Geochemical characteristics of ophiolitic rocks from the southern margin of the Sivas basin and their implications for the Inner Tauride Ocean, Central-Eastern Turkey

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ABSTRACT
Number of dismembered ophiolite bodies crop out between Sivas and Malatya on the top of the Eastern Tauride platform in the central-eastern Turkey. One of which at the southern margin of the Sivas basin in the Tecer Mountain area comprises melange and the lower part of an oceanic lithospheric section on top of the Tauride platform. The mantle tectonites are characterized by variably serpentinized harzburgites and dunites, and are intruded by numerous isolated dykes. The gabbroic cumulates consist of olivine gabbro, gabbronorite and gabbronorite. The major and trace element geochemistry of the mafic cumulate rocks suggests that the primary magma was compositionally similar to those observed in modern island-arc tholeiitic sequences. The isolated dykes are exclusively basaltic in composition and display geochemically two distinct subgroups: Group I is represented by high TiO₂ (0.87–1.47 wt.%) and other incompatible elements, whereas Group II is characterized by low TiO₂ (0.36–0.66 wt.%) and other incompatible elements. The Group I isolated diabase dykes have flat to slightly LREE-depleted profiles (La/YbN = 0.32–0.79), whereas the Group II isolated diabase dykes are more depleted in general and have a LREE-depleted character (La/YbN = 0.19–0.49). This suggests that the isolated dykes were derived from an island arc tholeiitic magma (Nb/Y = 0.02–0.05) with different degrees of partial melting (Group II > Group I) and relatively high oxygen fugacity in intra-oceanic subduction zone. The ophiolitic rocks in the study area may well be compared with the Divriği ophiolite to the southeast. All the evidence suggests that the isolated dykes in the Tecer Mountain area differ from the alkaline isolated dykes cutting the Divriği ophiolite. Since the late stage dykes (~76 Ma) in the Divriği area are alkaline, the tholeiitic isolated dykes in the present study should have been emplaced prior to the alkaline dykes during Late Cretaceous SSZ-spreading (~90 Ma) within the Inner Tauride Ocean.

1. Introduction
The Tauride Mountain Range in southern Turkey includes a number of Late Cretaceous ophiolites, mélanges and related metamorphic rocks. From west to east, these are the Lycian nappes, the Tekirova (Antalya) ophiolite, the Beyşehir-Hoyran nappes, the Mersin ophiolite, the Alihoca ophiolite, the Pozanti-Karsanı ophiolite, the Pınarbaşı ophiolite and the Divriği ophiolite (Figure 1). Situated above the Tauride passive continental margin, they mainly exhibit three tectono-stratigraphic/magmatic units such as, from bottom to top, ophiolitic mélangé, sub-ophiolitic metamorphic sole and dismembered oceanic lithospheric section. Except for the mélangé unit, the mantle tectonites, cumulates and metamorphic soles are intruded mostly by isolated microgabbro-diabase dykes and, to a lesser extent, pyroxenite dykes. The isolated dykes are not deformed, indicating that they were emplaced shortly after formation of the metamorphic soles, but they do not extend into the underlying mélanges and platform carbonates. The ophiolites along the Tauride belt were formed in supra-subduction zone (SSZ) settings and emplaced in the Late Cretaceous from different oceanic basins (Andrew & Robertson, 2002; Bağcı, Parlak, & Höck, 2006; Çelik, 2007; Çelik & Chiaradia, 2008; Çelik & Delaloye, 2003; Collins & Robertson, 1997; Collins & Robertson, 1998; Dilek, Thy, Hacker, & Grundvig, 1999; Dilek & Whitney, 1997; Elitok, 2001; Elitok & Drüppel, 2008; Parlak & Delaloye, 1996; Parlak, Delaloye, & Bingöl, 1996; Parlak, Höck, & Delaloye, 2000, 2002; Parlak & Robertson, 2004; Parlak, Yilmaz, & Boztuğ, 2006; Robertson, 2002; Robertson, Parlak, & Ustaomer, 2012; Robertson & Woodcock, 1981a, 1981b, 1981c, 1982; Robertson, Parlak, Metin, et al., 2013; Vergili & Parlak, 2005). The metamorphic soles beneath the ophiolites along the Tauride belt yield well-constrained Late Cretaceous ⁴⁰Ar/³⁹Ar plateau ages (Çelik, Delaloye, & Féraud, 2006; Dilek et al., 1999; Parlak & Delaloye, 1999).
Figure 1. U-Pb ages of Tethyan ophiolites in Turkey and surrounding areas. Data are from (1) Dilek and Thy (2006), (2) Dilek, Furnes, and Shallo (2008), (3) Liati, Gebauer, and Fanning (2004), (4) Mukasa and Ludden (1987), (5) Konstantinou, Wirth, and Vervoort (2007), (6) Dilek and Thy (2009), (7) Parlık, Karaoğlan, Rızaoğlu, Klötzli, et al. (2013), (8) Karaoğlan, Parlık, Klötzli, Thöni, and Koller (2013), (9) Koglin (2008), (10) Koglin, Kostopoulos, and Reichmann (2009), (11) Topuz et al. (2012), (12) Sarıfakıoğlu, Dilek, and Uysal (2012), (13) Karaoğlan, Parlık, Klötzli, Thöni, and Koller (2012), (14) Robertson, Parlık, Ustaömer, et al. (2013), (15) Karaoğlan, Parlık, Klötzli, Koller, and Rızaoğlu (2013).

Abbreviations: LO: Lesvos Ophiolite, AO: Antalya Ophiolite, BHO: Beyşehir-Hıyon Ophiolite, ORO: Orhaneli Ophiolite, KO: Kınık Ophiolite, EO: Eldivan Ophiolite, MO: Mersin Ophiolite, PKO: Pozań-Karsanti Ophiolite; Os: Osmanlıye Ophiolite, GO: Göksun Ophiolite, PO: Pınarbasi Ophiolite, IO: İspendere Ophiolite, DO: Divriği Ophiolite, KM: Komürhan Ophiolite, SO: Sevan Ophiolite, plg: plagiogranite, gb: gabbro, dk: dyke, tnl: tonalite, rhy: rhyolite [Map modified after Dilek and Flower (2003) and Çelik et al. (2011)].
Figure 2. 1/500,000 scale geological map of the Ulaş-Kangal-Dirği (Sivas) regions, showing the distribution of the Tauride platform, ophiolites, granitoids and cover sediments (from MTA, 2002).
Figure 3. Geological map of the southern margin of the Sivas basin in the Tecer area (Kavak, 2010). Source: Kaan Şevki Kavak.
The Late Cretaceous Divriği (Sivas) ophiolite, tectonically resting on top of the Munzur limestone (Tauride platform), is located between Çetinkaya and Divriği (Sivas) towns in east-central Anatolia and consists of, from bottom to top, an ophiolitic melange, metamorphic sole and remnants of oceanic lithosphere (mantle tectonites, cumulates, isotropic gabbro and sheeted dykes) (Parlak et al., 2006; Yılmaz, Ankal, & Yılmaz, 2001). The Divriği ophiolite formed in a suprasubduction zone setting above a north-dipping intra-oceanic subduction zone within the Inner Tauride Ocean (Parlak et al., 2006). The crystallization age of the SSZ-type oceanic crust was determined as 88.8 ± 2.5 Ma by LA-MC-ICP-MS U-Pb zircon on the gabbroic cumulates (Parlak, Karaoğlu, Rızaoğlu, Klötzli, et al., 2013). The alkaline to tholeiitic amphibolites from the metamorphic sole yielded similar 40Ar–39Ar cooling ages (89.65 ± 0.97 and 87.49 ± 0.48 Ma) that can compare well with the age of the overlying SSZ-type crust (Parlak, Karaoğlu, Rızaoğlu, Klötzli, et al., 2013). The isolated dykes intruding the Divriği ophiolite are alkaline and were interpreted to have been derived as a result of slab break-off (Parlak et al., 2006) in the late Cretaceous (75.9 ± 0.30 Ma) before the final emplacement (Parlak, Karaoğlu, Rızaoğlu, Klötzli, et al., 2013).

In the Tecer Mountain area along the southern margin of the Sivas basin, the ophiolite-related rocks in tectonic contact with the Tauride platform crop out beneath the Upper Cretaceous-Palaeocene Tecer limestone along a NE-SW-trending tectonic zone that is parallel to the main Divriği ophiolite further to the southeast (Figure 2). The contact relation of the two zones in the study area is obscured by extensive Oligo-Miocene sedimentary cover. The study area includes mainly the Tauride platform, the melange and ophiolitic rocks. The ophiolitic rocks are dominated by variably serpentinized mantle harzburgite and gabbroic cumulates. The mantle tectonites are intruded by a number of isolated dykes, mainly microgabbro to diabase and, less commonly, pyroxenite. Parlak et al. (2006) recorded that the isolated microgabbro to diabase dykes in Divriği (Sivas) ophiolite were derived from an alkaline magma, derived from late-stage melts with enriched compositions. Such melts with enriched compositions would be generated along local fractures or tears in the subducting plate or large-scale break-off. The geochemistry of the isolated dykes cutting the mantle tectonites in the Tecer Mountain area has a tectonic significance, and it was considered important to test whether they are similar to the isolated dykes in Divriği ophiolite or different in origin.

The root zone of the ophiolites in the Eastern Taurides and on the top of the Niğde-Kırşehir microcontinent has been debatable. According to some workers the ophiolites were derived from the Inner Tauride Ocean between, located between Niğde-Kırşehir microcontinent and the Tauride-Anatolide continent (Dilek et al., 1999; Okay & Tüysüz, 1999; Pourteau, Candan, & Oberhänsl, 2010; Robertson, Parlak, & Ustaömer, 2009; Robertson, Parlak, Metin, et al., 2013). However number of authors have preferred to correlate all of these ophiolites with the Northern Neotethys (Gönçüoğlu, Dirik, & Kozlu, 1996–1997; van Hinsbergen et al., 2016).
limestone) which is tectonically overlain by ophiolitic rocks in the region (Figure 4) with a mélange unit at the contact. This melange includes blocks of basalt and pelagic limestone set in an ophiolite-derived matrix (Robertson, Parlak, Metin, et al., 2013). In some places, towards the contact with the Tauride platform in the Yılanlıdağ area, olistoliths of limestone and radiolarite are set in sheared serpentinites (Figure 5). The melange unit is overlain by mantle tectonites cut by isolated diabase and pyroxenite dykes at different structural levels (Figure 5). A minor amount of cumulate gabbro is locally exposed (Figure 5). Actively mined chromitite occurrences within the mantle tectonites form a considerable economic resource in the region. A complete ophiolite suite southeast of the present study area, called the Divriği ophiolite (Yılmaz et al., 2001), was interpreted to have been derived from the same (i.e. Inner Tauride) oceanic basin (Parlak et al., 2006; Robertson, Parlak, Metin, et al., 2013). The mantle tectonites are dominated by limestone) which is tectonically overlain by ophiolitic rocks in the region (Figure 4) with a mélange unit at the contact. This melange includes blocks of basalt and pelagic limestone set in an ophiolite-derived matrix (Robertson, Parlak, Metin, et al., 2013). In some places, towards the contact with the Tauride platform in the Yılanlıdağ area, olistoliths of limestone and radiolarite are set in sheared serpentinites (Figure 5). The melange unit is overlain by mantle tectonites cut by isolated diabase and pyroxenite dykes at different structural levels (Figure 5). A minor amount of cumulate gabbro is locally exposed (Figure 5). 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serpentinites, serpentinized harzburgites and contain, to a lesser extent, dunites (Figure 6(a) and (b)). The serpentinite is widely altered to listwaenite. The serpentinized harzburgites display porphyroclastic to mesh textures and consist of olivine (70–85 vol.%), orthopyroxene (15–20 vol.%), clinopyroxene (<3 vol.%), and chromian spinel (1–1.5 vol.%). Dunites consist of olivine grains that are divided into numerous small grains by a serpentine mesh texture. The isolated dykes cutting the mantle tectonites are quite common and are typically microgabbro-diabase, microdiorites and pyroxenite. The dykes have sharp contacts with the host rocks and lack chilled margins, suggesting that the host rocks were still hot at the time of dyke emplacement (Figure 6). The pyroxenite dykes have a granular texture and are from 10 to 60 cm thick (Figure 6(c)). They are made anhedral clinopyroxene (85–90 vol.%), orthopyroxene (7–8 vol.%) and opaque minerals. The microgabbro-diabase dykes, 50 cm to 2 m thick, exhibit a subophitic texture (Figure 6(f)) and contain plagioclase (50–55 vol.%) and clinopyroxene (20–30 vol.%). The clinopyroxenes are partly replaced by amphibole. The microdiorites have microgranular to intergranular textures and are characterized by plagioclase (55–60 vol.%), amphiboles (25–30 vol.%) and pyroxenes (5–10 vol.%). Epidote and chlorite are secondary phases. Some of the amphiboles have been transformed from pyroxenes. The gabbro, gabbronorite and olivine gabbro mafic cumulate blocks (Figure 6(d) and (e)) are very fresh and exhibit a banded cumulate texture. The gabbros consist mainly of plagioclase (60–70 vol.%), clinopyroxene (15–20 vol.%) and orthopyroxene (2–3 vol.%). The gabbronorite comprises plagioclase (55–65 vol.%), orthopyroxene (15–20 vol.%) and clinopyroxene (20–25 vol.%). The olivine gabbro contains cumulus olivine (20–25 vol.%), plagioclase (~60 vol.%), clinopyroxene (15–20 vol.%) and orthopyroxene (1–2 vol.%). The ophiolite-related rocks south of the Teker Mountains along the southern margin of the Sivas basin are interpreted as part of the Divriği ophiolite found more to the south-southeast (Figure 2).
Table 1. Major and trace element contents of the isolated dykes in the study area.

| Sample | IAT-type isolated dykes | Low isolated dykes |
|--------|--------------------------|-------------------|
|        | TO-1                     | TO-3              |
|        | TO-5                     | TO-6              |
|        | TO-12                    | TO-11             |
|        | TO-14                    | TO-16             |
|        | TO-19                    | TO-21             |
|        | TO-23                    | TO-24             |
|        | TO-25                    | TO-26             |
|        | TO-27                    | TO-28             |
|        | IAT-type isolated dykes  | Low isolated dykes |
|        | TO-1                     | TO-3              |
|        | TO-5                     | TO-6              |
|        | TO-12                    | TO-11             |
|        | TO-14                    | TO-16             |
|        | TO-19                    | TO-21             |
|        | TO-23                    | TO-24             |
|        | TO-25                    | TO-26             |
|        | TO-27                    | TO-28             |

| | SiO₂ | TiO₂ | Al₂O₃ | FeO* | MgO | CaO | Na₂O | K₂O | P₂O₅ | MnO | Cr₂O₃ | LOI | Sum  |
|---|------|------|-------|------|-----|-----|------|-----|------|-----|-------|-----|------|
| IAT-type isolated dykes | 46.20 | 1.47 | 15.46 | 12.86 | 7.39 | 9.42 | 16.26 | 3.92 | 0.12 | 0.22 | <0.002 | 0.003 | 99.77 |
| TO-1 | 47.87 | 1.05 | 15.77 | 9.57 | 7.42 | 5.91 | 16.41 | 2.38 | 0.08 | 0.15 | <0.002 | 0.001 | 99.77 |
| TO-3 | 44.71 | 1.23 | 17.97 | 9.22 | 6.12 | 12.05 | 17.05 | 1.19 | 0.09 | 0.13 | <0.002 | 0.002 | 99.79 |
| TO-5 | 50.76 | 1.11 | 13.64 | 10.62 | 8.92 | 11.79 | 12.14 | 2.71 | 0.07 | 0.09 | <0.002 | 0.002 | 99.78 |
| TO-6 | 47.02 | 0.87 | 11.36 | 9.13 | 7.51 | 8.94 | 9.22 | 2.15 | 0.10 | 0.14 | <0.002 | 0.002 | 99.76 |
| TO-12 | 45.65 | 0.94 | 13.40 | 7.42 | 7.51 | 8.94 | 9.22 | 2.15 | 0.10 | 0.14 | <0.002 | 0.002 | 99.76 |
| TO-11 | 44.05 | 1.31 | 15.32 | 7.42 | 7.51 | 8.94 | 9.22 | 2.15 | 0.10 | 0.14 | <0.002 | 0.002 | 99.76 |
| TO-14 | 50.25 | 0.90 | 13.40 | 7.42 | 7.51 | 8.94 | 9.22 | 2.15 | 0.10 | 0.14 | <0.002 | 0.002 | 99.76 |
| TO-19 | 46.19 | 1.45 | 15.32 | 7.42 | 7.51 | 8.94 | 9.22 | 2.15 | 0.10 | 0.14 | <0.002 | 0.002 | 99.76 |
| TO-21 | 46.32 | 1.50 | 15.32 | 7.42 | 7.51 | 8.94 | 9.22 | 2.15 | 0.10 | 0.14 | <0.002 | 0.002 | 99.76 |
| TO-23 | 42.44 | 0.37 | 15.32 | 7.42 | 7.51 | 8.94 | 9.22 | 2.15 | 0.10 | 0.14 | <0.002 | 0.002 | 99.76 |
| TO-24 | 43.95 | 0.48 | 15.32 | 7.42 | 7.51 | 8.94 | 9.22 | 2.15 | 0.10 | 0.14 | <0.002 | 0.002 | 99.76 |
| TO-25 | 51.08 | 0.37 | 15.32 | 7.42 | 7.51 | 8.94 | 9.22 | 2.15 | 0.10 | 0.14 | <0.002 | 0.002 | 99.76 |
| TO-26 | 6.74 | 0.85 | 15.32 | 7.42 | 7.51 | 8.94 | 9.22 | 2.15 | 0.10 | 0.14 | <0.002 | 0.002 | 99.76 |
| TO-27 | 4.80 | 0.85 | 15.32 | 7.42 | 7.51 | 8.94 | 9.22 | 2.15 | 0.10 | 0.14 | <0.002 | 0.002 | 99.76 |
| TO-28 | 5.40 | 0.85 | 15.32 | 7.42 | 7.51 | 8.94 | 9.22 | 2.15 | 0.10 | 0.14 | <0.002 | 0.002 | 99.76 |

Note: Total Fe is expressed as FeO*. < means below detection limit.
carbonate-clastic facies (Atabey & Aktımur, 1997; İnan & İnan, 1987; Robertson, Parlak, Metin, et al., 2013). In some places, the contact is tectonic (Figure 2). The Tecer formation, composed of a shallow marine mixed

Table 2. REE contents of the isolated dykes in the study area.

| Sample| TO-1| TO-3| TO-5| TO-6| TO-12| TO-11| TO-16| TO-19| TO-21| TO-24| TO-22| TO-26| TO-27| TO-28 |
|-------|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|
| La     | 2.5 | 2.5 | 2.5 | 2.1 | 2.1  | 2.8  | 2.4  | 2.3  | 1.4  | 1.1  | 1.1  | 1.1  | 1.1  | 1.7  |
| Ce     | 6.8 | 7.1 | 7.2 | 6.1 | 5.4  | 6.5  | 8.8  | 6.6  | 8.8  | 7.3  | 5.1  | 1.4  | 2.9  | 1.6  |
| Pr     | 1.4 | 3.2 | 2.8 | 1.1 | 0.9  | 0.7  | 0.8  | 1.5  | 2.2  | 1.2  | 0.1  | 0.2  | 0.0  | 0.0  |
| Nd     | 5.1 | 5.7 | 5.7 | 5.6 | 5.6  | 5.6  | 5.6  | 5.6  | 5.6  | 5.6  | 5.6  | 5.6  | 5.6  | 5.6  |
| Sm     | 2.9 | 2.4 | 2.4 | 2.1 | 1.7  | 2.0  | 2.9  | 2.9  | 1.7  | 0.9  | 0.0  | 0.0  | 0.0  | 0.0  |
| Eu     | 1.1 | 0.9 | 0.9 | 0.9 | 0.9  | 0.9  | 0.9  | 0.9  | 0.9  | 0.9  | 0.9  | 0.9  | 0.9  | 0.9  |
| Gd     | 4.2 | 3.3 | 3.1 | 3.1 | 3.1  | 3.1  | 3.1  | 3.1  | 3.1  | 3.1  | 3.1  | 3.1  | 3.1  | 3.1  |
| Tb     | 2.8 | 1.9 | 1.5 | 1.1 | 1.1  | 1.1  | 1.1  | 1.1  | 1.1  | 1.1  | 1.1  | 1.1  | 1.1  | 1.1  |
| Dy     | 8.5 | 2.5 | 2.5 | 2.5 | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  |
| Ho     | 12  | 8.5 | 7.1 | 5.9 | 5.9  | 5.9  | 5.9  | 5.9  | 5.9  | 5.9  | 5.9  | 5.9  | 5.9  | 5.9  |
| Er     | 3.5 | 1.7 | 1.5 | 1.3 | 1.3  | 1.3  | 1.3  | 1.3  | 1.3  | 1.3  | 1.3  | 1.3  | 1.3  | 1.3  |

Table 3. Major, trace and rare earth element contents of the cumulate gabbros and pyroxenite dyke in the study area.

| Sample| TO-7| TO-8| TO-10| TO-18| TO-17 |
|-------|-----|-----|------|------|------|
| SiO₂  | 41.62| 45.07| 46.48| 46.43| 49.97 |
| TiO₂  | 0.10| 0.22| 0.12| 0.05| 0.05 |
| Al₂O₃ | 26.61| 14.67| 16.87| 20.82| 11.4 |
| FeO*  | 2.48| 7.08| 8.77| 3.98| 3.98 |
| MgO   | 9.38| 15.84| 10.83| 9.46| 20.37 |
| CaO   | 13.79| 14.01| 15.95| 12.59| 20.04 |
| Na₂O  | 6.6| 1.15| 0.57| 0.05| 0.05 |
| K₂O   | 0.01| 0.04| 0.07| 0.01| 0.01 |
| P₂O₅  | <0.01| <0.01| <0.01| <0.01| <0.01 |
| MnO   | 0.09| 0.12| 0.15| 0.11| 0.11 |
| Cr₂O₃ | 0.08| 0.21| 0.24| 0.17| 0.17 |
| LOI   | 5.1| 3.8| 0.5| 3.4| 3.4 |
| Sum   | 99.83| 99.71| 99.76| 99.75| 99.64 |
| Ba    | 9| 5| 2| 6| 6 |
| Co    | 30.3| 57.6| 55.3| 68.1| 48.6 |
| Cs    | <0.01| <0.01| <0.01| <0.01| <0.01 |
| Ga    | 9.0| 10.6| 12.1| 1.5| 1.5 |
| Hf    | <0.1| <0.1| <0.1| <0.1| <0.1 |
| Nb    | <0.1| <0.1| <0.1| <0.1| <0.1 |
| Rb    | 5| 4| 8| <1| <1 |
| Sr    | 130.7| 56.0| 80.7| 97.1| 5.2 |
| Ta    | <0.1| <0.1| <0.1| <0.1| <0.1 |
| Th    | <0.2| <0.2| <0.2| <0.2| <0.2 |
| U     | <0.1| <0.1| <0.1| <0.1| <0.1 |
| V     | 12| 154| 141| 124| 124 |
| Zr    | <0.1| 5.5| 4| 9| 9 |
| Y     | 2.9| 6.2| 1.2| 8| 8 |
| Pb    | 3.1| 1| 1| <1| <1 |
| Ni    | 379.3| 289.0| 92.0| 93.3| 134.5 |
| Sc    | 2| 45| 30| 55| 55 |
| La    | <0.1| 0.5| 0.3| 1| 1 |
| Ce    | <0.1| 0.18| 0.03| 0.03| 0.03 |
| Pr    | <0.02| 5.2| 2.2| 0.04| 0.04 |
| Nd    | <0.3| 1.2| 0.03| 0.03| 0.03 |
| Sm    | <0.5| 0.5| 0.05| 0.05| 0.05 |
| Eu    | <0.5| 0.26| 0.09| 0.09| 0.09 |
| Gd    | <0.5| 0.17| 0.03| 0.03| 0.03 |
| Tb    | <0.05| 0.09| 0.02| 0.02| 0.02 |
| Dy    | <0.05| 0.1| 0.02| 0.02| 0.02 |
| Ho    | <0.05| 0.09| 0.02| 0.02| 0.02 |
| Er    | <0.05| 0.09| 0.02| 0.02| 0.02 |
| Tm    | <0.05| 0.09| 0.02| 0.02| 0.02 |
| Yb    | <0.05| 0.09| 0.02| 0.02| 0.02 |
| Lu    | <0.05| 0.09| 0.02| 0.02| 0.02 |

Note: Total Fe is expressed as FeO*; < means below detection limit.

The oldest unit resting unconformably above the ophiolitic unit is the Upper Cretaceous-Palaeocene Tecer formation, composed of a shallow marine mixed carbonate-clastic facies (Atabey & Aktımur, 1997; İnan & İnan, 1987; Robertson, Parlak, Metin, et al., 2013). In some places, the contact is tectonic (Figure 2). The Tecer
Major and trace element concentrations in the isolated dykes are presented in Table 1 and 2. The isolated dykes display variable loss on ignition (LOI) values between 1.8 and 6% (Table 1) and this wide variation is a crude measure of their degree of alteration and reflects the proportion of secondary hydrated aqueous or carbonate phases (Rollinson, 1993). As mobility of major and trace elements (LIL-large ion lithophiles) has been noted due to alteration after formation of a rock (Hart, Erlank, & Kable, 1974; Humphris & Thompson, 1978; Thompson, 1991), rare earth elements (REE) and HFS (high field strength) elements which are resistant to mobility caused by alteration have been used (Floyd & Winchester, 1978; Pearce & Cann, 1973).

The Nb/Y vs. Ti/Y ratio diagram discriminates between the tholeiitic and alkaline magmas (Pearce, 1982). The isolated dyke samples from the southern margin of the Sivas basin exhibit Ti/Y (194–300) and Nb/Y (.02–.05) ratios, suggesting derivation from a tholeiitic magma (Figure 7(a)). Isolated dykes intruding the Tauride ophiolites at different structural levels (i.e. Lycian, Mersin, Pozantı-Karsanti, Pınarbaşı and Divriği) are also plotted for comparison. Those from the different Tauride ophiolites were generally derived from a tholeiitic magma (Çelik, 2007, 2008; Çelik & Chiaradia, 2008; Çelik & Delaloye, 2003; Parlak et al., 1995, 2006; Parlak & Delaloye, 1996), although alkaline magma-derived isolated dykes have also been reported (Çelik, 2007; Parlak et al., 2006). The isolated dykes from the study area are exclusively represented by basaltic rock types based on their Nb/Y (.02–.05) and Zr/Ti (.003–.01) ratios (Pearce, 1996) (Figure 7(b)).

All the interelement relations and immobile trace element contents suggest two geochemically distinct subgroups, both derived from tholeiitic magma, in the isolated diabase dykes cutting the ophiolites in the Tecer Mountain area (Sivas). The first geochemical group contains higher TiO₂ (.87–1.47 wt.%), Zr (20.5–73.2 ppm), Y (19.2–31.8 ppm), Hf (.9–2.4 ppm) and Nb (.6–1.4 ppm) and low MgO (4.57–8.30 wt.%), while the second geochemical group has low TiO₂ (.36–.66 wt.%), Zr (7.8–18.7 ppm), Y (10.2–14.1 ppm), Hf (.4–.7 ppm) and Nb (.2–.6 ppm) and high MgO (6.74–11.25 wt.%) (Table 1).

Immobile trace element variations (Zr vs. Ti, Zr vs. Y and Zr vs. V) as well as FeO* (Figure 8) display generally a positive correlation and similar trend to the tholeiitic isolated dykes reported from the other Tauride ophiolites. This evidence is consistent with crystallization of olivine, clinopyroxene and plagioclase (Pearce, 1982; Pearce & Norry, 1979). Decreasing MgO contents relative to Zr suggest that olivine was an important phase during primary fractionation (Figure 8). The inter-element relations based on immobile elements suggest that the tholeiitic isolated dykes from the study area and the other parts of the Tauride ophiolites show similar geochemical formation, in turn, is unconformably overlain by continental to shallow marine sediments ranging in age from Oligocene to Plio-Quaternary (Figure 3).

3. Analytical method

To determine the geochemical and petrological characteristics of the isolated diabase and pyroxenite dykes and cumulate gabbro from the ophiolitic rocks at the southern edge of the Sivas basin, south of the Teker Mountains, a total of 22 samples were analyzed at Acme Analytical Laboratories Ltd (Canada) for whole rock major, trace and rare earth elements. Major element contents were determined from a LiBO₂ fusion by ICP-ES (Inductively coupled plasma-emission spectrometry) by using 5 grams of sample pulp. Trace element contents were determined from a LiBO₂ fusion by ICP-MS (Inductively coupled plasma-mass spectrometry) by using 5 grams of sample pulp. The results of the analyses are presented in Tables 1–3.
features, consistent with co-magmatic relationships, whereas the alkaline dyke rocks (Zr > 100 ppm) from the Pozanti-Karsanti and Divriği ophiolites exhibit a different evolutionary trend (Figure 8).

In order to characterize the degree of partial melting of the source from which the isolated dykes were derived, a Ce/Y vs. Zr/Nb plot of elements with different degrees of incompatibility is used in Figure 9(a). Partial melting is lowest where Ce/Y values are the highest and increases with increasing Zr/Nb values. In the isolated diabase dykes, the Zr/Nb values for Group I (23–96.5) are relatively higher and those of Group II are lower (31.17–39). This indicates that the isolated dykes were derived from the same source (tholeiitic), but with different degrees of partial melting; the Group I dykes with lower degrees of partial melting and the Group II dykes with higher degrees of partial melting (Figure 9(a)). To identify the mantle source for the isolated diabase dykes, Sm/Yb vs. Ce/Sm ratios were plotted together with Ocean Island Basalt (OIB) and Mid-Ocean Ridge Basalt (MORB) compositions (Figure 9(b)). Accordingly, both groups of the isolated diabase dykes have low Sm/Yb (.44–1.07) and Ce/Sm (1.57–3.22) values (Table 2) suggesting their derivation from a more depleted MORB-like mantle source, similar to the tholeiitic isolated diabase dykes cutting ophiolites in the Tauride belt (Figure 9(b)).

Chondrite-normalized rare earth element (REE) profiles for the isolated diabase dykes are given in Figure 10(a). They are illustrated to compare the REE contents of isolated diabase dykes cutting ophiolites in the Tauride belt. Group I isolated diabase dykes have a flat to slightly LREE-depleted profile (La/YbN = .32–.79) and overall REE abundances between x6 and x23 chondritic (Figure 10(a)). The Group II isolated diabase dykes are more depleted in nature and have a slightly LREE-depleted profile (La/YbN = .32–.79) and overall REE abundances between x6 and x23 chondritic (Figure 10(a)). The Group II isolated diabase dykes are more depleted in nature and have a slightly LREE-depleted profile (La/YbN = .32–.79) and overall REE abundances between x6 and x23 chondritic (Figure 10(a)). The Group I isolated diabase dykes have a flat to slightly LREE-depleted profile (La/YbN = .32–.79) and overall REE abundances between x6 and x23 chondritic (Figure 10(a)). Both the Group I and the Group II dykes display similarities to the tholeiitic dykes and the low-Ti dykes of the Tauride ophiolites (Figure 10(a)) and hence typical island arc tholeiites (i.e. Papua New Guinea, Mariana, Solomon Island, Macquarie Island) (Gust & Johnson, 1981; Jakes & Gill, 1970; Stern, 1979). An N-MORB normalized multi-element diagram for the isolated dykes is presented in Figure 10(b). Except

Figure 8. Variation of selected major and trace elements for the isolated dykes in the study area and other Tauride ophiolites. Data for the isolated dykes of the Tauride ophiolites are the same as in Figure 7.
for the relatively more depleted nature of the Group II isolated dykes compared to Group I, they exhibit similar enrichment/depletion patterns relative to N-MORB (Figure 10(b)): (a) LIL element variations (Rb, Ba, K, Sr etc.), (b) a strong negative Nb anomalies, (c) flat-lying HFS elements. The elevated concentrations of LILE relative to HFSE in subduction zone magmas originate from fluids derived from the subducting slab. These slab-derived fluids carry high concentrations of LILE while the HFSE, most notably Nb, are retained in the slab (Arculus & Powell, 1986; Pearce, 1982; Wallin & Metcalf, 1998; Yogodzinski, Volynets, Koloskov, Seliverstov, & Matvenkov, 1993). Therefore the negative Nb anomaly is clearly intrinsic to the parental magma of the isolated dykes. Th enrichment relative to other incompatible elements is interpreted as indicating a subduction zone component (Pearce, 1983; Wood, Joron, & Treuil, 1979). The negative Nb and positive Th anomalies suggest a suprasubduction zone setting for their genesis. Flat to slightly LREE-depleted patterns and a strong Nb-depletion in MORB-normalized multi-element diagrams for the crustal rocks have been documented in many supra-subduction zone type ophiolites from the Eastern Mediterranean region (Alabaster, Pearce, & Malpas, 1982; Al-Riyami, Robertson, Dixon, & Xenophontos, 2002; Bağcı & Parlık, 2009; Bağcı, Parlık, & Höck, 2008; Beccaluva, Coltorti, Giunta, & Siena, 2004; Beccaluva, Coltorti, Saccani, & Siena, 2005; Dilek & Thy, 2009; Meffre, Aitchison, & Crawford, 1996; Parlık, 1996; Parlık, Höck, Kozlu & Delaloye, 2004; Parlık, Rızaoğlu, Bağcı, Karaoğlan, & Höck, 2009; Parlık et al., 2000; Parlık, Karaoğlan, Rızaoğlu, Nurlu, et al., 2013; Parlık, Çolakoğlu, et al., 2013; Pearce, 2003; Pe-Piper, Tsikouras & Hatzipanagiotou, 2004; Rızaoğlu, Parlık, Höck, & İşler, 2006; Saccani & Photiades, 2005; Vergili & Parlık, 2005; Yalıniz, Floyd, & Gençoğlu, 1996, 2000).

Th-enrichment and Nb-depletion seen in the multi element diagram (Figure 10(b)), are characteristic geochemical features for subduction related settings. On a Nb/Th vs. Y diagram (Jenner, Dunning, Malpas, Brown, & Brace, 1991) to discriminate arc and non-arc settings (Figure 11) the isolated diabase dykes cutting the ophiolite body in the Tecer Mountain area (Sivas) clearly confirm their subduction-related origin (Nb/Th = 1.5–5). Ti/V ratio is used to distinguish Island Arc (≤20), MORB (20–50) and Ocean Island Basalt (>50) (Shervais, 1982). The Ti/V ratio of the Group I dykes range from 14 to 25 and the Group II dykes range from 7.9 to 10.2, suggesting that although the Group I dykes have a minor overlap with MORB values they all formed in a supra-subduction zone setting (Figure 12). The transitional composition from mid-ocean ridge basalt (MORB) to island arc basalt for the Group I dykes may well be attributed to subduction initiation process (Hall, Gurnis, Sdrolias, Lavier, & Müller, 2003). Reagan et al. (2010) described fore-arc basalts (FAB) in the Mariana fore-arc, exhibiting similarities to mid-ocean ridge basalts (MORB) that were derived from more depleted mantle sources with subduction component. These fore-arc basalts (FAB) from the Izu-Bonin-Mariana (IBM) system yielded ages around 51.5 Ma that have been interpreted as the age of subduction initiation (Ishizuka et al., 2011; Reagan et al., 2013). This indicates that melts forming the oceanic crust in a fore-arc spreading environment during subduction initiation are compositionally more akin to depleted mid-ocean ridge basalts and become more boninitic as subduction progressed with melting of more depleted mantle (Reagan et al., 2013).

A V/Yb diagram is used to show the effect of oxygen fugacity from MORB to Island Arc Tholeiites (IAT). V is more incompatible in the higher oxidation states and this causes more V to be partitioned into the magma (Pearce, 2014; Pearce & Parkinson, 1993). V/Yb contents of the isolated dykes from the study area are presented in Figure 13. MORB magmas are thought to be generated in relatively reducing conditions (quartz-fayalite-magnetite buffer: QFM-1) whereas oceanic arc magmas are generated at higher oxygen fugacity (quartz-fayalite-magnetite buffer: QFM + 1) (Ballhaus, 1993; Kelley & Cottrell, 2012; Pearce & Parkinson, 1993). The Group I dykes display oxygen fugacities around the QFM trend, transitional between MORB and IAT, whereas the low-Ti
elements (i.e. Cs, Hf, Nb, Ta, Th, U and rare earths) in Table 3 are attributed to the high proportion of cumulus minerals and low amounts of intercumulus-trapped liquid in the magma chamber. The major (Al<sub>2</sub>O<sub>3</sub>, MgO, CaO) and trace (Ni, Cr, Co, Sr) element geochemistry of gabbroic cumulates suggest that olivine, spinel, clinopyroxene and plagioclase fractionation played an important role within a magma chamber during their genesis at the base of an intra-oceanic arc setting. Similar features were reported from the cumulate rocks of the Mersin, Pozantı-Karsantı, Kızıldağ (Hatay) and Tekirova (Antalya) ophiolites (Bağcı, Parlak, & Höck, 2005; Bağcı et al., 2006; Parlak et al., 1996, 2000, 2002). The pyroxenite dyke cutting the mantle tectonite is characterized by low contents of TiO<sub>2</sub> (.04–.07 wt.%), P<sub>2</sub>O<sub>5</sub> (.02 wt.%), large-ion lithophile (LIL) elements such as Ba (.04–.07 ppm), Rb (3.8–6.2 ppm), other incompatible elements, i.e. Zr (4.5–5.5 ppm), Y (.2–6.2 ppm), and REE. In contrast, the concentrations of Al<sub>2</sub>O<sub>3</sub> (14.67–26.61 wt.%), CaO (12.59–15.95 wt.%) and MgO (9.38–15.84 wt.%) are high (Table 3). The gabbro (TO-7) sample has exceptionally high Al<sub>2</sub>O<sub>3</sub> and low FeO*<sup>+</sup>, suggesting that it contains a very high proportion of plagioclase. Whereas the olivine gabbro samples (TO-8 and 10) have high MgO, Cr and low Al<sub>2</sub>O<sub>3</sub>, suggesting high proportion of olivine. The gabbronorite (TO-18) sample has high Al<sub>2</sub>O<sub>3</sub>, MgO, FeO* and CaO, suggesting high proportion of plagioclase, clinopyroxene and orthopyroxene phases. The low concentrations of the incompatible trace elements (i.e. Cs, Hf, Nb, Ta, Th, U and rare earths) in Table 3 are attributed to the high proportion of cumulus minerals and low amounts of intercumulus-trapped liquid in the magma chamber. The major (Al<sub>2</sub>O<sub>3</sub>, MgO, CaO) and trace (Ni, Cr, Co, Sr) element geochemistry of gabbroic cumulates suggest that olivine, spinel, clinopyroxene and plagioclase fractionation played an important role within a magma chamber during their genesis at the base of an intra-oceanic arc setting. Similar features were reported from the cumulate rocks of the Mersin, Pozantı-Karsantı, Kızıldağ (Hatay) and Tekirova (Antalya) ophiolites (Bağcı, Parlak, & Höck, 2005; Bağcı et al., 2006; Parlak et al., 1996, 2000, 2002). The pyroxenite dyke cutting the mantle tectonite is characterized by low contents of TiO<sub>2</sub> (.05 wt.%), LIL and high-field strength (HFS) elements, whereas it is rich in Ni (134.5 ppm), Cr (.42 wt.%), MgO (20.37 wt.%) and CaO (20.04 wt.%) (Table 1). Low Nb/Y ratios in the cumulate rocks (.02–.04) are characteristic of subalkaline (tholeiitic) basalts (Winchester & Floyd, 1977). Major element compositions of the cumulate gabbros, pyroxenite
whereas the isolated diabase dykes plot in the arc-related non-cumulate field (Figure 14). This implies that both the cumulate and non-cumulate mafic-ultramafic rocks formed in a subduction-related tectonic setting. Rare earth element (REE) concentrations of three cumulate gabbros and one pyroxenite sample are given in Table 3. Overall, they display more depleted REE patterns than the isolated dykes (Figure 10(a) and (b)). The cumulate rocks exhibit slightly depleted light rare earth element (LREE) to flat heavy rare earth (HREE) element patterns ($\text{La/Yb}_N = 0.3–1.1$) and overall REE abundances of between $\times 5$ and $\times 0.3$ chondritic (Figure 10(a)). The pyroxenite dyke within the mantle tectonites exhibit the most-depleted REE patterns, with overall REE abundance from $\times 0.3$ to $\times 0.8$ chondritic and flat patterns ($\text{La/Yb}_N = 0.72$). The N-MORB normalized multi-element diagram for the gabbros and pyroxenite also confirms their depleted nature (Figure 10(b)).

5. Discussion & conclusion

The ophiolitic rocks from the southern margin of the Sivas basin, south of the Tecer Mountain area are thought to be the northwestern extension of the Divriği (Sivas) ophiolite, cropping out between Çetinkaya and Divriği towns (Sivas). The Divriği ophiolite formed in a suprasubduction zone setting during the late Cretaceous and was emplaced onto the Tauride platform (Parlak et al., 2006; Parlak, Karaoğlan, Rızaoğlu, Klötzli, et al., 2013). Other ophiolites along the Tauride platform (the Lycian nappes, Tekirova, Beysëhir-Hoyran nappes, Mersin, Alihoca, Pozanti-Karsanti, Pınarbaşı and Divriği) originated in different oceanic basins, namely the İzmir-Ankara Erzincan ocean, the Inner Tauride ocean and the Southern Neotethys. The Lycian nappes (Köyceğiz/Yeşilova ophiolites and associated mélanges) at the western end of
Taurides, are interpreted to have been derived from the northerly Neotethyan oceanic basin (Collins & Robertson, 1997, 1998, 1999). The Antalya Complex, including the Tekirova ophiolite, has been compared with the Troodos ophiolite (Cyprus), the Baer-Bassit ophiolite (northern Syria) and the Kızıldağ (Hatay) ophiolite. These ophiolites originated within the Southern Neotethys (Çetinkaplan et al., 2016; Robertson & Waldron, 1990; Robertson & Woodcock, 1981a, 1981b, 1981c, 1982; Robertson et al., 2012). The Beyselit-Hoyran Nappes further to the east originated near the southern margin of the Inner Tauride Ocean and reached their present position by out-of-sequence thrusting in the Late Cretaceous (Andrew & Robertson, 2002). The Mersin, the Pozanti-Karsanti, the Alihoca ophiolites and associated units were rooted in the Inner Tauride Ocean that evolved between the Ízmir-Hattousa Suture zone and the Tauride platform to the south and were thrust southwards onto the Tauride platform (Dilek & Whitney, 1997; Dilek et al., 1999; Lytwyn & Casey, 1995; Parlak & Robertson, 2004; Polat & Casey, 1995; Polat, Casey, & Kerrich, 1996). The Pınarbaşı (Kayseri) and the Đivnići (Sivas) ophiolites formed by spreading above a northward-dipping, intra-oceanic subduction zone within the Inner Tauride Ocean and were emplaced onto the East Tauride platform as a result of trench-margin collision during the latest Cretaceous (Parlak et al., 2006; Robertson, ParlaK, Metin, et al., 2013; Vergili & ParlaK, 2005).

The Inner Tauride Ocean is believed to have separated the Tauride-Anatolide block from the Central Anatolian Crystalline Complex (Andrew & Robertson, 2002; Dilek et al., 1999; Görür, Tüysüz, & Şengör, 1998; Görür et al., 1984; Okay & Tüysüz, 1999; Pourteau et al., 2010; Robertson et al., 2009). This oceanic basin was consumed as a result of north-dipping subduction and closed during the latest Cretaceous to early Cenozoic times. There are number of arguments supporting the existence of the Inner Tauride suture, evolved during the Late Triassic to Eocene, between the Central Anatolian Crystalline Complex and the Tauride-Anatolide Block such as; (a) contrasting metamorphic histories of the Central Anatolian Crystalline Complex and the Tauride-Anatolide Block (Dilek & Whitney, 1997; Fayon, Whitney, Teysier, Garver, & Dilek, 2001; Okay, Harris, & Kelley, 1998; Pourteau et al., 2010; Robertson et al., 2009; Seaton, Whitney, Teysier, Toraman, & Heizler, 2009; Sherlock, Kelley, Inger, Harris, & Okay, 1999; Whitney & Dilek, 1998; Whitney & Hamilton, 2004; Whitney, Teysier, Dilek, & Fayon, 2001; Whitney, Teysier, Fayon, Hamilton, & Heizler, 2003), (b) late Cretaceous I-type calc-alkaline granitoids from the western margin of the Central Anatolian Crystalline Complex (Kadioğlu, Dilek, & Foland, 2006), (c) well-preserved metamorphic soles with a consistent late Cretaceous (92–93 Ma) ages compared to the ophiolites of the İzmir-Ankara-Erzincan suture zone (Çelik et al., 2006, 2011; ParlaK & Delaloye, 1999; ParlaK, Čolakoğlu, et al., 2013; ParlaK et al., 2006), (d) existence of blueschist blocks within unmetamorphosed melanges associated with some of the Tauride-Anatolide ophiolites (Droop, Karakaya, Eren, & Karakaya, 2005; Gönçüoğlu, Özcan, Turhan, & Işık, 1992; van der Kaaden, 1966; Okay, 1982; Pourteau et al., 2010; Rimmler, 2003), (e) the Tauride-Anatolide continent, a good example of a subducted, exhumed passive margin within a collisional orogen (Robertson et al., 2009), (f) the arc-related setting of the volcanics within the post-collisional basins (i.e. Ulükışla) covering the southern margin of the Central Anatolian Crystalline Complex (Andrew & Robertson, 2002; Clark & Robertson, 2002; Göktên, 1993; Göktên & Floyd, 1987; Görür et al., 1984, 1998).

Petrological studies of the mantle tectonites of the Tauride ophiolites show that two types of mantle residues, such as Mid-Ocean Ridge (MOR) and Suprasubduction zone (SSZ) type exist, suggesting a low degree of partial melting in a mid-ocean ridge environment during the opening stage of the Neotethyan oceanic basins, followed by re-melting and depletion in a suprasubduction zone (SSZ) setting (Aldanmaz, Schmidt, Gourgaud, & Meisel, 2009; Caran, Çoban, Flower, Ottley, & Yilmaz, 2010; Saka, Uysal, Akma, Kalivoda, & Hochleitner, 2014; Uysal et al., 2012). The crustal rocks (i.e. isotropic to cumulate gabbro, sheeted dykes) of the ophiolites along the Taurides suggest that they were mainly derived from island arc thelithic melts in a SSZ setting (Bağcı et al., 2006; ParlaK et al., 1996, 2000, 2002). Individual dyke emplacement in mantle tectonites, tectonically underlying metamorphic soles as well as crustal rocks of the ophiolites along the Tauride belt, is a conspicuous feature. These individual dykes were not observed within the ophiolitic melanges, suggesting that they intruded prior to mélangé formation and after ophiolite emplacement onto the Tauride platform. Individual dykes were observed to be undeformed or unmetamorphosed after their emplacement. The petrology of isolated dykes along the Tauride belt suggests that they originated from depleted or enriched mantle sources as a result of either (a) ridge-subduction (Lytwyn & Casey, 1995; Polat et al., 1996), or (b) slab break-off (Çelik, 2007; ParlaK et al., 2006), or (c) multiple intra-oceanic thrusting and emplacement in small oceanic basins (Çelik, 2007; Çelik & Chiaradia, 2008) and (d) asymmetrical ridge collapse (Dilek et al., 1999).

ParlaK (2016) suggested that subduction initiation and roll-back processes (Stern & Bloomer, 1992) could best explain the structural and petrological relationships of the ophiolite genesis, metamorphic sole formation and subsequent dyke emplacement along the Tauride mountain range. During subduction initiation, mainly OIB-like alkaline and MORB-type thelithic basalts were accreted to the base of the overriding oceanic plate and metamorphosed under amphibolite facies conditions between about 96–90 Ma ago, based on 40Ar–Ar ages. Following the subduction initiation and metamorphic sole formation, old and dense lithosphere sinking into the asthenosphere rolled back and the metamorphic
sole was attached to the base of the overriding plate. Hot asthenosphere flowed upward into the region above the sinking plate margin. Crustal formation was fed by melts, including both boninitic (high-Mg andesites) to island arc tholeiitic magmas, leaving a refractory harzburgitic mantle residue. After ~2 Ma, post-metamorphic isolated dykes intruded the metamorphic sole and the overlying oceanic lithosphere (91–86 Ma; 40Ar–39Ar data). Late stage dykes with enriched compositions are interpreted to have been derived from local fractures or tears in the subducting plate rather than large-scale breakoff.

The geochemistry of the isolated dykes cutting the mantle tectonites in the studied region clearly show that they were derived from a tholeiitic magma in a suprasubduction zone (SSZ) setting within the Inner Tauride Ocean in the Late Cretaceous. The REE and multielement diagrams, as well as trace element (i.e. V, Ti) contents, suggest that the isolated dykes are characterized by two subgroups, namely the Group I normal tholeiitic dykes and the Group II low-Ti tholeiitic dykes, suggesting progressive source depletion in a SSZ setting. Melting of the mantle in the presence of water makes the melting process more oxidising and that in turn increases the proportion of vanadium in the higher oxidation states. Because V is more incompatible in the higher oxidation states, this causes more vanadium to be partitioned into the magma. Thus, subducted water led to a melting regime that produces magmas with not just lower Ti but also higher V (Pearce, 2014; Pearce & Parkinson, 1993). The V–Ti diagram of Shervais (1982) clearly shows that the V/Ti ratio is low in MORB, intermediate island arc tholeites (IAT) and high in boninites. Pearce (2014) stated that subduction-initiation ophiolites commonly form a distinct time trend on the V/Ti diagram of Shervais (1982): from more MORB-like when subduction begins, to more IAT-like as subduction influence increases, to more boninitic-like as the slab subducts far enough to act as a barrier to mantle flow. The isolated dykes in the study area exhibit relatively higher oxygen fugacities (Figure 13) and suggest their origin was from an intra-oceanic subduction related setting. The major and trace element (including REE) geochemistry of the mafic cumulate rocks suggests that the primary magma was compositionally similar to those observed in modern island-arc tholeiitic sequences and the eastern Mediterranean ophiolites.

The isolated dykes cutting the metamorphic sole and the mantle tectonites in the Divriği (Sivas) region yielded a 75.9 ± 30 Ma 40Ar–39Ar cooling age (Parlak, Karaoğlan, Rızaoğlu, Klötzli, et al., 2013), and exhibit an alkaline (Nb/Y = 0.68–2.11) character, geochemically similar to within-plate alkaline basalts (Parlak et al., 2006). Whereas the crustal rocks (cumulates, isotrope gabbro and sheeted dykes) of the Divriği ophiolite are tholeiitic in composition and geochemically depleted in nature (Parlak, Yılmaz, Boztuş, & Höck, 2005). They formed in a suprasubduction zone tectonic setting north of the Tauride platform in the Late Cretaceous (~90 Ma) (Parlak et al., 2005; Parlak, Karaoğlan, Rızaoğlu, Klötzli, et al., 2013). Its alkaline isolated dykes were probably the result of late-stage magmatism fed by melts that originated within an asthenospheric window due to slab break-off, shortly before the emplacement onto the Tauride platform to the south (Parlak et al., 2006). This may suggest that melts with enriched and depleted compositions were effective during the crustal architecture above an intraoceanic subduction zone for the Divriği ophiolite and the ophiolite in the Tecer Mountain area.

The ophiolite rocks from the southern margin of the Sivas basin around the Tecer Mountains and the Divriği (Sivas) region exhibit number of similarities. (a) They display a common tectono-stratigraphy from bottom to top (Tauride platform, melange and ophiolite). (b) The ophiolites in the region namely the Pınarbaşı (Kayseri), Gürün, Divriği (Sivas), Kuluncak, Hekimhan (Malatya), Dağlıca (Afşin-Kahramanmaraş) were interpreted as fragments of regional-scale thrust sheet of emplaced SSZ-type oceanic lithosphere onto the Eastern Tauride carbonate platform during latest Cretaceous time and displaced by later tectonics and suture tightening (Robertson, Parlak, Metin, et al., 2013). (c) Robertson, Parlak, Metin, et al. (2013) stated that the Taurides as a whole exhibit a common palaeogeography and tectonic evolution during Triassic-Eocene time. (d) Mesozoic carbonate platform and continental margin units in the Divriği (Sivas) region are interpreted as rifted northern margin of the Tauride-Anatolide microcontinent bordering the Inner Tauride Ocean in the north (Robertson, Parlak, Metin, et al., 2013). All the evidence suggests that the ophiolites and related rocks in the southern margin of the Sivas basin around Tecer Mountain area and Divriği (Sivas) region were derived from an oceanic basin, so called Inner Tauride Ocean, to the north of the Tauride platform.

The tholeiitic isolated dykes cutting the mantle tectonites in the Tecer Mountain area differ from the alkaline isolated dykes cutting the Divriği ophiolite. Since the late stage dykes (~76 Ma) in the Divriği (Sivas) area are alkaline in nature, the tholeiitic composition of the isolated dykes in the present study suggests that they were emplaced prior to the alkaline dykes during Late Cretaceous (~90 Ma) SSZ-spreading.

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