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Research Article

Multi-stage Evolution of the Mehmetalan Ophiolite: Cr-Spinel Characteristics of Podiform Chromitites

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Abstract – In this study, we aimed to report preliminary Cr-spinel chemistry results from the podiform chromitites of the Mehmetalan Ophiolite to shed light on their petrogenesis and tectonic settings. Mehmetalan ophiolite is ordinarily represented by peridotite (harzburgite, dunite, serpentinite), ultramafic-mafic cumulates (layered-isotropic-pegmatitic gabbro, pyroxenite-dunite intercalation). The mafic-ultramafic lithologies are locally cut by pyroxenite and isolated diabase dykes. In the chromites, lens-shaped massive, nodular and partially banded structures are seen, although alteration with Fe is not very common. However, the effects of dynamic metamorphism are observed as fractures on Cr-spinels. Chromitites of Mehmetalan Ophiolites can be divided into two groups according to the composition of their Cr#. Cr-spinel in the Group-1 (high-Al) chromitites have much lower Cr# values (0.49–0.52) than those in the Group-2 (high-Cr) chromitites (0.72–0.74). The spinel types of high-Al chromitites (Group-1) are spinel and magnesiochromite, whereas high-Cr chromitites (Group-2) with metallurgical character are magnesiochromite. Mineralogical and geochemical data obtained from Mehmetalan Ophiolite chromitites show that high-Al composition chromitites (Group-1) are associated with MORB-type melts formed from partial melting at a lower rate. In contrast, high-Cr chromitites (Group-2) are formed concerning boninitic composition melts formed by re-depleting the previously partially depleted mantle.

Keywords – Cr-spinel, Chromitite, Geochemistry, Mantle Peridotite, Mineral Chemistry, Ophiolite, Van

I. INTRODUCTION

Ophiolites, representing fragments of the oceanic lithosphere, can provide critical clues into the oceanic tectonic processes over time ([1], [2]). Ophiolites are widely situated along the Alpine-Himalayan orogenic belt, particularly in Türkiye, associated with E–W trending suture zones. They have different tectonic settings, including supra-subduction zones (SSZ), mid-ocean ridges (MOR), and back-arc basins.

Podiform chromitites are seen only in ophiolitic peridotites, and their name comes from their pod-like form. They typically host in harzburgites, commonly enclosed in dunite envelopes [3]. Studies of podiform chromitites in Cretaceous ophiolites shed light on understanding Cretaceous plate tectonics, geodynamics, and mantle-crust material cycle. Most researchers have admitted that ophiolitic chromite was formed during the melt-melt interaction and/or melt-rock reaction in the mantle section of ophiolites in the supra-subduction zone (SSZ) tectonic setting of the ophiolites ([4]–[17]).

Chromitites are generally categorised as high-Al types and high-Cr with Cr# (=Cr/[Cr+Al]) of <0.6 and ≥0.6, respectively [18]. High-Cr chromitites are arc-related and derived from boninitic magmas ([3], [4], [6], [19], [20]), whereas the high-Al chromitites are thought to originate from arc tholeiite or MORB-like magmas. ([4], [10], [16], [21], [22]) There is a consensus among researchers that high-Cr chromitites (Cr#>0.6) are located in the deeper parts of the mantle, while high-Al chromitites (Cr#<0.6) are located in the shallower parts of the mantle ([17], [23]–[27]).

Many ophiolite units cropping out east of the Southeastern Anatolian Ophiolite Belt have been subjected to intense deformation, making them difficult to identify and study. Conducting Cr-spinel studies in chromitites associated with ophiolites, which are less affected by alteration and deformation than ophiolitic rocks, provides more reliable data about the petrogenesis and tectonic environments of these units.

We report preliminary Cr-spinel chemistry results from the podiform chromitites of the Mehmetalan Ophiolite to shed light on their petrogenesis and tectonic settings.

II. GEOLOGICAL SETTING AND DESCRIPTION OF THE CHROMITITES OF MEHMETALAN OPHIOLITE

The study area is east of the Eastern Anatolian Accretionary Complex and northeast of Van province (Fig. 1). The geological units from oldest to youngest are Paleozoic metamorphic rocks, Upper Cretaceous ophiolitic mélange, Oligocene–Miocene sedimentary rocks, Middle Miocene to Quaternary aged volcanic rocks and cover sediments. Within this zone, ultramafic-mafic rocks representing parts of a dismembered ophiolite complex called Mehmetalan, Alabayır, Mollatopuz, and Yukarıbakçıklı [27]. Mehmetalan ophiolite is dominated by peridotite (harzburgite, dunite, serpentinite), ultramafic-mafic cumulates (layered-isotropic-pegmatitic gabbro, dunite-pyroxenite intercalation). The mafic-ultramafic lithologies are locally cut by pyroxenite and isolated diabase dykes ([28]–[30]).

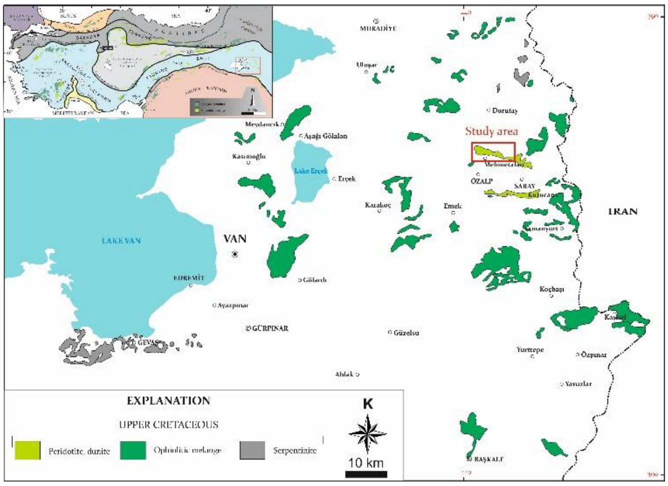

Fig. 1 Simplified map of Anatolia (adapted from [31] and references therein) and distribution of ophiolitic rocks in the east of Lake Van [32].

A more intense tectonism and deformation effect is observed since the mineralization is within the Eastern Anatolian Accretionary Complex (Fig. 2A-F). Especially in the mining site, the host rocks of the chromitite masses are intensely serpentinized (Fig. 2B). In the Mehmetalan area, chromitites are located within the mylonitic fault zone [33] (Fig. 2C-F). Chromite mineralization is observed in lens-shaped massive, nodular and partially banded types (Fig. 2D-F). Chromite nodule's size range from 0.3–1.5 cm [27].

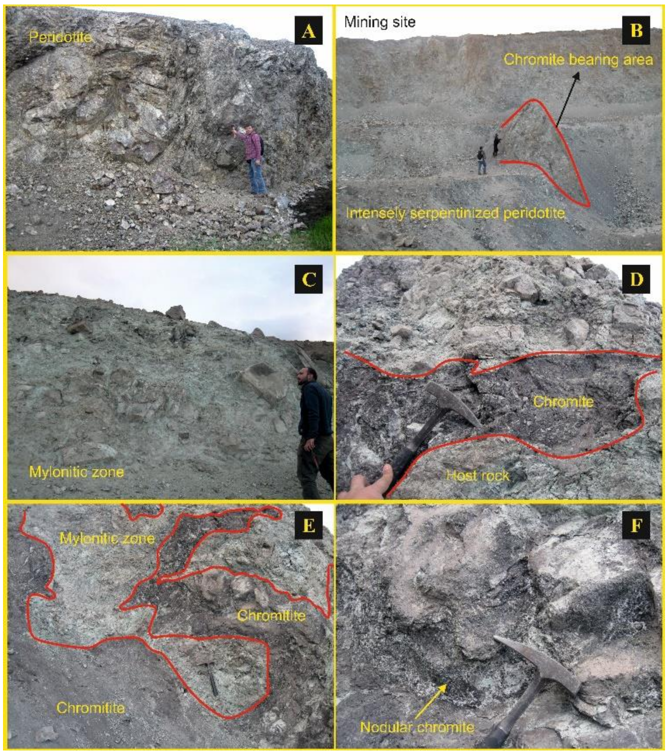

Fig. 2 Field views of the Mehmetalan ophiolitic rocks and chromitites.

Although no significant alteration with Fe is observed in Cr-spinels, there are fractures in some minerals due to the effect of dynamic metamorphism. There are highly serpentinised silicates in the form of inclusions in the chromite crystals (Fig. 3).

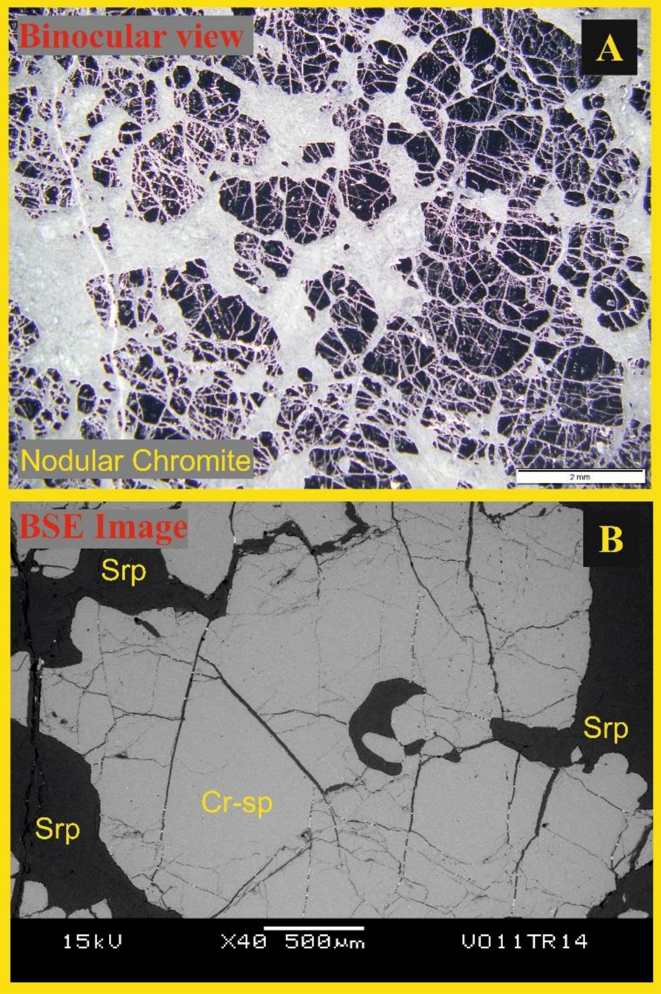

Fig. 3 Binocular (A) and BSE images (B) of Mehmetalan chromitites.

III. MATERIALS AND METHOD

Polished thick sections were prepared at the Fırat University Department of Geological Engineering (Elazığ-Türkiye) and studied under optical microscopy (reflected light-Leica). Major-element compositions of spinels in the Mehmetalan chromitite were investigated by a JEOL EPMA JXA−8900R electron probe micro-analyser (EPMA) at the Institute of Earth Sciences, Academia Sinica (Taipei, Taiwan). Observations under a reflected light optical microscope and a scanning electron microprobe (SEM) were used to provide qualitative data about the samples. Back-scattered electron (BSE) images were acquired from the polished sections. The mineral identification was made using Oxford Instruments Ltd., Xmax−50 with INCA−350, and the precise compositions were obtained using EPMA equipped with four wavelength dispersive spectrometers. Secondary- and back-scattered electron images led the analyses to the object positions. The analytical requirements were set to 15 kV acceleration voltage, 12 nA beam current and 2 μm beam diameter for chromite. Peak counting times for each element were 10 s (30 s for Ti). Detection limits were lower than 600 ppm for all elements [34].

Mehmetalan chromitites can be divided into two groups according to their Cr# values (=Cr/[Cr+Al]). Group-1's Cr# is <0.6 (high-Al chromitite), while Group-2 is ≥0.6 (high-Cr chromitite). Some oxide values of high-Al chromitites (Group-1) are as follows: Cr_2O_3 (41.10–42.09), Al_2O_3 (26.04–28.42) and FeO (15.13–17.53). The Cr# and Mg# values of these high-Al composition chromitites are 0.49–0.52 and 0.57–0.64, respectively. TiO_2 value was quite low and remained below the detection limit. The broad ranges of variation of some major oxides (wt%) in fresh centres of Cr-spinels in high-Cr chromitites (Group-2) are Cr_2O_3 (53.9–56.81), Al_2O_3 (13.35–14.45), FeO (13.70–16.16), and TiO_2 (0–0.07). The Cr# and Mg# values of these metallurgical chromitites range between 0.72–0.74 and 0.62–0.67, respectively.

IV. DISCUSSION

The formation of chromitites in the ophiolites is very complex and has been debated. One of the sources of serious controversy is the chromite concentration and the source of chromite. The origin of the dunite envelope around the chromitites is also debated. Are these dunite envelopes a crystal accumulation, refractory residue or a product of a magma-harzburgite (melt-rock) reaction [35]? In some cases, the chromite pods cut the foliation planes of the host rock (harzburgite), indicating that these pods are younger formations. According to some researchers, the podiform chromitites are cumulate, filling magma channels within the mantle peridotite, primarily cutting their host rocks ([36]–[37]). Many authors have gradually recognised the discoveries of ultra-high pressure (diamond) and crust-originated (zircon) minerals in ophiolitic chromitites. However, the formation models of these unusual minerals and their host chromitites are still under great debate (Liu et al., 2021).

Hydrous melting in supra-subduction zone (SSZ) environments can generate arc tholeiitic to boninitic magmas depending on the degree of melting and the composition of the peridotites. The lherzolitic peridotites, which are structurally lower in the mantle range, presumably symbolise the restite after mid-ocean ridge basalt (MORB) extraction ([38]–[39]).

Electron microprobe analyses of chromite overlap the compositional fields for typical ophiolitic podiform chromitites (Fig. 4A). The spinel types of high-Al chromitites (Group-1) are spinel and magnesiochromite, while high-Cr chromitites (Group-2) with metallurgical character are magnesiochromite (Fig 4B). Group-1 samples plot between abyssal-SSZ field due to lower Cr# values (0.49–0.52). However, Group-1 samples fall within boninite field close to the SSZ peridotite (Fig. 4B).

The first comprehensive study of chromitites in the eastern part of the Van region was held by [27]. The Mehmetalan chromitites were divided into two groups regarding their mineral chemistry. Group-I chromitites (with Cr# of 0,63-0,75) formed in shallow parts of the mantle at or near the MOHO transition zone, whereas Group-II chromitites (with Cr# of 0,83-0,88) formed in deeper parts of the mantle environment. The chromitites were formed in a fore-arc tectonic setting from a parental boninitic magma and cut by OIB-type diabase dikes; therefore, most probably, a slab roll-back mechanism could be considered for the Neotethys Ocean [27].

We propose a multi-stage model for the formation of the Mehmetalan chromitites. Mineralogical and geochemical data obtained from Mehmetalan Ophiolite chromitites show that high-Al composition chromitites (Group-1) are associated with MORB-type melts formed as a result of partial melting at a lower rate, while high-Cr chromitites (Group-2) are formed concerning boninitic composition melts formed by re-depletion of the previously partially depleted mantle.

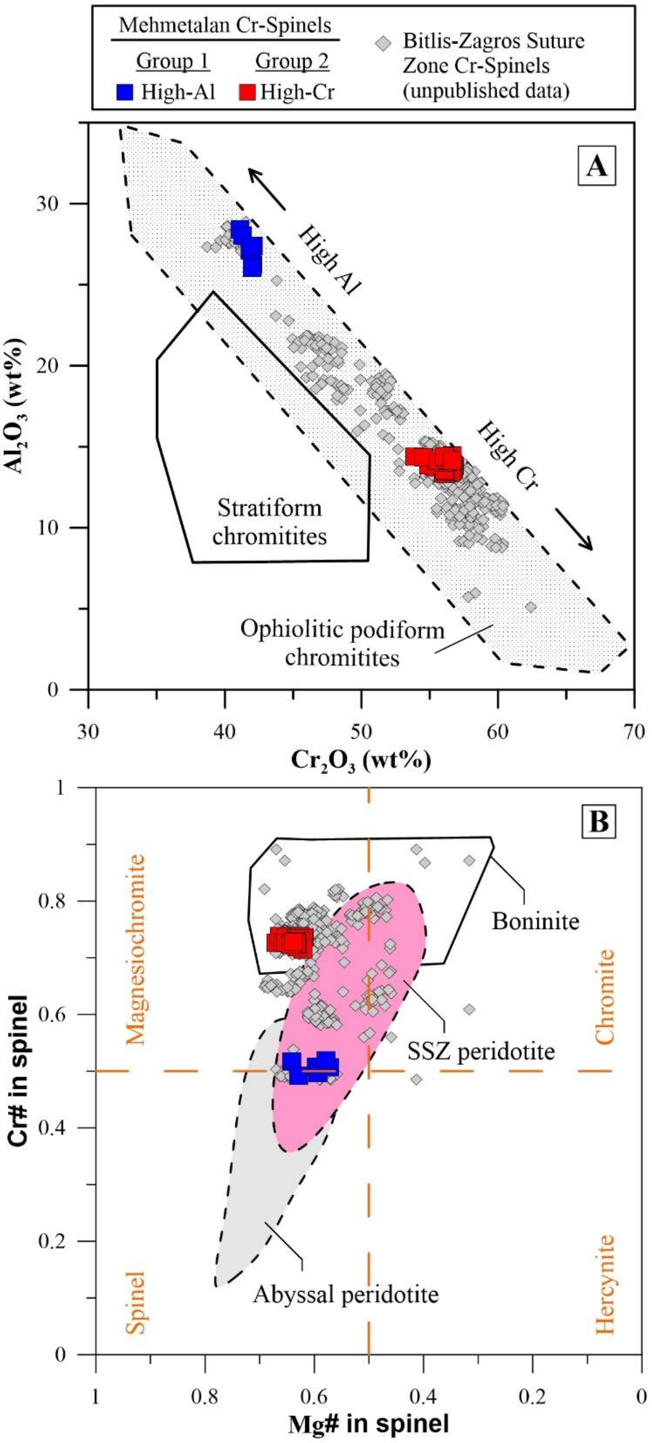

Fig. 4 Chromite major oxide data distribution of the Mehmetalan chromitites in the Cr# [Cr/(Cr + Al)] vs Mg# [Mg/(Mg + Fe^{2+}). The abyssal and forearc peridotite fields are from [40], and the boninite field is from [41] (A), Al_2O_3 (wt.%) vs Cr_2O_3 (B).

V. CONCLUSION

Within the scope of this study, the podiform chromitites of the Mehmetalan ophiolite can be divided into two subgroups as Group-1 and Group-

2, considering Cr# (Cr/(Cr + Al)). These are high-Al chromitites in Group-1 Cr# 0.49–0.52 and Group-2 high-Cr chromitites in the 0.72–0.74 range. The proposed multi-stage model for the formation of Mehmetalan chromitites is that Group 1 chromitites are formed due to low-grade melting of the mantle. Then Group-2 is formed by re-depleting the previously partially melted mantle in the SSZ environment concerning melts with boninitic composition.

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