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Lonsdaleite, Diamond, and Graphite in a Lamprophyre: Minette from East-Thuringia/Germany

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Abstract

We present a microscopical and Raman spectroscopical study of a minette sample from East-Thuringia/Germany. This sample contains needle-like graphite with micro-diamond crystals and his changed carbon products. Besides diamonds in larger graphite needles, there are also whisker-like needles of lonsdaleite and diamonds in quartz and orthoclase, which are later inserted into the minette rock by supercritical fluids or melts. That means we have a two-stage process at the formation of the minette.

Keywords: *Minette, Raman spectroscopy, Lonsdaleite, Diamond, Graphite, Depth of origin, Supercritical fluid*

Introduction

Vein-like lamprophyres are here decimeter-to-meter thick intrusions, which can be assigned as deep-reaching faults that permeate the earth's mantle and the crust. The origin of the lamprophyric magma is still discussed because all information about it is based on geochemical studies [1]. In this short contribution, we will show that careful mineralogical studies can contribute to this question. We forswear to a thorough description of this magmatic rock because of its extensive literature, for example, Beuge and Kramer (1977) [2-6].

Sample Material

The minette sample 2210 is from a 50 cm thick vein in a small quarry at Highway F 92, about 1 km northwards from Cunsdorf. A petrographic characteristic of the orbicular minette rock is in Beuge and Kramer (1977) [2] Figure 1 inside - together with a mineralogical description and chemical composition. The reddish brown ocelli are composed predominantly of alkali feldspar, quartz, actinolite, and chlorite. The black interstice is composed of femic phenocrysts of biotite, amphibole, and pyroxene. During the study of a lamprophyre sample (sample 2210; see Kramer 1988) [1], a thick section of minette from E-Thuringia (Cunsdorf, Meltheuer Mulde in the immediate vicinity of the Bergaer Sattel, near Elsterberg), we found, as a surprise, many crystals of diamond-graphite intergrowths. Figure 1 shows the studied sample. Further minerals found with Raman spectroscopy, often containing carbon, are anatase, calcite, orthoclase, and quartz. Apatite is present in two different generations: an early magmatic type as phenocrysts and a late apatite in the form of larger lamellas. The chemical composition (main and trace elements) of the studied minette sample (sample No. 2210) is in Kramer (1988) [1] and Beuge and Kramer (1977) [2] here represented by samples 3 and 4. Beuge and Kramer (1977) [2] found in the orbicular minette rock from Cunsdorf near Elsterberg 5600 ppb Hg. Kramer and Just (1995) [7] also present REE and other trace elements (Ba, F, Bi, Hg, Cr, Ni, Th, U).

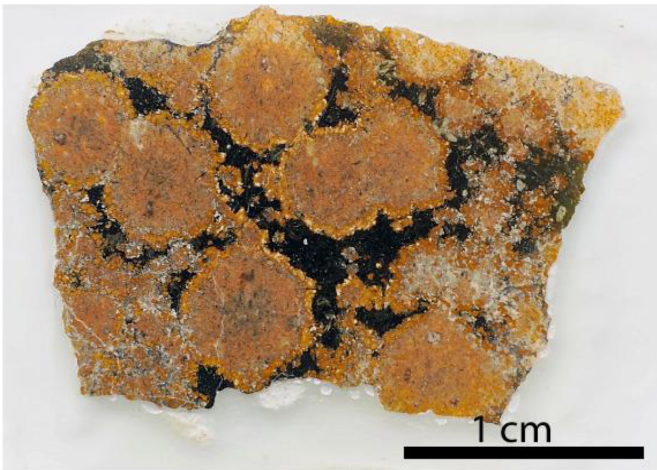

Figure 1: Petrologic thick section (about 500 µm thick) of the orbicular minette sample from Cunsdorf near Elsterberg.

Methodology: Microscopy and Raman Spectroscopy

We use Raman spectroscopy here to characterize the diamond crystals in the minette, which show high-pressure and high-temperature origin. For the study of the minette sample, we use the Raman spectrometer EnSpectr R532 combined with the Olympus BX43 microscope both for transmitted and reflected light and equipped with a rotating stage and polarizers (for parallel and perpendicular positions). Note here that the incident laser light is always polarized – in our case, N – S [8]. Generally, we used an Olympus long-distance 100x objective lens for the studies. As references, we applied a water-clear diamond crystal from Brazil (1331.63 ± 0.60 cm^{-1} and a semiconductor-grade silicon single-crystal (520.70 ± 0.15 cm^{-1}). For this study, we generally used laser energies of ≤ 30 mW on the sample to minimize the heating by the laser light for the studies.

Results

Diamonds - lonsdaleite - Graphite

The minette sample contains many black needles. Some are whisker-like. They are mainly composed of carbon with remnants of diamond, according to Raman spectroscopy (Figure 2).

Figure 3 shows such a Raman spectrum of diamonds in graphite-like needles in the minette quartz. This quartz also contains remnants of cristobalite.

Ten different crystals of micro-diamonds give a mean of 1332.9 ± 10.2 cm^{-1} and a Full Width at Half Maximum (FWHM) of 71.6 ± 28.8 cm^{-1}. A typical Raman spectrum is shown in Figure 4. However, a large proportion of the thick needles give diamond un-typical Raman spectra: 1355 ± 5.7 cm-1 with FWHM = 67.2 ± 9.8 cm-1 (17 different crystals). According to Zaitsev (2001) [9], this carbon is disordered or nanocrystalline defective graphite or amorphous diamond-like carbon. According to our ideas, diamonds are the precursor of this carbon.

Besides the thick needles (Figure 2), here, mostly with diamond microcrystals, there are also significant thinner, whisker-like needles (Figure 5), mainly in quartz and orthoclase, which give distinct lower

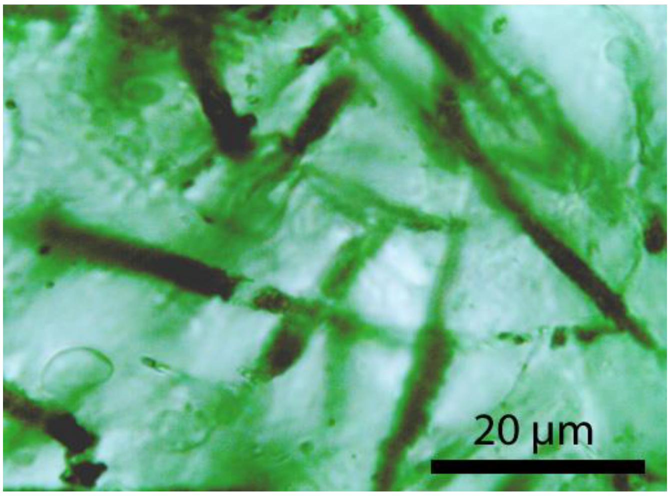

Figure 2: Needels of carbon in the quartz matrix. The quartz matrix contains many remnsants of cristobalite, often also shaped as light needles.

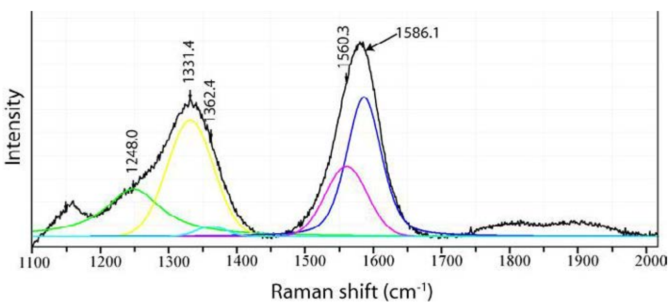

Figure 3: Raman spectrum of diamond in a thick graphite needle (see Figurs 2) in the orbicular minette sample from Cunsdorf near Elsterberg.

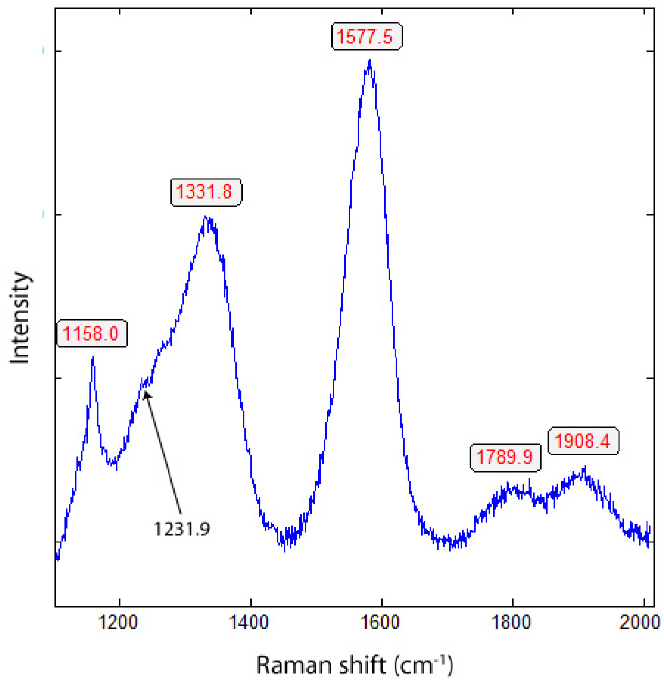

Figure 4: Raman spectrum of a small black needle in quartz and orthoclase in the orbicular minette sample from Cunsdorf near Elsterberg. In the quartz are many anatase inclusions.

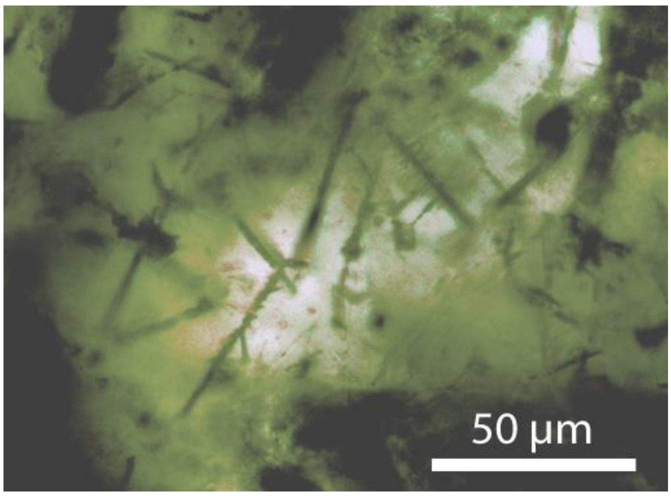

Figure 5: Whisker-like lonsdaleite crystals in quartz-cristobalite-high tridymite of the minette sample from Cunsdorf near Elsterberg.

values of the Raman band. Besides the needles, there are also more or less isometric and statistic-distributed graphite grains (with about ~10 to 20 µm diameter). The Raman spectra of these grains show nondiamond carbon phases (see further above).

From the Raman measurement, we obtained for the whisker-like needles of lonsdaleite in quartz and orthoclase of the minette a mean for 15 different needles of 1323.5 ± 2.4 cm^{-1} an FWHM = 75.6 ± 10.9. Only a tiny number have diamond-like band positions: 1333.2 ± 3.1 cm^{-1} (n = 7). The astonishing is that the needles do not bend. Figure 6 shows a typical Raman spectrum of a lonsdaleite-like diamond from the minette sample. The carbon G-band is always present at around 1562 cm^{-1}. In the case of the diamond, this G-band has significantly shifted to higher values than the lonsdaleite-like diamond: 1577 – 1586 cm^{-1}.

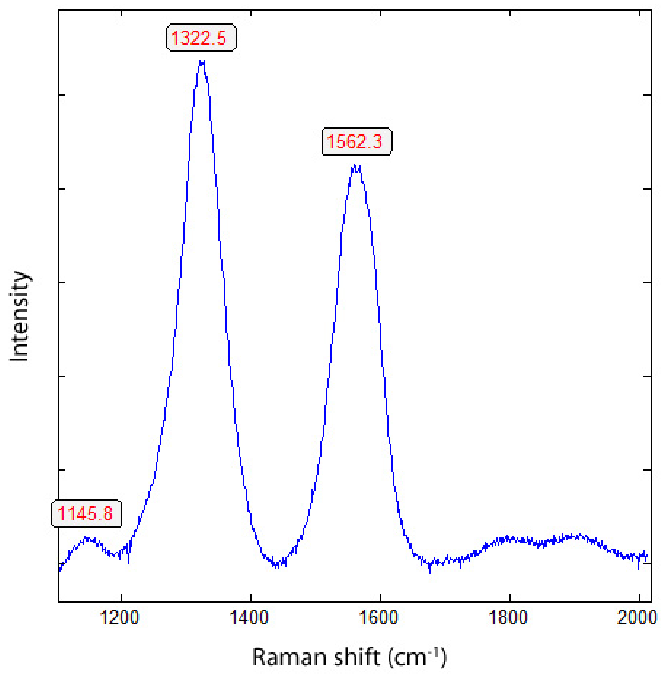

Figure 6: Raman spectrum of lonsdaleite-like diamond in orthoclase and quartz of the minette sample from Cunsdorf/E-Thuringa, Germany.

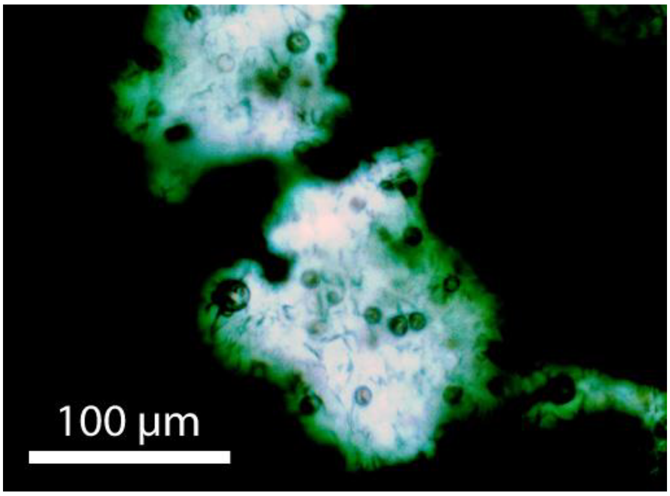

Figure 7: Many globules of anatase in minette quartz from Cunsdorf/E-Thuringa, Germany.

The minette sample contains relatively large amounts of quartz. Besides lonsdaleite-diamond-graphite needles, some such quartz grains include slight spheric inclusions of anatase [TiO_2] (Figure 7). The formation of such small globules in quartz is considered a mystery alone. According to our studies, starting with Thomas et al. (2022) [10], spherical minerals, like the anatase here, are a solid hint to their speedy transport via supercritical fluids or melts.

Anatase

Anatase is widespread as perfect crystals in the minette rock. An exception is the anatase globules (Figure 7) in irregular, tubular quartz aggregates. Obviously, there are two different age generations. The spheric anatase crystals, included in quartz, are introduced into the rock via supercritical phases. The interstitial quartz between the lonsdaleite whisker is partially composed of high-tridymite (extreme high 150 cm^{-1} Raman band) and cristobalite, which indicates a high temperature of about 1470°C [11,12].

Interpretation and Discussion

As a rule, lamprophyres seldom contain melt inclusions for the estimation of formation temperatures. Only for a kersantite in the Kirchberger granite (sample 296/85), Thomas (1989) [13] has determined a temperature of 1175 °C from homogenization measurement on melt inclusion in apatite using a microscope heating stage. After the correlation of the bulk composition and the temperature (Thomas 1990) [14], the formation temperature of the lamprophyres should be1170 ± 37°C and corresponds very well with the measured data. If we take a temperature of 1200°C, it results in a minimum pressure of about 4.5 GPa (diamond-graphite equilibrium), which corresponds to a depth of about 150 km or more. Most diamonds in the typical minette rock show a transformation of diamond into carbon. Only the diamonds in orthoclase and quartz are well preserved. Therefore, we assume that the quartz and orthoclase are later added into the minette rock (see the globules of anatase), maybe by contamination of supercritical fluids/melts. So, the formation of the minette rock is at least a two-step process. Supercritical fluids use partially the same ascent ways. Up to now, the highest pressure determined is 12-15 GPa (Thomas 2024) [15,16], corresponding to a depth of about 560 km. We think that the same depth is conceivable for the origin of lamprophyres. Maybe supercritical fluids or melts use the same paths as lamprophyres, which are obviously their predecessors. Conceivable is also an interaction of both mantle related magmatic phases (supercritical fluid/melt and lamprophyre magma).

Acknowledgment

The studied minette sample 2210 from Cunsdorf near Elsterberg/E-Thuringa is from Kramer. We dedicate this short contribution to Dr. Wolfgang Kramer for his 85 birthday in August 2024.

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