Geological Evidence does not Support a Shallow Origin for Diamonds in Ophiolite

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Abstract: Farré-de-Pablo et al. (2018) report a new occurrence of in situ microdiamonds enclosed in chromite from ophiolitic chromitite pods hosted in the Tehuitzingo serpentinite of southern Mexico. The discovery enlarges the number of occurrence of the ophiolite-hosted microdiamonds to 7 countries in the world, including India (Das, 2015, 2017), Albania (Xiong et al., 2017; Wu et al., 2017), Turkey (Lian et al., 2017), Myanmar (Chen et al., 2018), Russia (Yang et al., 2015), and China (Bai et al., 1993; Xu et al., 2009). The microdiamonds occur in ophiolitic podiform chromitites and peridotites, and are generally interpreted as UHP phases formed at pressures > 4 GPa (Yang et al., 2014; Griffin et al., 2016; Das et al., 2017). However, Farré-de-Pablo et al. (2018) conclude that the Tehuitzingo diamonds were formed under low-temperature and low-pressure conditions during serpentinization, which challenges the current knowledge of diamond formation. Here, we discuss several lines of evidence that do not support the authors’ conclusion.

(1) The authors suggest a two stage of model for the Tehuitzingo microdiamonds crystallization. It begins with crystallization of high-T, magmatic chromite that produced grains with cores of high-Al chromite. In the second stage, the magmatic chromite developed cracks, that were then filled with hydrothermal fluids and secondary minerals, such as serpentine, quartz and chlorite, and microdiamonds that are thought to have crystallized in situ. At the same time the rim of the chromite grain was altered to typical porous ferritchromite that is slightly enriched in Fe3+. The authors suggest that these chemical trends reflect reaction of primary high-Al chromite and matrix olivine with reducing fluids to produce secondary Cr- and Fe3+-rich and Al- and Mg-depleted porous chromite in equilibrium with chlorite (Farré-de-Pablo et al., 2018, and references herein).

We plotted the Mg number [Mg/(Mg+Fe2+)] atomic ratio and Cr number [Cr/(Cr+Al)] atomic ratio of 191 chromite analysis in Fig. 1, which clearly show that the chromite of the healed fractures has essentially the same composition as that of unaltered magmatic cores, but significantly different from the ferritchromite of the grain rims. Therefore, it is difficult to understand why the diamond-bearing fracture in chromite was healed by magmatic chromite after “serpentinization”?

Thus, we suggest an alternative scenario in which the diamonds, along with a carbon-rich fluid, were incorporated into the chromite grain at the time it crystallized in the diamond stability field in the mantle (Yang et al., 2015). We note that the Tehuitzingo diamond grains occur as small crystal nuclei associated with amorphous carbon, a feature consistent with in situ diamonds in chromitites of the Luobusa and Ray-Iz ophiolites that show no signs of serpentinization (Fig. 2) (Yang et al., 2014, 2015; Zhang et al., 2016). Thus, facilitating later crack formation as the chromite cooled, thereby, allowing ingress of late-stage, serpentinizing fluids. Such fluids could modify the silicate minerals but not the diamonds. It is entirely possible that the silicate minerals in the linear arrays with diamond were retrograded from high pressure phases, i.e., quartz from coesite, and chlorite + serpentine from baiwenjiite (BWJ) crystals (Yang et al., 2007; Griffin et al., 2016). A similar phenomenon has been observed in the Luobusa chromitites where octahedral grains of antigorite define rough linear arrays in healed fractures in chromite grains (Griffin et al. 2016). These antigorite grains are likely hydrated alteration products of BWJ crystals, the latter being predicted to be stable at T~2000°C and 15 GPa (Kiefer et al., 1999). Similarly, diamonds in healed fractures in chromite may have crystallized in the deep mantle and been preserved during late-stage serpentinization. Thus, we conclude that it is highly unlikely that the Tehuitzingo diamonds and serpentinite were formed by a single process. Otherwise, it is hard to understand why serpentinization is so widespread in mantle rocks, but so few diamonds have been found in serpentinites. Most ophiolite-hosted diamonds that we have recovered are from completely fresh, unserpentinized chromitites and peridotites (Yang et al., 2015).

(2) Can diamond be generated in low P-T serpentinization environments? The authors quoted a paper by Simakov et al. (2015) to confirm the possibility that “alteration of ultramafic rocks by hydrothermal C-O-H fluids at pressures as low as 0.1 GPa and <1000°C produces nano- and microdiamonds.” We note that Simakov et al. (2015) did report an occurrence of nanodiamonds, primarily of 6 and 10 nm across, in Hyblean asphaltalene-bearing serpentine xenoliths (Sicily, Italy). However, although the sample is a serpentinized and carbonated block of peridotite that equilibrated in the upper mantle in the spinel-peridotite stability field, no evidence was offered to...
by many researchers (e.g. Butler and Woodin, 1994; Schwander and Partes, 2011). In CVD the temperature distribution, solubility and internal energy clearly depend on the type of excitation, which can be generated by microwave (MW), radiofrequency (RF), laser inducement (LI), direct current (DC), hot filament (HF) and chemical activation (CA) (Schwander and Partes, 2011). Although Kaminsky et al. (2016) suggested that the crystallization of a carbonado-like aggregate in the Avacha volcano of Kamchatka was likely due to CVD during or shortly after the course or shortly after one of the volcanic eruption pulses, the energy source for the activation of the chemical processes that liberate and deposit carbon (the source of diamond) was not confirmed. Generally, diamond formation by CVD is a complex process requiring temperatures of ~600–1000°C, mostly higher than the temperatures of serpentinization (< 700°C) (Ulmer and Trommsdorff, 1995; Maeda et al., 1998; Battaille et al., 1999; Deschamps et al., 2013), which shows clearly that CVD diamond would rarely, if ever, generated by serpentinization of ultramafic rocks in nature.

(3) Another critical evidence is that several thousands of microdiamonds recovered from fresh samples of chromitite and peridotite but serpentine from many ophiolites in different parts of the world, which does not support that diamonds could be generated by low P-T serpentinization. Also Farré-de-Pablo et al. (2018) have clearly ignored the presence of many other UHP phases occurring both as inclusions in the ophiolite-hosted diamonds and as associated grains in the host chromitites and peridotites. Yang et al. (2007) reported the discovery of coesite rimming a grain of FeTi alloy in the Luobusa chromitite, which requires minimum pressures of ~2.8 GPa. They suggested that the coesite is a pseudomorphic replacement of stishovite, and implying a pressure of > 9GPa. Further detailed investigation on the coesite grains revealed the occurrence of submicroscopic inclusions of high-pressure nitrides, oxides, and native Fe within the coesite (Dobrzheletskaya et al. 2009), an assemblage interpreted as having formed under high-pressure and highly reduced conditions at a depth of at least 300 km (Dobrzheletskaya et al. 2009). Coesite also occurs as inclusions in many ophiolite-hosted diamonds, which cannot be explained by serpentinization (Yang et al., 2015). The discovery of coesite and clinopyroxene exsolution lamellae in a chromite grain from the Luobusa chromitite provided “real” in-situ evidence of UHP crystallization of chromite (Yamamoto et al., 2009). Das et al. (2015, 2017) reported UHP minerals including C2/c clinoinststitite, disordered coesite and high-pressure Mg2SiO4 in peridotite from the Nidar ophiolite, which require derivation from the mantle transition zone (410–660 km) (Das et al., 2015, 2017). The UHP phase TiO2 (II) has been recovered from chromitites of several ophiolites, where it is intergrown with coesite or corundum. These occurrences provide solid data for the deep formation of UHP minerals in chromitites and peridotites, and are much more convincing than speculative models involving low-pressure serpentinization.

In conclusion, serpentinization typically occurs in mantle rocks at mid-ocean ridges and subduction zone environments, where it can be generated by hydrothermal alteration at temperatures lower than 700°C and pressures less than 1 GPa (Evans, 1977; Ulmer and Trommsdorff, 1995; Deschamps et al., 2013). The fluids responsible for serpentinization are commonly seawater, which may have evolved through interaction with the crust. Oxygen isotopic study indicates that serpentinization typically begins at temperatures of 300–500°C (Mével, 2003).
No experimental research has shown that diamond, even microdiamond, can be formed under the low P-T conditions of serpentinitization. If diamonds could be formed in this way they would presumably be widely associated with serpentinites on earth. Obviously, this is not the case.

**Key words:** diamonds in ophiolite, serpentinitization, chemical vapor deposition, UHP crystallization

**Acknowledgments:** This research was financially supported by the Natural Science Foundation of China (41720104009, 41802034 and 41802055) and Natural Science Foundation of Jiangsu (BK20180349).

**References**


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