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Diamonds in the oceanic mantle: a new occurrence on Earth

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Introduction

Macrodiamonds (>1mm), which occur typically in alkaline ultramafic rocks (e.g., kimberlites) in old continents, are attractive for their highly economic value as well as for their scientific significance as a high-pressure mineral in probing the nature of the geological processes in deep Earth. On the other hand, microdiamonds (< 1mm) were not so interested for their poor economic valuable and less occurrences on Earth. However, in recent decades things have been changed since much more microdiamonds have been reported in various rock types and different tectonic environments on Earth, and their origin and formation process have attracted more attention for geoscientists globally. A well-known type of microdiamond in metamorphic rocks is regarded as a typical ultrahigh pressure (UHP) mineral occurring at plate boundaries related to deep subduction of continental crust and its subsequent exhumation. However, microdiamonds we report here occur in oceanic mantle and are regarded as a new occurrence of diamond recognized on Earth, which is called ophiolite-hosted diamonds.

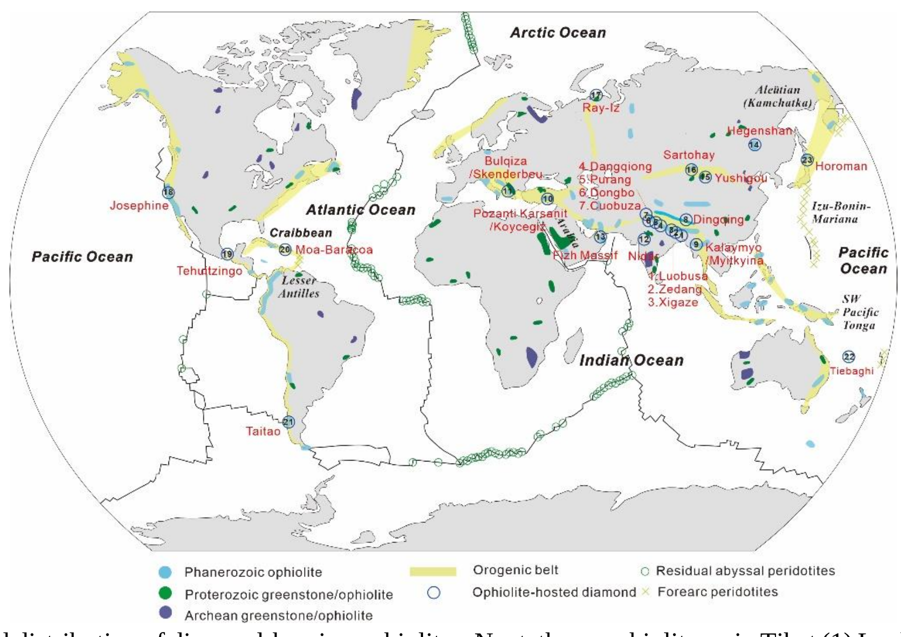

Figure 1: Global distribution of diamond-bearing ophiolites. Neotethyan ophiolites： in Tibet (1) Luobusa; (2) Zedang; (3) Xigaze; (4) Dangqiong; (5) Purang; (6) Dongbo; (7) Cuobuza; (8) Dingqing; (9) Kalaymyo & Myitkyina in Myanmar; (10) Pozanti Karsanti & Koycegiz in Turkey; (11) Bulqiza & Skenderbeu in Albania (12) Nidar; in India; (13) Fizh Massif in Oman; Paleozoic ophiolites in the Ural-Central Asian Orogenic Belt： in China (14) Hegenshan; (15) Yushigou; (16) Sartohay; (17) Ray-Iz in Russia; Other ophiolites in the Pacific circle: (18) Josephine in USA; (19)Tehuitzingo in Mexico; (20) Moa-Baracoa in Cuba; (21) Taitao in Chile; (22) Tiebaghi in New Calidonia; (23) Horoman in Japan (modified after Yang et al., 2021)

Over 20 occurrences of ophiolite-hosted diamonds on Earth

In the past decades, over 20 locations of microdiamonds and associated ultrahigh-pressure and super-reducing mineral groups have been discovered in the mantle sequences of ophiolites with different ages around the globe, distributed across different continents (Fig. 1). These ophiolites include the Mesozoic Tethyan ophiolites along the Yarlung Zangbo and the Bangong-Nujiang suture zones in Tibet-China, the Indus Suture Zone in India, and the Indo-Burma Range in Myanmar, and the Mediterranean mountain belts in Albania and Turkey; some other diamond–bearing Mesozoic ophiolites along the Pacific Rim in Japan and the western USA, at the Caribbean plate margin in Cuba; Paleozoic ophiolites in the Uralides and the Central Asian Orogenic Belt in Russia and China; and, the Cenozoic ophiolites in Chile at the western Andean Orogenic Belt and in the New Caledonian Peridotite Nappe in the southern hemisphere (Yang et al., 2021; Liu et al., 2021, references herein).

Most of the recovered diamonds are 0.2 x 0.4 mm in size, and a few up to 0.7 mm long, yellow to pale green in color, with a cubo-octahedral polycrystalline or single crystal with partial cubo-octahedral form. All analyzed microdiamonds contain significant nitrogen contents (from 108 to 589 atomic ppm ± 20%) with a consistently low aggregation state and show identical infrared (IR) spectra dominated by strong absorption between 1130 cm^{-1} and 1344 cm^{-1}, and therefore characterize type Ib diamond (Xu et al., 2018). They contain fluid inclusions, such as water, carbonates, silicates, and hydrocarbons, and some unusual IR peaks were never found in gem-quality diamonds. Differences in IR, Raman, and PL spectra of these diamonds from HP-HT synthetic and CVD synthetic diamonds show that they are of natural origin. All spectra patterns suggest that these micro-diamonds were formed in different but unique geological environments compared to those of gem-quality diamonds (Moe et al., 2018).

In situ diamonds in chromitite

In addition to thousands of microdiamond grains that have been discovered in mineral separates from the peridotites and associated podiform chromitites in ophiolites, importantly, several in-situ diamond crystals have been also found in chrome ores from the Luobusa ophiolite in Tibet and Ray-Iz ophiolite in Russia. These in-situ diamonds are hosted in small patches of amorphous carbon within chromite grains and provide strong evidence for their natural origin, as well as for the processes of their formation (Yang et al., 2014; 2015).

High pressure and reduced mineral inclusions in diamonds

Using FIB and TEM techniques, a complex assemblage of mineral inclusions has been found in microdiamonds, including Ni-Mn-Co and Si-Sn alloys, Mn-rich silicate minerals, Ca-silicate perovskite, coesite, graphite and amorphous carbon, fluid inclusions, either Si or SiC, a Si-Cl-K quench phase, and a Si-Al-Th phase containing some rare earth elements (Yang et al., 2015; Wu et al., 2018).

Interestingly, solid CO_2 inclusions have been observed in microdiamonds, two in the Luobusa chromitites, three in the Luobusa peridotites, and four in the Ray-Iz chromitites, with the IR spectra peaks at 2375, 2513, 3687, and 3748 cm^{-1} (Moe et al., 2018). So far, only one solid CO_2 inclusion has been previously reported in natural diamond, with IR spectra peaks of CO_2 (3,752; 3,620; 2,376, and 650 cm^{-1}) caused by internal pressures of 5 GPa; this solid CO_2 inclusion must, therefore, have been trapped at even greater pressures in the hot mantle, corresponding to depths of about 220 to 270 km (Schrauder and Navon,1993). The peaks observed in the ophiolite-hosted microdiamonds are located at even higher positions at 2513 and 3687 cm^{-1}, possibly caused by much higher internal pressures (>5GPa) during diamond growth.

High pressure mineral group in chromitite

A high pressure and reduced mineral assemblage in chromitites, such as psuedomorph of stishovite, qingsongite (cBN, a cubic boron nitride mineral), and a high-pressure polymorph of rutile (TiO2 II), suggest their formation pressures of 10-15 GPa at temperatures ~1300 °C, consistent with mantle depths of >380 km, near the Mantle Transition Zone (Yang et al., 2007; Dobrthinetskaya et al., 2014). The UHP phase TiO2 (II) has been recovered from chromitites of several ophiolite massifs in which it is intergrown with coesite or corundum. These coexisting mineral phases thus provide solid data for the deep formation of these UHP minerals in chromitites and peridotites. In addition, the discovery of coesite and clinopyroxene exsolution lamellae in the chromites from the Luobusa ophiolite has provided "real" in-situ evidence of former CF-type structured chromite, which is stable at depths over 380 km (Yamamoto et al., 2009). Das et al. (2015, 2017) have reported UHP minerals including C2/c clinoenstatite, disordered coesite, and high-pressure Mg_2SiO_4 in peridotites from the Nidar ophiolite in India. These mineral assemblages require P-T conditions of their formation within the mantle transition zone (410–660 km).

Light carbon isotope of diamond

The carbon isotopes of microdiamonds from chromitites and peridotites of the Tibetan, Russian, Albanian and Turkiye ophiolites, as measured by secondary ion mass spectrometry (SIMS), have $\delta^{13}C_{PDB}$ ranging from -18 to -28‰ (Yang et al., 2015; Lian et al., 2017; Xu et al., 2018; Wu et al., 2018). These values are much lighter than those of diamonds from either kimberlites (-4 to -8‰) or UHP metamorphic belts (main -5 to -18‰). The source of this light carbon is unknown, but most likely it is organic carbon, subducted from the surface, and the widespread occurrence of minerals with these values suggests the existence of some type of separate carbon reservoir in the deep mantle that is distinct from that producing kimberlite diamonds. The features and carbon isotopes of these microdiamonds indicate that their formation is most likely related to carbon-riched fluids from deep recycled subducted slabs.

Conclusions

Ophiolites represent on-land remnants of ancient oceanic crust, preserved along suture zones in orogenic belts (Dilek and Furnes, 2011), and facilitate global-scale recycling of deep subduction materials. They thus provide us with a critical geological record deep mantle circulation and deep Earth dynamics. The widespread occurrence of ophiolite-hosted diamonds and associated UHP mineral groups around the globe suggests that they may be a common feature of in-situ oceanic mantle.

Part of References

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