the region was thought to have produced widespread lavas and pyroclastic deposits of calc-alkaline basaltic andesite to rhyolite composition. However, in the Selendi Basin, one of the NE-trending basins in western Anatolia, there are two distinct volcanic unit compositions associated with the Lower Miocene sedimentary rocks: (1) a calc-alkaline, high-potassic felsic unit; and (2) alkaline, ultrapotassic lamproitic units, i.e. both are bimodal in character. The calc-alkaline felsic volcanic rocks (Eğretiltidağ volcanic unit) are composed of wide-spread pyroclastic rocks and lava flows, whilst the ultrapotassic-lamproitic mafic rocks (Kuzayır lamproite) consist of small-volume syn-sedimentary lava flows. The geochemical characteristics of the Kuzayır lamproite are similar to those of the 'Mediterranean lamproites' that were widely produced in post-orogenic tectonic settings. A temporal and spatial association between these volcanic units clearly describes a post orogenic bimodal volcanic activity. The data also imply that the continental extensional tectonic regime in western Anatolia began, at least, in the Early Miocene, and produced not only calc-alkaline felsic activity but also mantle-derived alkaline, ultrapotassic volcanic rocks.

Key Words: Western Anatolia, lamproite, ultrapotassic volcanism, bimodal volcanism, continental extension

Introduction

Western Anatolia, the eastern part of the Aegean extensional province has experienced an intense crustal extension since the latest Oligocene–Early Miocene (e.g., Seyitoğlu & Scott 1991; Seyitoğlu et al. 2002; Sözbilir 2001, 2002; Westaway 2003; Bozkurt & Sözbilir 2004; Purvis & Robertson 2005; Purvis et al. 2005; Westaway et al. 2005; Koçyiğit 2005; Bozkurt & Mittwede 2005).
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This crustal extension is responsible for the formation of core-complexes (e.g., Menderes core complex; Bozkurt & Park 1994; Hetzel et al. 1995; Lips et al. 2001; Gessner et al. 2001; Ring et al. 2003; İşık et al. 2004; Sözbilir 2005; Bozkurt & Rojay 2005; Rojay et al. 2005; Thomson & Ring 2006; Kazdağ Core Complex; Okay & Sätir 2000), detachment faults (Emre 1996; Hetzel et al. 1995; Koçyiğit et al. 1999); NE–SW- and E–W-trending sedimentary basins (Helvacı & Yağmurlu 1995; Seyitoğlu & Scott 1991; Yılmaz et al. 2000; Bozkurt 2003; Purvis & Robertson 2004, 2005) and associated widespread volcanism (Yılmaz 1989, 1990; Seyitoğlu & Scott 1992; Aldanmaz et al. 2000; Yılmaz et al. 2001; Akal 2003; Akay & Erdoğan 2004; Erkül et al. 2005a, b, 2006; Yücel-Öztürk et al. 2005; Aldanmaz 2006; Figure 1). The volcanic products in the region, from Late Oligocene to Quaternary, can be divided into two groups, based on their chemical composition: (1) latest Oligocene to Middle Miocene calc-alkaline, and (2) Late Miocene to Quaternary sodic alkaline basaltic group (Yılmaz 1989, 1990; Güleş 1991; Seyitoğlu & Scott 1992; Seyitoğlu et al. 1997; Ercan et al. 1997; Floyd et al. 1998; Yılmaz et al. 2000, 2001; Aldanmaz et al. 2000; Alıcı et al. 2002; Innocenti et al. 2005; Erkül et al. 2005a, b, 2006; Aldanmaz 2006; Figures 1 & 2). Magmatic rocks of the first group are generally rhyolite to basaltic andesite in composition and exhibit calc-alkaline affinity with shoshonitic, high-potassic characters that chemically characterize derivation from multiply-enriched-mantle lithosphere with variable contamination by materials from continental crust. The chemical signatures of the volcanic rocks in this group exhibit great similarities to those produced along convergent plate margins and are characterized by enrichments in LILE (relative to HFSE; Ta, Nb negative anomalies) and high Sr and low Nd isotope ratios (Yılmaz 1989, 1990; Güleş 1991; Aldanmaz et al. 2000; Aldanmaz 2006). The Late Miocene–Early Pliocene volcanic products of the region are more basic in composition and exhibit alkaline character (Güleş 1991; Aldanmaz et al. 2000; Alıcı et al. 2002; Aldanmaz 2006). The geochemical characteristics of these rocks are similar to those of the OIB magmas with low Sr and high Nd isotope ratios (e.g., McKenzie & O’Nions 1995).

A temporal transition from mainly calc-alkaline to alkaline volcanic activity of the region has generally been accepted to be related to a compressional tectonic regime, followed subsequently by an extensional tectonic regime. Yılmaz (1989, 1990) suggested that the latest Oligocene–Early Miocene calc-alkaline products were related to A-type subduction, i.e. compressional tectonic regime. According to this view felsic products were yielded from a metasomatised mantle source and subsequently were contaminated by crustal materials. This view is also supported by later geochemical/isotopic studies (e.g., Güleş 1991). It is also proposed that the subsequent Late Miocene–Pliocene alkaline volcanic activity was associated with an extensional tectonic regime, after a short time span in the Middle Miocene, on the basis of an acceptance that the extensional regime commenced in the Middle Miocene (Şengör et al. 1985; Şengör 1987). Thus, this view considers the calc-alkaline to alkaline transition was the result of a change in the tectonic regime from compression to extension.

On the other hand, after a number of studies suggested that the extensional tectonics in the region had already commenced in the latest Oligocene (e.g., Seyitoğlu & Scott 1991; Seyitoğlu et al. 2002; Sözbilir 2001, 2002; Westaway 2003; Bozkurt & Sözbilir 2004; Purvis & Robertson 2005; Purvis et al. 2005; Westaway et al. 2005; Koçyiğit 2005), wide-spread calc-alkaline volcanic products were thought to be formed under a N–S-directed extensional setting (e.g., Seyitoğlu & Scott 1992; Seyitoğlu et al. 1997; Aldanmaz 2006). This view also implies that the increasing alkaline affinity of the rocks and their volume can easily be explained by crustal thinning as extension proceeded, such that the crustal contribution to the magma decreased (Seyitoğlu et al. 1997). Aldanmaz et al. (2000) and Aldanmaz (2006) have suggested that the latest Oligocene–Early Miocene calc-alkaline volcanic magmatic activity was related to thermal perturbation resulting from the removal of the thermal boundary layer of the mantle lithosphere following plate collision and lithospheric thickening, and the geochemical characteristics of the rocks can be explained by their generation from heterogeneously enriched (metasomatised) mantle lithosphere, most probably by pre-collisional subduction events.

In the extensional settings, such as continental rifting, it is well-known that sedimentation is generally associated with syn-rift bimodal volcanic activity (e.g., East African Rift System: Gasparon et al. 1993; Trua et al. 1999). The extensional terranes in the extension are associated with the core complex formations, such as in the Basin and Range province, and are also characterized by syn-
extensional bimodal volcanic activity (e.g., Suneson & Lucchitta 1983; Wernicke et al. 1987; Gibson & Nutman 2004). The term bimodal volcanism is used in the case of coeval associations of felsic and mafic end-member occurrences; which are thought to be generated from mantle and crustal sources. Melting of the continental crust produces felsic magmas, whilst the source of the mafic volcanism is the mantle that is raised closer to the surface by the deep faults in extending terranes. The mantle undergoes decompressional melting as extension proceeds and supplies the heat source to melt the crust.

In this study the term bimodal volcanic activity is used to describe mafic, ultrapotassic, alkaline (lamproitic) and felsic, high-K, calc-alkaline (ryholitic) volcanic association. Mafic ultrapotassic lavas are generally associated with the high-K felsic volcanic products in the post-collisional systems (e.g., Mitchel & Bergman 1991; Prelević et al. 2004). For instance within the Mediterranean region, ultrapotassic volcanism is spatially and temporally associated with the Late Cretaceous–Cenozoic convergence of Africa–Arabia with Eurasia, which resulted in the Alpine orogen (Wilson & Bianchini 1999; Prelević et al. 2005). This type of lamproites, which are generated in an extensional setting due to post-orogenic relaxation of an over-thickened lithosphere in convergent plate boundaries, are orogenic lamproites and are named as ‘Mediterranean lamproites’, and are generally found in close association with high-K, calc-alkaline volcanic rocks (Pecerillo & Manetti 1985; Venturelli et al. 1991; Mitchell & Bergman 1991; Prelević et al. 2005).

In western Anatolia, the eastern part of the Aegean extensional province, alkaline and/or ultrapotassic volcanic rocks have been shown to be Middle Miocene in age or younger (Yılmaz 1989, 1990; Güleç 1991; Aldanmaz et al. 2000; Innocenti et al. 2005), but recently, Erkül et al. (2005a, b, 2006) have reported mildly alkaline olivine basalt (19.7±0.4 Ma Ar-Ar age) in association with calc-alkaline felsic occurrences of Early Miocene age (19–20 Ma K-Ar age) from the Bigadiç borate basin (Figures 1 & 2). These deposits can provide useful constraints for the Early Miocene extensional volcanism.
The main scope of this study was focused on the Lower Miocene volcano-stratigraphy and geochemistry of the Lower Miocene volcanic units of the Selendi Basin which lies between Demirci and Uşak-Güre basins (Figure 1). Early Miocene volcanic activity in the basin is characterized by two volcanic units with different compositions: (1) mafic alkaline, ultrapotassic lamproite; (2) calc-alkaline, high-K felsic rocks. These volcanic units are temporally and spatially in close association and interfinger with Lower Miocene sedimentary rocks. Thus, these observations suggest that the ultrapotassic volcanism in western Anatolia had already began in Early Miocene with minor products and was accompanied by wide-spread felsic calc-alkaline volcanic activity (i.e. bimodal volcanism). This bimodal volcanic activity is most probably related to extensional tectonics, similar to those found in the Basin and Range extensional province.

Stratigraphy of the Selendi Basin

Previous Studies

One of the NE-trending basins, the Selendi Basin, lies between Demirci and Uşak-Güre basins to the west and east, respectively, and is cut by Simav Graben to the north (Figure 1). According to previous studies, the rock units exposed in the study area are, from bottom to top, the Menderes Massif, ophiolitic rocks of the Üzmir-Ankara zone, the Hacibekir Group, the İnay Group, Plio–Quaternary sedimentary (Asartepe Formation) and volcanic (Kula basalts) units and recent alluvial deposits (Figures 2 & 3). The first detailed study in the area was reported by Ercan et al. (1983). According to these authors, the basin stratigraphy begins with the Middle–Upper Miocene Hacibekir Group, which, in turn, is overlain, via an angular unconformity, by the Lower–Upper Pliocene İnay Group. These units are unconformably overlain by Quaternary sediments (Figure 3a). Ercan et al. (1983) have revealed that the Hacibekir Group interfingers with, and is conformably overlain by, felsic volcanic rocks, namely the Dikendere and Karaboldere volcanics, respectively. Later, Seyitoğlu (1997) showed that the Hacibekir Group was deposited during the Early Miocene on the basis of palynological and radiometric ages from the dacitic rocks interfingerling with the İnay Group (Figure 3b). Ercan et al. (1983) and Seyitoğlu (1997) argued that the basin fill unconformably overlies the basement rocks. These studies accept that the development of the Selendi Basin was firstly controlled by N–NNE-trending normal faults that are also thought to have controlled the calc-alkaline rhyolitic volcanic activity. On the other hand, Purvis & Robertson (2004, 2005) have claimed that the basin began to form on a corrugated detachment fault during the Early Miocene.

Since this study is focused on the Lower Miocene volcano-sedimentary rock units of the Hacibekir Group, a brief summary of the overlying units is given below.

Geological Setting

The basement rocks of the Selendi Basin are represented by the metamorphic and ophiolitic rocks of the Menderes Massif and the İzmir-Ankara zone, respectively. The metamorphic rocks were also intruded by granitic stock(s) (Rahmanlar granite). The basement rocks are overlain by two distinct volcano-sedimentary successions that are separated by a basin-wide angular unconformity: (i) Hacibekir Group and (ii) İnay Group. The Hacibekir Group includes four units (Figure 3). The sedimentary units are represented by the Kırktköy and Yeniköy formations and volcanic units are the Eğretildağ volcanic unit and Kuzayır lamproite. The sedimentary units also include some ophiolite rocks and limestone blocks. The outcrops of the Eğretildağ volcanic unit, around the Eğretildağ, were previously mapped as part of the Beydağ and Karaboldere volcanic units (Ercan & Öztunalı 1983). However, pyroclastic rocks interfingerling with the İnay Group unconformably overlie the dacitic-rhyolitic volcanic rocks to the west of the Eğretildağ that were previously included to the Beydağ volcanics (e.g., Ercan & Öztunalı 1983). An angular unconformity has been mapped in this study between these volcanic units and they are renamed as the Yağcıdağ and Eğretildağ volcanic units. Thus, the Eğretildağ volcanic unit comprises the felsic volcanic rocks conformably overlying the Hacibekir Group, whilst, the Beydağ volcanic unit interfingers with the İnay Group. The Kuzayır lamproite, described here for the first time, is also intercalated with the Yeniköy Formation of the Hacibekir Group. The Eğretildağ volcanic unit cuts through and conformably overlies the Yeniköy
Figure 3. Comparative columnar sections of the Selendi Basin: (a) Ercan et al. (1983); (b) Seyitoğlu (1997); (c) Purvis & Robertson (2005); and (d) this study. Age data from (1) Seyitoğlu (1997), (2) Purvis & Robertson (2005), (3) Ercan et al. (1996) and (4) Innocenti et al. (2005).
Formation. All these units are covered by the İnay Group with an angular unconformity. The İnay Group is also unconformably overlain by the younger units (Figure 3d).

**Hacibeğir Group**
The Hacibeğir Group consists of sedimentary (e.g., Kürtköyü and Yeniköy formations) and volcanic units (Kuzayır lamproite and Eğreltidağ volcanic unit; Figure 3d).

**Kürtköyü Formation.** The Kürtköyü Formation is characterized by grey, reddish brown and yellow conglomerate, sandstone and minor limestone and claystone intercalations, and crops out in a large area to the southwest of the Selendi town. Clastic rocks of the unit are made up mainly of metamorphic clasts such as quartzite, marble, schists and augen gneisses.

**Yeniköy Formation.** The Yeniköy Formation is widely exposed at the north of the Selendi town, and consists of yellowish-brown sandstone, claystone and minor conglomerate intercalations. Sandstone layers display typical turbidite sequences. This unit also includes lamproitic lava flow intercalations that are mapped as a distinct unit, namely the Kuzayır lamproite (see below).

The Kürtköyü and Yeniköy formations also include olistostromal blocks of ophiolitic rocks and recrystallized limestones in variable clast sizes from metres to kilometres in diameter. The clastic rocks of the Kürtköyü and Yeniköy formations show soft-sedimentary deformation structures along the block contacts where the clastics were intruded into the blocks along their cracks. In previous literature, several age data exist, indicating that the Hacibeğir Group was deposited at least during Early Miocene time (Ercan et al. 1983; Seyitoğlu 1997).

**Kuzayır Lamproite.** The name Kuzayır lamproite is applied to greyish-black mafic lava flows cropping out around Kuzayır village (Figures 5 & 6). The lava flows are up to 5 m thick and cover an area up to 1 km. In hand specimen, they are characterized by dark brown phlogopite minerals within a dark grey to black matrix. The lower contact of the lava flows with the underlying sedimentary rocks display chilled and glassy margins with minor in-situ fragmentation and irregular columnar joints (Figure 6a). The sedimentary rocks, just below the lower contact of the lava flows were deformed during the emplacement. On the other hand, the upper contact is very sharp and the Yeniköy Formation, just above the lava flow, is undeformed (Figure 6b). The lava flows were sharply covered by the mudstones and siltstones.

**Eğreltidağ Volcanic Unit.** The Eğreltidağ volcanic unit is exposed around Eğreltidağ and Eskin village (Figures 4 & 5). It consists mainly of dacitic-rhyolitic intrusions, lava flows and associated pyroclastic rocks. The dacitic intrusions are characterized by their typical porphyritic texture with plagioclase, sanidine and quartz phenocrysts and their domal shapes including columnar cracks in the field. They contain high-grade metamorphic xenoliths of gneisses and migmatites from the metamorphic basement. The block-and-ash flows include lava clasts that can reach up to 2 metres. The clasts characteristically show radial cracks. Crystal-rich pyroclastic rocks are very similar to the altered lava flows in the area. They contain biotite, plagioclase and sanidine minerals with minor pumice clasts and xenoliths.

The Eğreltidağ volcanic unit conformably overlies the Yeniköy Formation (Figure 7), and is unconformably overlain by the İnay Group. The age of the unit can be assumed as Early Miocene on the basis of its stratigraphical position and radiometric K-Ar data suggesting an 18.9 Ma age on mica minerals from a dacitic intrusion in the Eskin area (Seyitoğlu 1997).

**İnay Group**
The İnay Group consist of four units in the Selendi Basin. These are the Ahmetler Formation, the Ulubey Formation, the Yaşçığağ volcanic unit and the Orhanlar basalt. The Ahmetler Formation (Ercan et al. 1983; Seyitoğlu 1997), overlies the Hacibeğir Group with an angular unconformity. The Ahmetler Formation contains conglomerates and sandstones at the base. These are overlain by claystone, sandstone and intercalated tuff layers upward. The claystone beds contain altered boron minerals (Helvacı & Orti 1998). The unit vertically passes into the Ulubey Formation. The Ulubey Formation is well-exposed to the southwest of the Selendi Basin. This unit is composed mainly of lacustrine limestone and marls with minor tuffaceous fine-grained sediments (Ercan et al. 1983; Seyitoğlu 1997). The Ulubey Formation conformably overlies the Ahmetler Formation and the Yaşçığağ volcanic unit. The Yaşçığağ volcanic unit is exposed around Yaşçığağ. The unit is composed of lava flows and associated pyroclastic rocks of andesite to
Figure 4. Geological map of the Eskin area. See Figure 1 for location.
dacite in composition. The Yağcıltaş volcanic unit yielded radiometric age estimates of 14.9±0.6 K-Ar (Seyitoğlu 1997) and 15.61±0.14 – 16.42±0.09 Ma Ar-Ar on mica minerals (Purvis & Robertson 2004). The Orhanlar basalt crops out to the northern and northeastern parts of the basin. The unit is composed of basaltic lava flows with minor pyroclastic rocks. The lava flows conformably overly the marls and limestones of the Ulubey Formation.

On the basis of these data, the İnay Group was deposited during the Middle Miocene.

**Kocakuz Formation**

The name Kocakuz formation is applied to reddish boulder conglomerates with sandstone and local laminated limestone lenses. On the basis of the geological
map, the unit seems to be formed under the control of the NE-trending structural lines (Figure 4). This continental unit was included in the Asartepe Formation (Ercan et al. 1983) assuming that the age of the unit is Quaternary. On the other hand, since the Late Miocene Kabaklar basalt overlies the Kocakuz formation, these continental deposits are, most probably, Late Miocene in age. The data also imply that the NE-trending structural lines, actually forming the basin boundaries, were active during the Late Miocene, and presumably, at least for the eastern margin of the basin, are not related to the deposition of the either the Hacibekir Group or the Inay Group.

Figure 6. (a) The upper and (b) the lower contact between the Yeniköy Formation (Yf) and the overlying Kuzayar lamproite (Kl). a—massive; b—columnar flow. The hammer is 32.5-cm long.
Kabaklar Basalt

The name Kabaklar basalt is applied to the grey-black massive lava flows which are olivine-basalt in composition, around the Kabaklar village, eastward of the basin (Figure 12). The Kabaklar basalt was previously included into the Kula basalts (Ercan et al. 1983, 1992) but this unit has yielded 8.5–8.37 Ma (Late Miocene) radiometric ages (Ercan et al. 1996; Innocenti et al. 2005) and differs from the Kula volcanics in their geochemical features.
Petrography

The lavas of the Eğreltidağ volcanic unit include dacitic and rhyolitic rocks. The modal mineralogy of lava samples is characterized by quartz (10–15%) plagioclase (Ab55-65; 15–20%), sanidine (5–10%), biotite (3–5%), green amphibole (3–5%) and opaque phases (1%). Unhedral quartz crystals are usually embayed (Figure 8a). Plagioclase crystals are commonly resorbed due to magma reaction. Similar features can be seen unusually in some biotite phenocrysts. The lavas show generally porphyritic texture with subhedral plagioclase, sanidine and biotite and anhedral quartz phenocrysts. In some samples, amphiboles overprinted the earlier formed and embayed clinopyroxene crystals. Some lavas exhibit vitrophyric texture with small phenocrysts. Their matrix is characterized by perlitic texture.

Kuzayır lamproite exhibits an alkaline mineralogical composition with light brown euhedral phlogopite phenocrysts which are generally zoned (Figure 8b, c). The matrix of the lava flows also includes K-feldspar crystals (Figure 8d). The lavas also exhibit olivine crystals that are completely resorbed calcite and iddingsite. Clinopyroxenes are generally zoned.

Geochemistry

In order to classify the Lower Miocene volcanic rocks and to discuss their geochemical features, lavas from the Kuzayır lamproite and Eğreltidağ volcanic unit were analyzed. Carefully selected representative samples were prepared in the Dokuz Eylül University sample preparation laboratories. Major- and trace-element analyses were performed on representative lava samples of the volcanic units by ACME Analytical Laboratories Ltd. in Canada. Major oxides were reported on a 0.2 g sample analyzed by ICP-emission spectrometry following a Lithium metaborate/tetraborate fusion and dilute nitric digestion. Loss on ignition (LOI) is by weight difference after ignition at 1000 °C. The results are given in Table 1.

Major Element Characteristics and Classification

SiO₂ contents of the lavas of the Eğreltidağ volcanic unit are very high ranging from 65.73 to 71.94 wt%. Na₂O and K₂O contents range from 2.33 % to 3.30 wt% and from 3.91 % to 5.13 wt%, respectively (Table 1). On the basis of Shand’s Index they can be classified as peraluminous (Al₂O₃ / [CaO+Na₂O+K₂O]: 1.27–1.56; and [Na₂O+K₂O] / Al₂O₃: 0.47–0.67). Their Mg-numbers vary in the range of 25.11–42.89 (Mg#= molecular 100 MgO / (MgO + FeO + 0.8998 Fe₂O₃; Table 1). They are plotted in the trachydacite, dacite and rhyolite fields in the SiO₂ vs Na₂O+K₂O classification diagram of Le Bas et al. (1986) and in the high-K dacite and rhyolite fields in the SiO₂ vs K₂O diagram of Pecerillo & Taylor (1976) (Figure 9a, b). They are plotted in the subalkaline field in the Na₂O+K₂O – SiO₂ (total alkalis vs silica) alkaline-subalkaline discrimination diagram (Irvine & Baragar 1971; Figure 9c) and show calc-alkaline character in the AFM (Na₂O+K₂O – MgO – FeO) diagram (Irvine & Baragar 1971; Figure 9d).

The lavas of the Eğreltidağ volcanic unit show a clear positive correlation in their K₂O contents, but CaO, TiO₂ and Fe₂O₃ contents of the lava samples from this unit decreases systematically with respect to the increasing SiO₂ content as differentiation index (Figure 10). In the classification diagrams, the rocks of the Kuzayır lamproite fall in the phonotephrite, basaltic trachyandesite, fields and exhibit an alkaline character in the K₂O vs SiO₂ alkali-subalkali diagram of Irvine & Baragar (1971) (Figure 9a, c). The normative mineralogy of the unit includes K-feldspar, diopside, hyperstene and olivine and does not contain any normative quartz.

According to Foley et al. (1987), the volcanic rocks which have K₂O > 3 wt%, MgO > 3 wt% and K₂O/Na₂O > 2% are ultrapotassic; and to Bergmann (1987), ultrapotassic rocks which have K₂O > 3 wt% and MgO > 3 wt% are lamproitic. K₂O contents of the Kuzayır lamproite vary from 6.67 to 6.83 wt% and their K₂O/Na₂O ratios are in the range of 3.64–4.35. MgO contents vary in the range of 5.60–6.64 wt%, considerably higher than evolved magmas. Additionally, their SiO₂ contents vary from 50.54 to 53.59 wt%. Their Mg-numbers are also high, ranging between 64.02 and 68.91 (Table 1 and Figure 10). In addition to petrography, using these geochemical characteristics, the lava samples of the unit can be classified as ultrapotassic and lamproitic. Indeed, in the classification diagrams for the ultrapotassic rocks (Figure 11a), Kuzayır lamproite falls into the ‘lamproite’ field. On the basis of their Al₂O₃ vs CaO and SiO₂ vs CaO (both by wt%) they are classified as ‘lamproites’ (Group I) and ‘ultrapotassic rocks of active orogenic zones’ (Group III) (Figure 11c, d).
Trace Element Characteristics

The Nb contents of the Eğretili Dağ volcanic unit show a flat trend with respect to the increasing SiO₂ contents, while Sr and Rb concentrations are represented by negative and positive correlations, respectively (Figure 10). The highly fractionated-nature is also suggested by very low and constant Ni contents. The lava samples of the Eğretili Dağ volcanic unit are represented by LREE-enriched and flattening patterns from Dy to Lu (with minor enrichment in higher elements) relative to the chondrites (C1 chondrite; Sun & McDonough 1989; Figure 12a). Their (La/Lu)ₙ ratios are in the range of 7.5—14.4. They also show significant negative anomalies in Eu as reflected by lower Eu/Eu* ratios (0.45—0.77; Figures 10 & 12a). In the N-MORB-normalized (Sun & McDonough 1989) multi-element variation diagram (Figure 12b) they show highly enriched patterns especially in LIL elements, such as Cs, Rb and Ba. They are depleted in Nb with respect to the U, Th, K and LREE, represented by negative Nb-anomaly. Significant positive Pb anomalies are seen in the N-MORB-normalized spider diagram (Figure 12b). Additionally, the Eğretili Dağ volcanic unit show negative anomalies in P and Ti; this may indicate that apatite and ilmenite fractionation occurred during magmatic evolution of the unit (cf. Wilson 1989).

The Ni contents of the Kuzayr lamproite are very high, reflecting their more primitive nature with respect to the Eğretili Dağ volcanic unit (Figure 10). Higher Sr contents show a clear negative correlation with respect to the increasing SiO₂ (Figure 10). (La/Lu)ₙ ratios for the Kuzayr lamproite vary between 27.3—32.3, higher than Eğretili Dağ volcanic unit, and show LREE-enriched REE patterns (Figure 12a). Their Eu/Eu* values are between 0.83 and 0.91; therefore they show a slight negative Eu anomaly. They also show a negative Nb anomaly with respect to the neighbouring LIL and LRE elements in the N-MORB-normalized spider diagram (Figure 12b). They are also characterized by negative Pb anomalies.

<table>
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<th>TiO$_2$</th>
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<th>Fe$_2$O$_3$</th>
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<th>MgO</th>
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Discussion and Conclusions

This study presents a new field-based geochemical study from the Lower Miocene volcanic rocks interfingering with the Hacibekir Group in the Selendi Basin. Seyitoğlu (1997) suggested that the Hacibekir Group is cut by felsic volcanic rocks of Early Miocene age (Dikendere volcanics of Ercan et al. 1983). The volcanic rocks, cutting (in the Eskin area; Figure 4) and conformably overlying (in the Kuzayır area; Figure 5) the Hacibekir Group, are combined in the name of Eğretidağ volcanic unit, on the basis of field, petrographic and geochemical data. In this study it has also been documented that the Early Miocene volcanic activity has also produced alkaline, ultrapotassic volcanic rocks, namely the Kuzayır lamproite. The contact relations of the Kuzayır lamproite with the fine-grained sedimentary rocks of the Hacibekir Group clearly show that these are syn-sedimentary lava flows, rather than a younger sill.

Table 1. (continued)

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</tbody>
</table>
The timing of the Late Cenozoic N–S-extensional tectonics in western Anatolia, following the closure of the northern Neo-Tethys, is widely debated. Şengör et al. (1985) suggested that the Tortonian and younger basins, which belong to the N–S extensional regime, are related to the tectonic escape of the Anatolian block, since the late Serravallian (ca. 12 Ma). On the other hand, some workers have argued that the Neogene depressions (both of the E–W- and NE-trending basins) began to develop coevally during latest Oligocene–Early Miocene, resulting from either orogenic collapse of the over-thickened crust (Seyitoğlu & Scott 1991, 1992; Koçyiğit et al. 1999; Bozkurt 2001, 2004; Westaway 2003; Bozkurt & Sözbilir 2004; Westaway et al. 2005; Sözbilir 2005; Koçyiğit 2005; Bozkurt & Mittwede 2005; Bozkurt & Rojay 2005; Rojay et al. 2005) or back-arc rifting related to roll-back of the Aegean subduction zone (Okay & Satır 2000; Rosenbaum et al. 2002) or permutation of these two mechanism over the time (see Bozkurt 2004). It has long been believed that the mafic alkaline volcanism in western Turkey appears to be Late Miocene in age or younger and that the mafic volcanism is related to an extensional regime dating from the Middle Miocene (Yılmaz 1989, 1990; Savaşçın & Güleç 1990; Güleç 1991; Yılmaz et al. 2001; Tokçal et al. 2005; Aldanmaz 2006). On the other hand, Erkul et al. (2005a, b, 2006)
demonstrated the presence of alkali olivine basalt in the Lower Miocene from the Bigadiç borate basin, associated with calc-alkaline felsic volcanic units (i.e., bimodal volcanism). The presence of an alkaline rock of Early Miocene in this basin suggests that the other NE-trending basins may also include volcanic rocks derived from more primitive melts. In this perspective, the Kuzayr lamproite is more important for the tectono-magmatic evolution of the NE-trending basins, because it is the first alkaline and ultrapotassic rock of the region occurring in the Lower Miocene, although, previous studies have suggested that such ultrapotassic, alkali volcanic activity occurred during the Middle Miocene (e.g., Savaşçı & Oyman 1998; Akal & Helvacı 2002; Akal 2003; Innocenti et al. 2005).

The Afyon-Isparta region, easternmost part of the western Anatolia, is a large Neogene alkaline volcanic province (Savaşçı & Oyman 1998; Floyd et al. 1998; Akal & Helvacı 2002; Akal 2003). Alkaline volcanic rocks of the region are Middle Miocene–Pliocene in age. Savaşçı & Oyman (1998) have suggested that the volcanism was controlled by a N–S-trending transform fault system located on the Kirka, Afyon and Isparta trend. However, there are some ultrapotassic volcanic-subvolcanic occurrences in the Middle Miocene–Pliocene
in western Anatolia, which appears to be unrelated to this structural line (Figure 1). Furthermore, the alkaline-ultrapotassic volcanism can not be restricted either to this time interval, or to this trend, as presented here (see also Westaway et al. 2005).

Based on the petrogenesis of ultrapotassic rocks, the Kuzayr lamproite is plotted between Group I (lamproites) and Group III rocks (ultrapotassic rocks of the active orogenic zones) (Figure 11c, d). This is also supported by the low Nb contents (Figure 11b), which is the characteristic of subduction zones or post-collisional settings (Pearce 1982). This group of rocks is thought to be generated from a mantle source that has been metasomatised by subducted sediments and/or subduction zone fluids, released from a descending lithospheric slab, thus providing a source of incompatible elements such as K (e.g., Pearce 1982; Wilson 1989). Traditional classification of lamproites have also been

Figure 11. Classification diagrams for the Kuzayr lamproite: (a) K$_2$O-MgO-Al$_2$O$_3$ diagram for kimberlites, lamproites and lamprophyres (after Bergmann 1987); (b) variation of Nb vs Zr for potassic and ultrapotassic volcanic rocks (after Thompson & Fowler 1986); classifications of ultrapotassic rocks on the basis of CaO vs Al$_2$O$_3$ (c) and of CaO vs SiO$_2$ (d) (after Foley et al. 1987). Group I: lamproites; Group II: ultrapotassic rocks of continental rift zones; Group III: ultrapotassic rocks of active orogenic zones.
built on their tectonic settings; either orogenic (destructive plate margin) or anorogenic (intraplate) (Mitchell & Bergmann 1991). Orogenic ones are known as ‘Mediterranean lamproites’ (Spanish lamproites: Venturelli et al. 1991; Italian lamproites: Pecerillo & Manetti 1985; Balkan lamproites: Terzić & Svešnjikova 1991; Turkish lamproites: Akal & Helvacı 2002). Unlike anorogenic lamproites, orogenic ones are richer in SiO$_2$ wt% and alumina ($K_2O/Al_2O_3 < 0.8$) (Mitchell & Bergmann 1991). These values for the Kuzayır lamproite are in the range of 50.54–53.59 (wt%) and 0.51–0.54, respectively. Also, incompatible trace element characteristics of the Kuzayır lamproite are very similar to those of the other ‘Mediterranean lamproites’ (e.g., Italian and Spanish lamproites; Figure 12a, b). Except for the negative Pb anomaly in the N-MORB-normalized spider diagram, using the mentioned major and trace element characteristics, the Kuzayır lamproite can be included into the ‘Mediterranean lamproites’ which are thought to be generated in destructive plate margin, especially just after the collisional events between arc and continental crust (e.g., Prelevič et al. 2005). In other words, enrichment processes of the mantle source can be assumed to result from previous subduction events (Pearce 1982, 1983), just before the collisional events between Sakarya Continent and Anatolides. Hence, the Kuzayır lamproite is the oldest known lamproitic rock in Western Anatolia that was produced in extensional tectonics just after the collision-related compressional regime, i.e. post orogenic.

In conclusion, it is apparent from the field relationship and geochemical features that the sedimentary rocks of the Lower Miocene Hacibekir Group were accompanied by two contrasting types of volcanic activity: (1) alkaline ultrapotassic, and (2) calc-alkaline, high-K in character. The temporal association of the Kuzayır lamproite with the high-K, calc-alkaline Eğretildağ volcanic unit clearly describe a bimodal volcanism in the Early Miocene in the Selendi Basin, implying that the extensional tectonics prevailed in Early Miocene. Moreover, it is well-known that the ‘Mediterranean lamproites’ are temporally in close association with the shoshonitic and/or high-K calc-alkaline volcanic suites in post-orogenic extensional volcanic provinces (Prelevič et al. 2004). In the post-orogenic extensional settings it is possible that the post-orogenic magmatism is bimodal in character (e.g., Fan et al. 2001). These regions are, commonly, represented by mantle-derived mafic and felsic magmas. The data summarized above are in close harmony with the post-orogenic bimodal magmatism in the other localities of the world (e.g., Sial et al. 1999; Fan et al. 2001) and suggest that the extensional tectonics in western Anatolia has already begun during the Early Miocene, yielding not only high-K, shoshonitic and calc-alkaline felsic products but also mafic, alkaline and ultrapotassic volcanic rocks.

Figure 12. (a) Chondrite-normalized rare-earth element and (b) N-MORB normalized multi-element variation diagrams for the lavas of the Eğretildağ volcanic unit and Kuzayır lamproite. Normalization coefficients are from Sun & McDonough (1989).
Acknowledgements
This study was supported by Scientific and Technological Research Council of Turkey (TÜBİTAK; Project no: ÇAYDAG/103Y124) and Dokuz Eylül University Scientific Research Projects (BAP, 03.KB.FEN.058). We thank the two anonymous reviewers for their thoughtful and constructive comments. Darrel Maddy helped with the English of final text.

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EARLY MIOCENE VOLCANISM IN THE SELENDÜ BASIN


Received 30 March 2006; revised typescript received 07 August 2006; accepted 18 December 2006