Collision-related slab break-off volcanism in the Eastern Anatolia, Kepez volcanic complex (TURKEY)

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The Neogene-Quaternary volcanic products, related to Arabian and Anatolian Plate collision along the Bitlis Suture Zone, cover wide areas on both plates. One of these volcanic exposures on the Arabian Plate is the Kepez volcanic complex (KVC). This study aims to explain the petrogenesis of KVC. Although some examples display alkaline affinities, the majority of the volcanic rock is calc-alkaline and can be defined in three main groups. 40Ar/39Ar data obtained from dacite, basalt and andesite rock groups within the KVC yield ages of between 13.5 and 15.5 Ma. Geochemical and petrographical data show that the andesitic rocks are products of homogeneous mixing between basic end-member magmas and dacitic magmas which are the products of partial melting of lower crustal compositions. Basaltic products of KVC are asthenospheric mantle derived, while dacitic and andesitic volcanic rocks are crustal origin. High Sr and Nd isotope ratios may indicate that andesitic and dacitic rocks originated from continental crust. The lithospheric mantle, which is subducting underneath the Anatolian plate, must have experienced slab break-off processes 13–15 million years ago and sunk into the asthenosphere. KVC were produced with the collision between Arabian and Anatolian Plates and related uplift of the East Anatolia region.

Keywords: Kepez volcanics; slab-break-off volcanism; Eastern Anatolia; Miocene volcanics; collision volcanism

Introduction

The neotectonic evolution of Turkey results from the Hellenic arc in the west, the Eurasian plate, located throughout the Bitlis–Zagros suture, and also the Arab and African plates in the east (Dewey, Hempton, Kidd, Şaroğlu, & Şengör, 1986; Şengör, Gürür, & Şaroğlu, 1985; Şengör & Yilmaz, 1981). The collision of the Eurasian and Arab plates throughout the Bitlis suture zone led to contraction and crustal thickening in the East Anatolian area, the formation of the North Anatolian right lateral fault and the East Anatolian left lateral fault. This collision also causes the Anatolian plate to move west throughout these fault zones (Dewey et al., 1986; Gürsoy, Piper, & Tatar, 2003; Gürsoy et al., 2011). The Kepez volcanic complex (KVC) is thought to have formed an example of rarely alkaline but mostly calc-alkaline volcanism at a phase, following the collision of Late Miocene Arabian–Anatolian plates in the continent.

The KVC, first defined by Akkuş (1971), is comprised of basalt, trachybasalt, basaltic andesite, basaltic trachyandesite, andesite and dacitic rocks on the chemical nomenclature diagrams. Geochemical data indicate that the KVC is fundamentally formed of basaltic (basalt, trachybasalt), andesitic (basaltic andesite, basaltic trachyandesite, trachyandesite and andesite) and dacitic rocks.

According to petrographical and geochemical data, andesitic products are formed through a homogeneous mixture of basaltic and dacitic products. Petrographical, geochemical and geochronological data are correlated all with the geodynamic model of the region. Previous research suggested that the lithospheric mantle in East Anatolia was as thick as 45 km (Zor et al., 2003). However, research conducted in recent years the lithospheric mantle in this region is very thin or non-existent (Keskin, 2003; Şengör et al., 2008).

The closure process of the Neotethys Ocean located between the Eurasian–African plates, which began in the Late Cretaceous period resulted in continent–continent collision between the Anatolian block and Arabian plate at the end of Middle Miocene (Dewey et al., 1986; Şengör & Yilmaz, 1981; Şengör et al., 1985; Yilmaz, 1993). The collision of the Eurasian and Arabian plates throughout the Bitlis suture zone, which continues today, leads to contraction and crustal thickening in the East Anatolia region and the formation of the North Anatolian right lateral fault and the East Anatolian left lateral fault. It also causes the Anatolian plate to move west through-out these fault zones (Dewey et al., 1986). Collision-related compressional regime and volcanic activity began in the Late Miocene–Pliocene period and continued until historical periods without interruption (Yilmaz, 1993).

Geological setting

The study area is located in the west of Malatya (Turkey) and in the north of the Arab–Anatolian collision zone (Figure 1). The Upper Miocene KVC
unconformably overlies Middle–Upper Eocene Başören Formation (Leo, Onder, Kılıç, & Avcı, 1978; Özgenç & Kibici, 1994). The Başören Formation includes a sequence consisting of conglomerate, marl, sandstone and limestone. The ages of the KVC which moves over this formation were dated to be 13.5–15.5 Ma using Ar–Ar geochronology. The KVC was classified into three fundamental rocks types: basalt, andesite and dacite. These volcanic rocks, located in the north of the Arab–Anatolian collision zone, had formed due to the rising of the region following the collision phase of the Arabian and Anatolian plates immediately after the closure of the Neotethys Ocean in the Late Miocene period. Dacitic products (15.30 Ma ± 0.20), which formed as a result of partial melting of the lower continental crust, were first. They were considered to move into the asthenosphere at depth of the 40–45 km (Barazangi, Sandvol, & Seber, 2006; Keskin, 2003; Şengör, Özeren, Zor, & Gene, 2003; Zor et al., 2003) of the lithospheric slab after breaking due to the weight of the lithospheric slab and convection flows, basaltic products had settled in this region (13.50–14 Ma ± 0.20), together with aforementioned uplift by means of breakage. Basic and dacitic magmas had mixed due to the uplift of the basic products and formed andesitic products (14–15 Ma ± 0.20).

**Analytical techniques and sampling**

Twenty-seven samples were analysed for major and trace element concentrations at ACME laboratories Canada (Table 1). Major element analyses were conducted by X-ray fluorescence upon fused discs prepared using six parts of lithium tetraborate and one part of rock powder. The mixture was fused in crucibles of 95% Pt and 5% Au at 1050 °C for 60 min to form a homogeneous melt that was cast into a thick glass disc. Trace element concentrations were analysed by ICP-MS using a fusion method with precision better than ±3% (Online Appendix 1 in supplementary Information).

Eight samples were selected for ⁴⁰Ar/³⁹Ar geochronology based on mineral freshness and grain size of potassium-bearing minerals. For ⁴⁰Ar/³⁹Ar dating of the volcanic rocks 20–50 mg of purified rock powder at 250 μm were used. The samples analysed were whole rock from basalt, andesite and dacite. Whole rock basalt, andesite and dacite samples were crushed, sieved and cleaned in an ultrasonic bath. The samples were then loaded into aluminium foil packets. Samples analysed at Montpellier were irradiated in a single irradiation, at the University of Montpellier (Table 2).

Sr, Nd isotope analyses of ten whole-rock samples were performed at the Geosciences of Tübingen University in Germany. The samples were dissolved in 52% HF for four days at 140 °C on a hot plate. Digested samples were dried and redissolved in 2.5 N HCl Sr and light rare-earth elements were isolated on quartz columns by conventional ion-exchange chromatography with a 5-ml resin bed of Bio Rad AG 50W-X12, 200–400 mesh. Nd was separated from other rare-earth elements on quartz columns using 1.7 ml-Teflon powder coated with

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**Figure 1.** The geological map of the KVC.
Table 1. Major and trace element compositions of KVC.

| Sample  | K-2  | K-3  | K-4  | K-5  | K-9  | K-11 | K-13 | K-14  | K-16  | K-18  |
|---------|------|------|------|------|------|------|------|-------|-------|-------|
|         | Dacite | Basalt | Andesite | Andesite | Andesite | Dacite | Andesite | Andesite | Dacite | Andesite |
| SiO₂    | 62.84 | 49.51 | 59.56 | 60.55 | 61.88 | 61.81 | 64.11 | 53.22 | 54.17 |
| TiO₂    | 0.82  | 0.96  | 0.97  | 0.76  | 0.73  | 0.72  | 1.09  | 1.66  |
| Al₂O₃   | 16.24 | 17.29 | 17.17 | 16.35 | 16.15 | 16.47 | 16.40 | 16.35 |
| Fe₂O₃   | 4.68  | 5.41  | 5.46  | 5.49  | 5.21  | 4.69  | 4.35  | 3.99  | 8.68  | 8.52  |
| MgO     | 3.08  | 5.79  | 7.37  | 7.19  | 7.19  | 2.16  | 3.93  | 2.08  | 6.30  | 5.08  |
| MnO     | 0.07  | 0.07  | 0.07  | 0.07  | 0.05  | 0.05  | 0.12  | 0.11  |
| CaO     | 4.47  | 5.78  | 5.30  | 5.35  | 4.59  | 4.79  | 4.56  | 7.39  | 5.90  |
| Na₂O    | 3.79  | 4.53  | 4.24  | 3.33  | 4.13  | 4.31  | 3.63  | 4.64  |
| K₂O     | 2.82  | 2.14  | 2.15  | 3.30  | 2.33  | 2.46  | 1.56  | 1.99  |
| P₂O₅    | 0.19  | 0.42  | 0.20  | 0.16  | 0.07  | 0.07  | 0.23  | 0.43  |
| Cr₂O₃   | 0.008 | 0.003 | 0.002 | 0.003 | 0.002 | 0.007 | 0.004 | 0.039 | 0.019 |
| LOI     | 1.3   | 1.0   | 0.8   | 2.0   | 1.4   | 1.3   | 1.6   | 1.3   |
| Total   | 100.31| 100.32| 100.15| 100.32| 100.30| 100.30| 100.34| 100.33| 100.19|

(Continued)
| Sample | K-19 Dacite | K-26 Dacite | K-27 Dacite | K-28 Dacite | K-29 Andesite | K-31 Andesite | K-40 Dacite | K-41 Dacite | K-42 Andesite | K-44 Andesite |
|--------|-------------|-------------|-------------|-------------|---------------|---------------|-------------|-------------|---------------|---------------|
| LOI    | 1.6         | 2.1         | 1.3         | 1.4         | 1.5           | 1.0           | 1.8         | 1.6         | 1.4           |
| Total  | 100.30      | 100.35      | 100.36      | 100.36      | 100.29        | 100.23        | 100.34      | 100.31      | 100.31        |

| Sample | K-47 Dacite | K-50 Andesite | K-51 Andesite | K-54 Dacite | K-56 Basalt | K-58 Basalt | K-68 Andesite | K-69 Dacite | K-71 Dacite | K-72 Dacite | K-73a Basalt |
|--------|-------------|---------------|---------------|-------------|-------------|-------------|---------------|-------------|-------------|-------------|---------------|
| LOI    | 1.8         | 0.9           | 1.0           | 2.7         | 1.0         | 0.5         | 1.4           | 1.6         | 1.3         | 1.1         | 1.3           |
| Total  | 100.31      | 100.25        | 100.28        | 100.37      | 100.28      | 100.23      | 100.34        | 100.36      | 100.35      | 100.36      | 100.33        |
HDEHP, diorthophosphoric acid, as cation-exchange medium. Separation and purification of Pb were carried out on Teflon columns with a 100 μl (separation) and 40 μl bed (cleaning) of Bio-Rad AG1-X8 (100–200 mesh) anion exchange resin using an HBr–HCl ion-exchange procedure. All isotopic measurements were made.

| Sample | Rock       | Whole rock, Isochron Age (Ma) | Whole rock, Plateau Age (Ma) |
|--------|------------|-------------------------------|-----------------------------|
| K-4    | Trachybasalt | 14.22 ± 0.46                  | 13.99 ± 0.25                |
| K-9    | Andesite   | 14.82 ± 0.31                  | 14.19 ± 0.19                |
| K-14   | Dacite     | 15.73 ± 0.30                  | 15.30 ± 0.16                |
| K-19   | Dacite     | 13.27 ± 1.22                  | 15.30 ± 0.20                |
| K-29   | Andesite   | 15.45 ± 0.36                  | 15.17 ± 0.17                |
| K-31   | Basaltic trachyandesite | 14.53 ± 0.27        | 14.11 ± 0.16                |
| K-50   | Basaltic andesite | 15.60 ± 0.43              | 15.27 ± 0.16                |
| K-58   | Basalt     | 13.92 ± 0.21                  | 13.58 ± 0.17                |

Table 2. Ar–Ar dating results of KVC.

| Sample | Rock       | 87Sr/86Sr | 143Nd/144Nd |
|--------|------------|-----------|-------------|
| K-3    | Dacite     | 0.706480 ± 08 | 0.512515 ± 08 |
| K-4    | Trachybasalt | 0.703791 ± 10 | 0.512823 ± 09 |
| K-9    | Andesite   | 0.706723 ± 09 | 0.512438 ± 08 |
| K-19   | Dacite     | 0.705737 ± 10 | 0.512537 ± 09 |
| K-29   | Andesite   | 0.705367 ± 10 | 0.512579 ± 07 |
| K-31   | Basaltic trachyandesite | 0.704957 ± 10 | 0.512593 ± 08 |
| K-50   | Basaltic andesite | 0.702561 ± 10 | 0.512607 ± 09 |
| K-58   | Basalt     | 0.703918 ± 08 | 0.512743 ± 09 |
| K-68   | Andesite   | 0.706204 ± 07 | 0.512598 ± 08 |
| K-71   | Andesite   | 0.706268 ± 09 | 0.512609 ± 08 |

Notes: Standard: La Jolla 143Nd/144Nd: 0.511824 ± 07; La Jolla 143Nd/144Nd: 0.511827 ± 10.
Sr-Standard: NBS 987 87Sr/86Sr: 0.710250 ± 08; NBS 987 87Sr/86Sr: 0.710238 ± 10.

Table 3. Sr and Nd isotopic results of KVC.
Figure 2. Thin section views from KVC. (a, b) Olivine crystals in basaltic rocks; (c, d) Cooling interactions with augite minerals in the groundmass; (e) Plagioclase mineral core is riddled with glass and overgrown with clear rims; (f) Plagioclase have sieved texture; (g) Plagioclase reverse zoning texture; (h) Amphibole phenocrysts in andesitic lavas.
by Thermal Ionization Mass Spectrometry, on a Finnigan MAT 262 mass spectrometer. Sr was loaded with a Ta-HF activator on pre-conditioned W filaments and was measured in single-filament mode. Nd was loaded as phosphate on pre-conditioned Re filaments and measurements were performed in an Re double-filament configuration. The $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratios were normalised to $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$ and the $^{143}\text{Nd}/^{144}\text{Nd}$ isotope ratios to $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$. La Jolla Nd-standard yielded a value $^{143}\text{Nd}/^{144}\text{Nd}: 0.511827 \pm 0.07$ and $^{146}\text{Nd}/^{144}\text{Nd}: 0.511824 \pm 0.08$. Within same period NBS 987 Sr standard yielded $^{87}\text{Sr}/^{86}\text{Sr}: 0.710238 \pm 0.10$ (Table 3).

**Results**

**Petrography**

Basalts and trachybasalts which show holo–hypocrystalline porphyritic texture are black coloured and while they include olivine, pyroxene and microlites of opaque minerals (Figure 2(a) and (b)). Basalt and trachybasalts are dark coloured, and include olivine, pyroxene and opaque minerals mainly. They display holo to hypocrystalline textures.

Andesite group of rocks cover the trachyandesite, basaltic andesite, basaltic trachyandesite, andesite and dacite on the TAS (total alkali–silica) diagram (Le Maitre, 2002) (Figure 3).

The SiO$_2$ contents of the KVC range from 49.71 to 65.12%. On the Harker-type plots, compatible trends which range from basic to acidic magma are observed. While Fe$_2$O$_3$, MgO, TiO$_2$, CaO and P$_2$O$_5$ values are high, especially in the basic magma, these values exhibit a compatible decreasing trend towards acidic magma (Figure 4). The data point to the abundance of these elements in the scope of olivine and pyroxene minerals which are available in basic rock. Besides Na$_2$O and Al$_2$O$_3$ values generally exhibit a linear trend; however, an increasing trend is seen from basic to acidic magma for K$_2$O value. This indicates that K element was not consumed during the previous phases of magma; therefore, it is more common in the acidic products. These linear trends offer principal geochemical evidence of the existence of magma mixing between basic and acidic magmas at the same time. Similar trends are observed in the MgO ratio diagrams of major elements and show that there is fractioning of olivine and pyroxene. The linear trend (Figure 5) observed in the ratio diagrams of the

**Geochemistry**

**Major elements and classification**

KVC, are classified as basalt, trachybasalt, basaltic andesite, basaltic trachyandesite, trachyandesite, andesite and dacite on the TAS (total alkali–silica) diagram (Le Maitre, 2002) (Figure 3).

Figure 3. Total alkali silica classification diagrams of KVC (Le Maitre, 2002).
Figure 4. Variation of selected major element versus SiO₂ for KVC.
Figure 5. Variation of selected major element versus MgO for KVC.
Figure 6. Trace element variation diagrams for KVC using Th as differentiation index.
major element contents of the KVC against MgO points to the existence of mafic mineral fractionation and fractional crystallisation (Krienitz, Haase, Mezger, Eckardt, & Shaikh-Mashail, 2006). The fact that the linear trend shown on the ratio diagrams of CaO, Fe₂O₃ and TiO₂ against MgO, developed a negative tendency at about 6–7% indicates that fractional crystallisation became effective at MgO values of approximately 6–7%.

Figure 7. Spider diagrams for the KVC. Trace element concentrations of lavas to primitive mantle after Sun and McDonough (1989) and chondrite after Boynton (1984).

Figure 8. K/Sr–Ba/Rb ratio diagram of KVC testing the mixing relations between basalt as mafic end-member and dacite as silicic end-member (black dots is mixing line and mixing equations after Albarade, 1996).
Trace elements

High field strength elements (HFSE) are normally considered as ‘conservative’ elements in most geological settings. The HFSE have long been used as petrogenic tracers to classify igneous rocks and their tectonic settings. In magmatic rocks, HFSE become enriched during fractional crystallisation, and may reach the highest level in late acidic magma (Jiang, Wang, Xu, & Zhao, 2005). Th element was based because of all these reasons.

When Th ratio diagrams of major elements are analysed, incompatible elements such as Ba, Rb and La exhibit a richness towards dacitic rocks to basaltic ones; nevertheless, consumption is observed in Sr, Zr, Nb, Y and V elements from basaltic to dacitic rocks (Figure 6). On the primitive mantle and chondrite-normalised trace and rare-earth element (REE) distribution diagrams, both groups display an enrichment in LIL and LRE elements with respect to heavy rare-earth element (HREE) and HFSE, respectively, and negative Nb and Ti anomalies (Figure 7(a) and (b)). The negative anomaly of HFSE observed in these distribution patterns shows similarities to the negative anomalies which are seen in the intracontinental plate volcanics in which there is crustal interaction. This characteristic shows that some phases which include elements such as Nb and Ti do not take part in the melting and they consumed the first phases. REE Yb show negative anomalies (Figure 7(c) and (d)) which means is fractional crystallisation.

Magma mixing, fractional crystallisation and crustal contamination

There are three fundamentally different units observed, in terms of SiO₂ ratio diagrams (Figure 4). These are basaltic rocks (basalt, trachybasalt), andesitic rocks (basaltic andesite, basaltic trachyandesite, trachyandesite and andesite) and dacitic rocks. This discussion focuses on the petrogenesis of the mafic and intermediate rocks.

The origin of the intermediate rocks is likely related to magma mixing. In the case of the major element diagram which was correlated according to SiO₂ (Figure 4) and ratio diagrams of trace elements that were correlated with respect to Th (Figure 6), there is a prominent linear parallelism. The support of microscopic data (Figure 2(e), (f) and (g)) and linear trend of binary major/trace element ratio diagram leads to conclusion that andesite rocks were formed as a result of the mixture of basaltic and dacitic rocks at different ratios; basaltic andesite, basaltic trachyandesite and trachyandesite rocks constituted due to magma mixing. Melting and dissolution structures, petrographic evidence of homogeneous magma mixing in the plagioclase (Figure 2(e) and (f)) support the data on geochemical structures and provide evidence of rapid heating (Hibbard, 1995; Tsuchiyama, 1985).

Further evidence for magma mixing in the KVC is seen in the hyperbolic trend in K/Sr–Ba/Rb mixing model diagrams, which were conducted through the utilisation of average basic and acidic two extreme members (Figure 8). Similar distribution hyperbolic trends were observed on the ratio diagrams of Ba/Nb compared to La/Nb (Figure 9). Besides magma mixing textures, it is possible to mention the existence of a number of fractional crystallisation.

Discussion

This section proposes a geodynamic evolution model for the region after developing the idea that magma mixing, fractional crystallisation and crustal contamination processes generated these rocks.
The effects of crustal contamination are observed on SiO$_2$ ratio diagrams of trace elements (Figure 10), the correlation diagrams of trace elements with isotopic data (Figure 11) and particularly in the andesitic and dacitic rocks. A negative tendency is observed from basic members to acidic members, on the ratio diagrams of Nb/U, one of the trace elements, compared with SiO$_2$; nevertheless, a positive tendency is presented on the ratio diagram of Ba/Nb compared with SiO$_2$.

**Evolution model**

The KVC is one of the young volcanic complexes which significantly outcrops as a result of the collision in the East Anatolian Region. Chemical and petrographic characteristics of the KVC show that it consists of andesitic rocks which formed basaltic and dacitic magma mixtures. Magma mixture textures are seen petrographically as melting and dissolution structures and reverse zoning (Figure 2(e), (f) and (g)). Additionally, geochemical modelling, based on extreme basic and dacitic rock types, indicates that andesite rocks are products of magma mixture.

To determine the origin of the KVC, it can be seen that basic products present values closer (Figure 12) to the values of HIMU (mantle with high U/Pb ratio) and PREMA (PREvalent MAntle composition) among the borders of the mantle array. Andesitic and dacitic rocks are observed to be close to values of continental crust and particularly to the values of lower continental crust.
Figure 11. (a) Nb/U versus \(^{87}\text{Sr}/^{86}\text{Sr}\), (b) Pb/Nd versus \(^{143}\text{Nd}/^{144}\text{Nd}\) diagrams of KVC.

Figure 12. \(^{143}\text{Nd}/^{144}\text{Nd}\) versus \(^{87}\text{Sr}/^{86}\text{Sr}\) diagram of KVC.
Moreover, the number of Mg basalt rocks is very close together (K-4: 33.13 and K-73a: 31.00). These basaltic rocks are less evolved. In addition, trace SiO₂ ratio diagrams show similar results (Figure 13).

When this ratio was correlated with those introduced by Rollinson (1992), it was observed that basic products presented values closer to primary values of mantle; nevertheless, andesitic and dacitic rocks are similar to the continental crust values (Table 4). This lower Mg number indicates the basic end-member magma has undergone compositional changing by magma mixing, fractional crystallisation and contamination. Further, there are two group samples (Figure 12). First, basalts displaying the mantle affinity; second, isotopic crust like samples. Although, if it is claimed to be caused by magma mixing of andesitic rocks, the presence of fractional crystallisation is also possible, starting with the basaltic magma.

Table 4. Primitive mantle and continental crustal values given by Rollinson (1992) for some trace elements.

| Elements | Primitive mantle | Continental crust |
|----------|-----------------|-------------------|
| K/Nb     | 323             | 1341              |
| La/Nb    | 0.94            | 2.2               |
| Ba/La    | 9.6             | 25                |
| Ba/Nb    | 9.0             | 54                |
| Th/Nb    | 0.117           | 0.44              |
| Rb/Nb    | 0.91            | 4.7               |

(Figure 12). Moreover, the number of Mg basalt rocks is very close together (K-4: 33.13 and K-73a: 31.00). These basaltic rocks are less evolved. In addition, trace SiO₂ ratio diagrams show similar results (Figure 13).
The model which we suggest for the East Anatolian Region, one of the best examples of continental collision, is a slab break-off model (Davies & Blanckenburg, 1995; Keskin, 2003; Şengör et al., 2008). The Anatolian plate began moving to the North, beneath the Pontide during the Late Eocene–Oligocene (Şengör et al., 2003) period (Figure 14(a)). The oceanic slab of the Anatolian plate which is beneath the Pontide is considered to have melted during the Late Oligocene–Early Miocene period within the asthenosphere. The Arabian plate began moving beneath the Anatolian plate following the beginning of the closure of the Neotethys Ocean during the Late Oligocene–Early Miocene period (Figure 14(b)). The Anatolide Lithospheric Mantle (ANLM) began subducting into the asthenosphere due to its weight and the effect of convection flows during the Early Miocene period. Later, in the Middle Miocene period, the subduction angle had increased and it arrived at the phase of fraction. $^{40}$Ar/$^{39}$Ar age data which were acquired from the KVC show that dacitic rocks were the first volcanic products (15.3 ± 0.2 Ma) in the region. The dacitic rocks had outcropped due to uplift in the region following the partial melting of the lower continental crust (Figure 14(c)) (Davies & Blanckenburg, 1995; Keskin, 2003; MacKenzie & Bickle, 1988).

The crust thickness in the East Anatolian Region was considered to be 45 km (Zor et al., 2003). Recent seismic data (Al-Lazki et al., 2003; Gök, Türkelli, Sandvol, Seber, & Barazangi, 2000) suggested that either there is no lithospheric mantle in the region or, otherwise, it is relatively thin. With respect to recent geophysical research (Barazangi et al., 2006; Keskin, 2003; Şengör et al., 2003; Zor et al., 2003) in this region, the fraction in the lithospheric mantle is thought to be at the depth of 45–50 km.

When correlated with age in the region, the intrusive magmatic activity was not completed in a short time which it is formed by a process ongoing activity. Mantle origin basic products began rising to the surface (13.50–14 ± 0.2 Ma) in the region as a result of the lithospheric mantle slab breaking and dividing into the asthenosphere. As a result, magma started mixing with dacitic products (Figure 14(d)). Hence, similar age andesite products (14–15 ± 0.2 Ma) overcropped as a result of magma mixing together with approximate basic products (Figure 14(e)).

KVC ages are cooling age, which means dacitic and basaltic magmas can mix before reaching surface in the deep. So, it is possible that two different ages magmas are mixed. As it is well known, viscosity of basaltic magmas low, it can uplift and erupt first and fast due to high velocity.

**Disclosure statement**

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