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GR Focus Review

Microdiamonds — Frontier of ultrahigh-pressure metamorphism: A review

Larissa F. Dobrzhinetskaya *

Department of Earth Science, University of California at Riverside, Riverside, CA 92521, USA

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ABSTRACT

This is a comprehensive review paper devoted to microdiamonds from ultrahigh-pressure metamorphic (UHPM) terranes incorporated in orogenic belts formed at convergent plate boundaries in Paleozoic–Mesozoic–Alpine time. When in 1980 the first small diamonds were discovered within “amphibolite–granulate facies” metamorphic rocks, it came as a great surprise that buoyant continental crust could be subducted to depths of hundreds of kilometers and then subsequently exhumed. Since then, much progress has been made in understanding the mechanism of these diamonds' formation, and the number of new diamond-bearing UHPM terranes was significantly increased, especially within European orogenes. Moreover, new variations in tectonic settings in which UHP rocks can be formed and exhumed came to the attention of geologists simply due to the finding of diamonds in places previously “forbidden” for their formation—e.g., oceanic islands, ophiolites, and forearc environments. Over the past decade, the rapidly moving technological advancement has made it possible to examine microdiamonds in detail and to learn that part of them has a polycrystalline nature; that they contain nanometric, multiphase inclusions of crystalline and fluid phases; and that they keep a “crustal” signature of carbon isotopes. Scanning and transmission electron microscopy, focused-ion-beam techniques, synchrotron infrared spectroscopy, micro X-ray diffraction, and nano-secondary ion mass spectrometry studies of these diamonds provide evidence that they keep traces of fluid originated from both crustal and mantle reservoirs, and that they probably interacted with deep mantle plumes. Hypotheses proposed for diamond formation in subduction zones founded on both analytical and experimental studies are discussed. The paper also emphasizes that the discovery of these microdiamonds (as well as coesite) triggered a major revision in the understanding of deep subduction processes, leading to a clear realization of how continental materials can be recycled into the Earth's mantle and geochemically rejuvenate it.

Contents

* Tel.: +1 951 827 2028.
E-mail address: larissa@ucr.edu.

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1. Introduction

In late 1980 microdiamonds were first discovered within metasedimentary rocks of continental affinities of the Kokchetav massif, Kazhakstan (Rozen and Zorin, 1972), but they became known to the Western literature much later (Sobolev and Shatsky, 1990). These diamonds of 10- to 100-μm size occur as inclusions in garnet, zircon, diopside, phengite, quartz, kyanite, and also at the mineral grain boundaries in felsic gneisses, calc-silicate rocks, marbles, garnet pyroxenite, garnet–kyanite schists, quartzites, and others. These rocks were traditionally considered as metamorphic rocks of amphibolite and/or granulite facies associated with eclogites (e.g. Dobretsov et al., 1995). However, these tiny diamonds have deserved a special review and appreciation because they created a revolution in geology by "shifting" traditional scientific thinking and causing a critical re-evaluation of the main postulates of plate tectonics. According to one of the plate-tectonic paradigms, the continental crust is buoyant and cannot be subducted very deep, and metamorphic rocks of crustal origin have been for a long time known as a non-suitable place for diamond formations. Discoveries of microdiamond within metasedimentary rocks clearly refute this theory and suggest that continental slabs can be subducted to a depth of 120–150 km and more, then return back to the Earth's surface during tectonic exhumation.

Diamond is the strongest of all known minerals and synthetic compounds. Due to its chemical inertness, diamond is the most reliable natural sampling "container" for transporting fluid and solid materials from the depth of their crystallization within the Earth to the surface (e.g. Harte and Harris, 1994; Joswig et al., 1999; Gillet et al., 2002; Hayman et al., 2005; Wirth et al., 2009; Kopylova et al., 2010; Harte and Richardson, 2011). In this context, metamorphic diamonds serve as a best testimony to exhumation of rocks from depths in excess of about 120–150 km. The inclusions preserved inside diamonds can be used for reconstruction of the chemical/petrological reservoirs from which such diamonds were crystallized. The fact that microdiamonds from UHPM terranes are found as inclusions not only in refractory minerals such as zircon and garnet but also inside quartz, biotite, and muscovite + chlorite aggregates replacing garnet suggests that diamond remained well-preserved through the retrogressive amphibolite-grade metamorphism (e.g. Dobrzhinetskaya et al., 2003a). However, in some UHPM terranes diamonds are very strongly graphitized, mostly because of their very small size (<10–20 μm) and extremely extensive retrograded metamorphism accompanied by metasomatic processes. Despite of that, diamond itself remains as an unconditional witness that its buoyant host rocks were subducted into the upper mantle to a minimum depth of ~150 km and subsequently were exhumed to the Earth's surface. The intensive studies of metamorphic diamonds have spurred significant multidisciplinary progress in understanding continental collisions, mountain building, H_2O and other light elements circulating between subducting slab and mantle wedge, and the interaction of the subducting slab with the mantle plume.

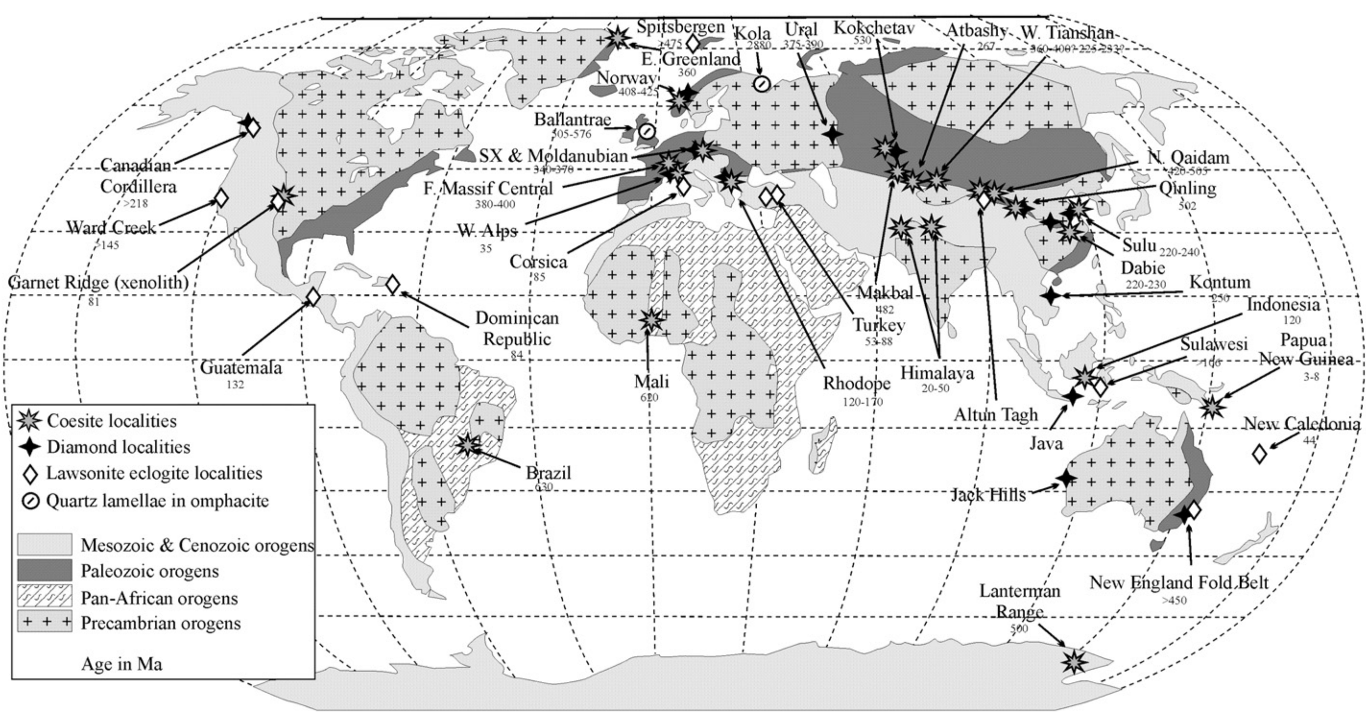

Fig. 1. Global distributions and peaks of metamorphic ages of coesite- and diamond-bearing UHPM terranes; SX — Saxothurnigan area of Bohemian Massif) (the figure is adopted from Dobrzhinetskaya and Faryad, 2011).