Genesis and Tectonic Setting of Peridotitic Spinels From the Divriği-Sivas Region, Eastern Turkey

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1. Introduction

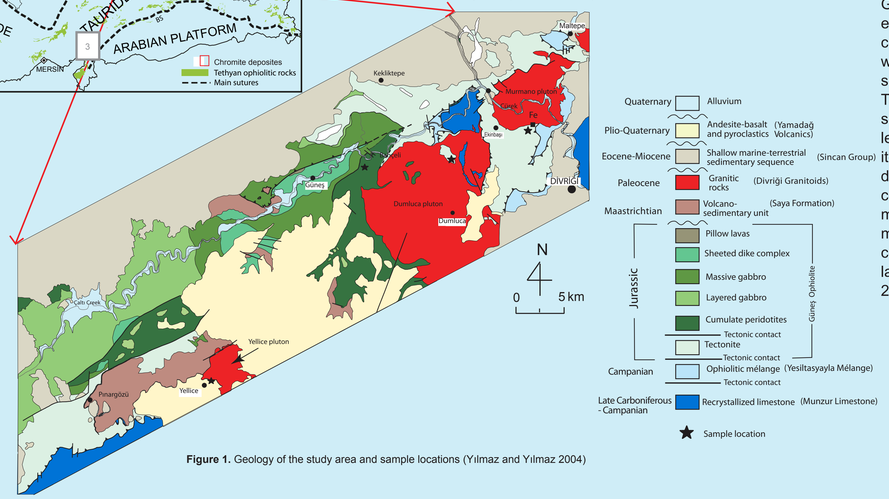


Figure 1. Geology of the study area and sample locations (Yılmaz and Yılmaz 2004)

In this study, we present new data on whole rock and spinel chemistry of peridotitic rocks in the Sivas province, eastern Turkey. The spinel chemistry and petrological characteristics are used to assess provenance of ophiolitic complex in the region. Our data are also compared to those of other Tethyan ophiolite complexes in Anatolia.

Güneş Ophiolite which was emplaced in the late Cretaceous starts at the bottom with tectonites that consist of serpentinized harzburgites. They are overlain by irregular segregations of pyroxenite levels and cumulate peridotites that contain wehrlite and dunite lenses. The series continues to the top with cumulates and layered- and massive-gabbros, sheet dyke complex and a thin pillow-lava level (Yılmaz and Yılmaz 2004).

2. Sample characterization

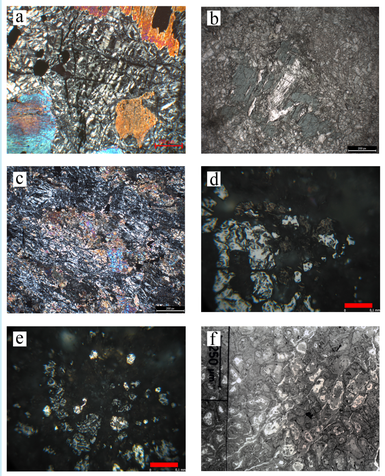


Figure 2. a. Clinopyroxene (Cpx), serpentine (Sp) and opaque minerals within wehrlite, b) uralitized clinopyroxene in the serpentinized ultramafic rock, c) clinopyroxene (diopsidic augite comp.), serpentine and opaque mineral association, d) mackinawite inclusions in pentlandite (iron-nickel sulfide) , e) disseminated pyrite and magnetite grains, f) ring-shaped magnetite surrounding silicate minerals.

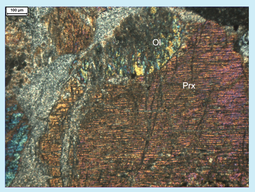


Figure 3 . Melt-rock interaction between olivine and pyroxene grains.

Wehrlite pods are characteristic with marks of melt-rock interaction that is revealed by embayed pyroxene margins, enveloped by olivine and olivine interfingering into pyroxene.

Chromites with size in the range of 250 to 750 micron are dark gray and show reflection colors darker than magnetites. As a result of progressive metasomatism, they are transformed to magnetite. Therefore granular, euhedral chromites are rarely observed. During this process, Fe-Cr spinels (ferritchromite) were formed as interphase between chromites and magnetites.

3. Serpentinite chemistry

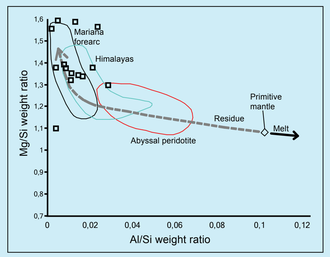


Figure 4. Mg/Si and Al/Si ratios of Divriği samples. During partial melting, the compositional variation expected is shown with black arrow (modified after Saumur et al., 2010) and the expected compositional change of residual mantle peridotites is shown as a dashed gray arrow which is originated from the primitive mantle (McDonough and Sun, 1995).

Divriği peridotites plot too far from the mantle point. Since Al is generally compatible with mantle minerals it is depleted through the partial melting process. Divriği samples are serpentinized in a SSZ environment and Mg/Si and Al/Si ratios of samples are similar to those of Himalayan and Mariana forearc serpentinites.

4. Mineral chemistry of spinels

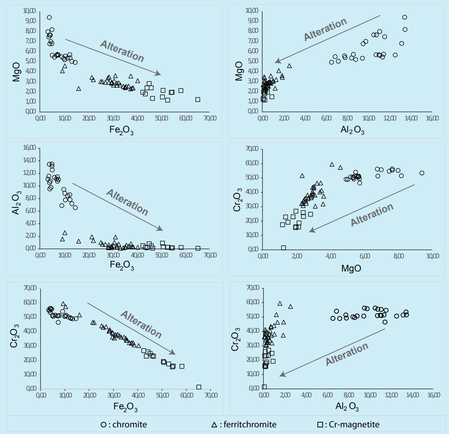


Figure 5. Major oxide relations for chromites, ferritchromites and Cr-magnetites.

There is an inverse correlation between MgO-Al_2O_3-Cr_2O_3 vs. Fe_2O_3 concentrations of chromites, ferritchromites and Cr-magnetites. Chromites are altered to first ferritchromite and then to Cr-magnetite as indicated by increasing Fe_2O_3 contents and decreasing MgO, Al_2O_3 and Cr_2O_3 concentrations

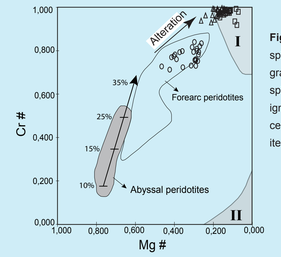


Figure 6. The core compositions of Cr-spinels are plotted in the Mg# vs. Cr# diagram (Azer, 2014). Compositions of Cr-spinels from I: metamorphic rocks, II: fresh igneous rocks. The arrow represents the percentage of partial melting of the host peridotite (Hirose and Kawamoto, 1995).

The core compositions of Cr-spinels are plotted in the Cr# – Mg# diagram (Figure 6 b). Cr# and Mg# values are positively correlated and consistent with those of forearc peridotites whilst altered zones depict composition of chromite spinels (magnetite) in metamorphic rocks. According to the model of Hirose and Kawamoto (1995), Cr-spinel compositions yield >35% partial melting and formation in a supra-subduction zone setting.

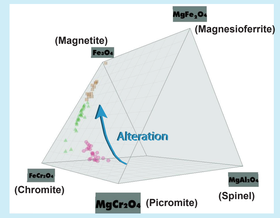
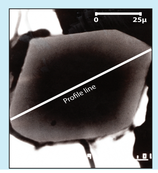


Figure 7. Distribution of chromite and alteration products in spinel prism diagrams.

chromite ferritchromite Cr-magnetite

Chromite with up to 51% dominates the composition of core. It is followed in decreasing order by picromite from 17 to 32%, hercynite from 10 to 18%, magnetite 2 to 14% and spinel from 3 to 12%. As a result of alteration, mineral composition at the rims is rather diverse where chromite is lowered to nearly 20% and magnetite is the dominant phase with an abundance of about 90%.



The grain showing a zoned structure consists of chromite at the core transforming to ferritchromite along the rims. Fe^{+2} and Mg concentrations remain unchanged from core to rim while Fe^{+3} concentrations are significantly increased but Al and Cr contents are notably decreased (Figure 8).

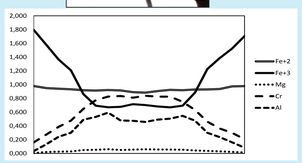


Figure 8. Profile analysis of altered chromite sample (sample no. N-83). Note that y-coordinateis given in mol numbers.

Cr# values of Divriği spinels are similar with those of selected high-Cr Turkish spinels to some extent but their Mg# values differ considerably possibly due to alteration. All spinel samples plot into supra-subduction zone peridotites and thus pointing to a podiform type ophiolite source (Figure 10).

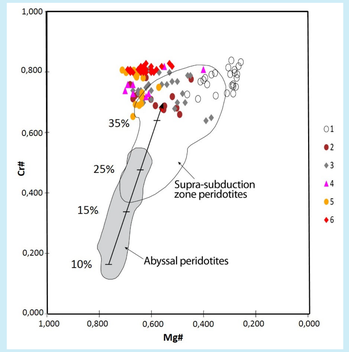


Figure 10. Cr# vs. Mg# diagram for selected Turkish chromites.

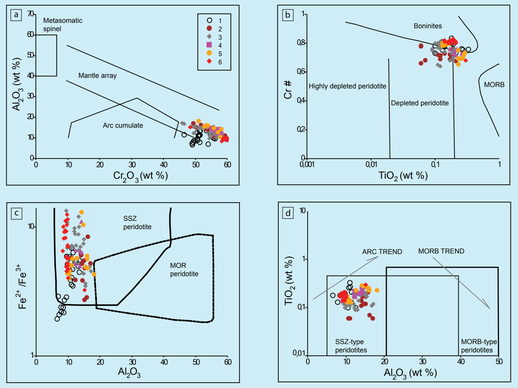


Figure 9. Comparison of Divriği chromites with those from various ophiolitic sequences in Turkey (see Figure 1 for locations) a) Distribution of fresh chromites in the Al_2O_3-Cr_2O_3 diagram (Franz and Wirth 2000), b) TiO_2-Cr# diagram for chromites (fields from Dick and Bullen, 1984; Jan and Windley, 1990; Arai, 1992), c) distribution of chromites in the Al_2O_3 vs.Fe^{+2}/Fe^{+3} diagram showing the distinction between supra-subduction zone (SSZ) and mid-ocean ridge (MOR) peridotites (fields from Kamenetsky et al., 2001), d) Al_2O_3-TiO_2 diagram showing compositional spectrum of chromites (fields from Kamenetsky et al., 2001).

As shown from Figure 9a, with the exception of a few Divriği samples, all the Turkish spinels under interest plot within the mantle array but are clustered close to the arc cumulate field. Cr_2O_3 and Al_2O_3 contents of samples from Antalya, Southeast Anatolia, Elekdağ, Eskişehir and Harmancık-Orhaneli regions are slightly higher than those of Divriği region.

In Cr# vs. TiO_2 diagram (Figure 9b), all the samples are grouped in a narrow site encompassing both bonninite and depleted peridotite fields.

According to Al_2O_3 vs. Fe^{+2}/Fe^{+3} diagram (Figure 9c), most Turkish spinels belong to supra-subduction zone (SSZ) peridotites. However, some of Divriği samples with lower Fe^{+2}/Fe^{+3} ratios and the lowest Al_2O_3 contents plot off the SSZ field. This might be attributed to hydrothermal alteration induced by granite intrusion.

Al_2O_3 and TiO_2 contents of the samples are indicative of SSZ origin with arc trend (Figure 9d).

5. Parental melt composition

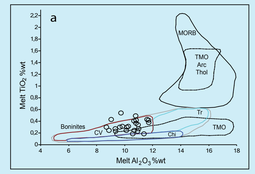
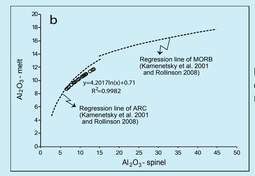
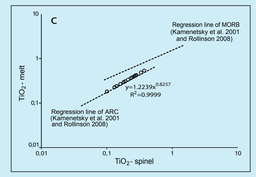


Figure 11. a) TiO_2-Al_2O_3 (wt. %) diagram constructed from computed melt compositions of Divriği chromites.

Chi: Chichijima bonninites, CV: Cape Vogel bonninites, Tr: Troodos bonninites, MORB: Mid-ocean ridge basalts, TMO: Thetford Mines Ophiolite



b)Al_2O_3(spinel)-Al_2O_3(melt) diagrams for Divriği chromites and melts



c) TiO_2 (spinel)-TiO_2 (melt) diagrams for Divriği chromites and melts.

These results suggest a boninitic affinity for the melts that generated the Divriği spinels (Wilson, 1989). In the Al_2O_3 vs. TiO_2 diagram (Figure 11a), samples are plotted within the boninite field (Page and Barnes, 2009) and mostly overlap with Cape Vogel boninites (Jenner, 1981; Walker and Cameron, 1983; Kamenetsky et al., 2002). The positions of Divriği samples in these plots yield an arc affinity (Figure 11b,c).

5. Conclusion

►The Divriği spinels in the Sivas province, eastern Turkey, show two distinct compositions. The chromite cores are represented by high Cr_2O_3 (46.50-56.24 wt. %) and very low TiO_2 contents (<0.3 wt. %). Cr-magnetites at the rims have much lower Cr_2O_3 (15.50-26.89 465 wt. %) which is accompanied by a decrease in MgO from 9.4 to 1.2 wt. % and an increase in Fe_2O_3 from 4.0 to 55.0 wt. %. Likewise, Cr# and Mg# values also followed the same trend.

►Prism diagrams built for measured spinel compositions show that chromite is the most abundant phase comprising almost 50% of the core while magnetite dominates the rims with a maximum abundance of 90%.

►When compared to selected high-Cr chromites in Turkey, Divriği spinels are found to have slightly lower Fe_2O_3 and Al_2O_3 contents and Fe^{+2}/Fe^{+3} ratios. Like some other Turkish spinels, Divriği samples were crystallized from a boninitic melt in a SSZ environment which is supported by intense degree of partial melting (~>45%) computed for spinels. Parental melt compositions of Divriği spinels computed using experimentally determined (FeO/MgO)melt, (Al_2O_3)melt and (TiO_2)melt values point out the arc setting which have Cr# lower than ~ 60 (usually between 10 and 40) with small to moderate amount of partial melting (5-15%).

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