DIAMONDS IN THE BOHEMIAN MASSIF – EVIDENCE FOR ULTRAHIGH-PRESSURE METAMORPHISM

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Abstract

Diamond and coesite were discovered in high-pressure granulites of the north Bohemian crystalline basement in the Eger Crystalline Complex and České středohoří Mts. Diamonds, confirmed by micro-Raman spectroscopy, occur as 5–10 μm-sized inclusions in kyanite and garnet as well as in accessory zircon. Coesite was identified within kyanite enclosed in garnet. Diamond and coesite form at pressures above 4 and 3 GPa, respectively, and the presence of these two minerals in the continental crust indicates ultrahigh-pressure metamorphic conditions reached only during a continental subduction deep into the mantle. Preservation of coesite in felsic-intermediate crustal rocks is a rather unique phenomenon due to its very limited metastable survival within exhumed terranes. Importantly, the north Bohemian crystalline basement represents only the fifth accepted location worldwide where diamond has been documented in situ in the continental crust rather than in mantle rocks such as peridotites. Our discovery also strongly supports the previously questioned Bohemian provenance of macroscopic diamonds, found in the České středohoří Mts. area in the 19th and 20th century.

Introduction

High-pressure granulites represent a major rock type of the internal domain of the Variscan crystalline basement in Europe, including the easterly-located Bohemian Massif. The unusual association of these crustal high-pressure granulites and mantle garnet peridotites recording apparently very contrasting peak pressures is a common but until now not fully understood phenomenon. It has been demonstrated that the peak mineral assemblages of predominant felsic, Saxony-type granulites, comprising garnet, kyanite, mesoperthitic feldspar and quartz, formed at ultra-high (~ 1000 °C) temperatures and plot in the eclogite facies field as defined by experimental studies on both acid and basic rock compositions (O´Brien – Rötzler 2003, Kotková 2007). We searched for evidence for ultrahigh-pressure (UHP) metamorphism of the high-pressure granulites, which would provide explanation for the apparently high thermal gradients needed for granulite formation as well as the granulite-garnet peridotite association. The north Bohemian crystalline basement was selected as a study area due to the lack of high temperature-medium pressure overprint in these granulites implying high exhumation and cooling rates (Kotková et al. 1996, Zulauf et al. 2002), the presence of garnet peridotites and also historical diamond finds in the area (Schafarik 1870, Ježek 1927).

Geological context

The high-pressure granulites along with migmatites and various gneisses constitute the crystalline basement of north Bohemia traditionally attributed to the Saxothuringian Zone of the Bohemian Massif. Granulites are exposed in the erosional window along the Eger (Ohře) River – in the Eger Crystalline Complex (ECC; ohárecké/oherské krystalinikum), and make up to several hundred meters thick sections with associated garnet peridotites in the drill-cores in the České středohoří Mts. basement (Kopecký – Sattran 1966, Kotková 1993, Kotková et al. 1996, Zulauf et al. 2002, Mlčoch – Konopásek 2010). Although the exposure in the area is poor due to voluminous alkaline volcanism as well as sedimentation associated to a large extent with the Cenozoic Eger Rift formation, sufficient material comprising both felsic and intermediate high-pressure granulites is available.

Methods and sample description

Polished thin sections of granulites were examined using transmitted and reflected light microscopy. Raman spectra for minerals were acquired using a confocal Raman spectrometer (LabRam HR: Horiba Jobin Yvon) at the Institut für Erd- and Umweltwissenschaften, Universität Potsdam.

We investigated both felsic and intermediate granulites from drill-cores in the České středohoří Mts. basement (T7 and T38 boreholes, located at Staré, and T21 located at Měrunice) and from granulite outcrops in Stráž nad Ohří, ECC. Granulites contain the high-pressure mineral assemblage garnet-kyanite-quartz-mesoperthite (felsic rocks) and garnet-clinopyroxene-feldspar-quartz (intermediate rocks).

Felsic granulite (T7 borehole, Staré; fig. 1A)

The rock is banded, consisting of the light part poor in biotite and dark irregular biotite-rich zone several millimetres thick with weak preferred orientation of biotite. Garnet (1–2 mm in diameter) and kyanite (mostly elongated grains 0.5–1mm long) porphyroclasts are surrounded by a fine-grained matrix composed of quartz, perthitic K-feldspar and subordinate secondary plagioclase with heterogeneous grain size (up to 0.3 mm) and lobate grain

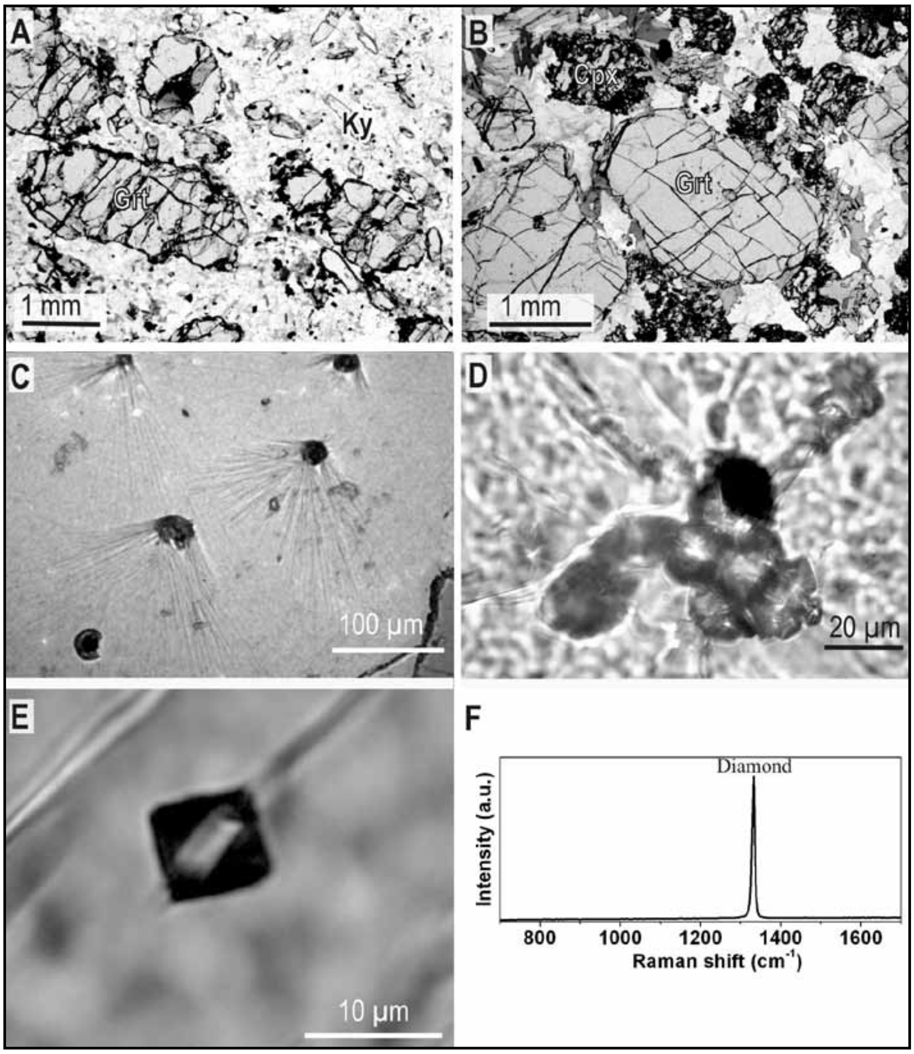

Fig. 1: A – felsic granulite, T7 borehole, České středohoří Mts. (PPL); B – intermediate granulite, T38 borehole, České středohoří Mts. (PPL); C – polishing scratches from diamond protruding from the thin-section, intermediate granulite, Stráž nad Ohří, ECC (reflected light); D – diamond cluster in garnet, intermediate granulite, T38 borehole (PPL); E – diamond enclosed in kyanite, T7 borehole, České středohoří Mts. (PPL); F – Raman spectrum of a diamond enclosed in garnet, T7 borehole, České středohoří Mts.

boundaries. The majority of kyanite grains show preferred orientation subparallel to that of the biotite banding. Biotite is disseminated in the matrix and forms discontinuous (continuous in the dark part) rims on garnets. Accessory phases are zircon, rutile, apatite, graphite and ore minerals (mainly pyrite), occurring as inclusions within major rock-forming minerals as well as in the rock matrix.

Intermediate granulite (T38 borehole; fig. 1B)

Garnet and clinopyroxene porphyroclasts occur within a rather equigranular fine-grained (grain size up to 0.4 mm) matrix, consisting of plagioclase and quartz. Whereas rounded to slightly elongated garnets are large, reaching 1–2.5 mm in diameter, clinopyroxene grains are as a rule smaller (0.5–1 mm), elongated, showing weak preferred orientation. Biotite occurs in clusters up to 0.5 mm in size, located within the matrix or rimming the garnet grains. Pyroxene grains feature irregular boundaries and are in places replaced by other phases, mainly amphibole. Accessory phases are zircon, rutile, apatite, ilmenite and graphite. The latter mineral occurs exclusively as inclusions in garnet and pyroxene.

Results

Micro-diamonds were discovered as 5–30 μm sized inclusions in garnet and kyanite in felsic granulites and in garnet and zircon in intermediate granulites. They are located below the surface of the sample or protrude from the thin section. Radiating polishing scratches from fragments of the grains that were broken off represent one of the prospecting tools for the diamonds (fig. 1C). Diamonds within garnet commonly have ragged surfaces, are sub-rounded, occur in clusters (fig. 1D), and appear with graphite, apatite, rutile, quartz and carbonate minerals, whereas diamond in kyanite forms well-defined single octahedra with only minor associated graphite (fig. 1E). Confocal micro-Raman analysis of these grains yielded an isolated peak at around 1332–1333 cm^{-1} characteristic of diamond (Ramaswami 1930; fig. 1F). Coesite with characteristic peak at about 521cm^{-1} has been identified as an inclusion in kyanite itself completely enclosed in garnet in a felsic granulite sample containing also polycrystalline quartz aggregates within garnet (Kotková et al. 2011).

Discussion and conclusions

Although the discovery of diamond in pyrope-bearing gravels in northern Bohemia in 1869 (Schafarik 1870) represented a sensation both in scientific and layman circles as the first reliable diamond find in Europe, its Bohemian origin was immediately questioned. It was assumed that a diamond from East India had become mixed up with the north Bohemian pyrope in the polishing workshop (Nature 1870). A second diamond was found in 1927 (Ježek 1927). Intensive diamond prospecting in the 1950´and 1960´ focused on Tertiary volcanic breccias, especially those containing pyrope xenocrysts, and considered as possible diamond host rocks analogous to kimberlites (Kopecký et al. 1967). No diamond was found during these works, and despite later studies of the two diamond grains failing to exclude endogenous as opposed to impact diamond genesis (Bouška et al. 1993), the origin of the Bohemian diamond still remained unexplained. Discovery of coesite, and diamond, in metamorphic rocks of crustal origin only 25 years ago (see Liou et al. 2009 and references therein) led to recognition of ultrahigh-pressure metamorphism as a product of deep subduction of the crust into the mantle. In the Bohemian Massif the deeply subducted rocks were returned to the surface but in other cases, such as in Eastern Australia (Barron et al. 2008) the subducted crust, still at depth, acts as the source for diamonds, including macroscopic (average 0.25 carat) grains, transported by younger alkali basalts. This newly recognised process in Earth sciences, ultrahigh pressure metamorphism, provides a new possibility for diamond formation following on from our gradually acquired understanding of sedimentary (redeposited, placer), mantle (garnet peridotite, garnet pyroxenite, transported by kimberlite) and impact diamond origins.

Our discovery of diamond and coesite in high-pressure granulites of north Bohemian crystalline basement has the following implications:

- it ranks the studied terrane on the short list of world localities (i. e. Kokchetav Massif in Kazakhstan, Saidenbachtal in German Erzgebirge, Rhodope Massif in Greece and the Qinling Mts. in China, see Liou et al. 2009) where diamond was documented in situ in the continental crustal rather than in mantle rocks,
- it represents the first robust evidence for UHP conditions in a major Variscan crustal rock type, allowing to envisage a larger UHPM unit involving the Saidenbach area where the rare, exotic diamond-bearing garnet-phengite gneisses occur (Nasdala – Massonne 2000),
- it strongly supports the Bohemian provenance of the macroscopic diamond found in previous centuries,
- it shows, that the ultra-high temperatures above 1 000 °C, deduced for the HP granulites and questioned by some authors (see O´Brien 2008), are realistic as the thermal gradients required under UHP conditions are not extreme,
- deep subduction and rapid exhumation (Matte 1998, Willner et al. 2002, Massonne – O´Brien 2003), rather than homogeneous crustal thickening (Schulmann et al. 2008) are required to explain the ultra-high metamorphic pressure and granulite-garnet peridotite association characteristic of the internal zone of the European Variscan belt.

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