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High-tridymite, Cristobalite, and Londsdaleite in a Minette Lamprophyre from E-Thuringia/Germany

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Abstract

The minette from Cunsdorf near Elsterberg in E-Thuringia has an astonishingly high number of tridymite and remnants of other quartz polymorphs. More exceptional is the high content of lonsdaleite whiskers and, in part, his degradation products in the form of diamonds and graphite in quartz and K-feldspar of this rock. The presence of lonsdaleite demands ultra-high-pressure conditions for the formation of the minette lamprophyre magma. The high number of lonsdaleite whiskers in a magmatic rock is unexpected.

Keywords: *Lonsdalite, Genesis of lamprophyres, Raman spectroscopy*

Introduction

During the study of a minette sample from E-Turinga [1], we found in quartz schlieren, besides quartz, lonsdaleite, also hints of high-tridymite and cristobalite. Cristobalite is rare, however. Such schlieres we interpret as remnants of supercritical fluids or melts, inserted into the minette rock by multi-interaction of both phases (supercritical fluid and lamprophyre magma) coming from the earth's mantle. The equilibrium temperature of both SiO_2 phases is, according to Frondel [2], 1470°C at low pressure. The inversion of cristobalite to tridymite is sluggish, and cristobalite can persist as a metastable form at room temperature. However, the coexistence of cristobalite and tridymite is an essential mark in quartz, together with diamond and lonsdaleite, for the origin and the emplacement of the minette lamprophyre.

Sample and Methods

The minette sample 2210 is from a 50 cm thick vein in a small quarry at Highway B 92, about 1 km northwards from Cunsdorf near Elsterberg, E-Thuringia. A more detailed description and references to it are provided by Thomas and Recknagel [1]. A more detailed description of the rock is in Beuge and Kramer [3] as well as in Kramer [4]. We use Raman spectroscopy here to characterize the cristobalite and high-tridymite in quartz schlieres in the minette. For measurements, 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), is used. 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 12 mW on the sample. To identify the minerals of the minette sample, we used the RRUFF database [5].

Result and Discussion

The Raman study of a mixture of SiO_2 polymorphs, developed on the long way from the mantle to the upper crust, is a challenge [6]. The monocline modification of tridymite dominates the Raman spectrum (Figure 1). The bands at 66.3, 83.0 (not shown), 142.6, 194.7, 334.5, and 430.0 cm^{-1} correspond, according to Kanzaki [6], well to the monocline tridymite of the Steinbach iron meteorite (IVA-an). The Steinbach meteorite (which fell near Meissen/Germany in 1540-1550) forms, according to Grady et al. [7], almost equal amounts

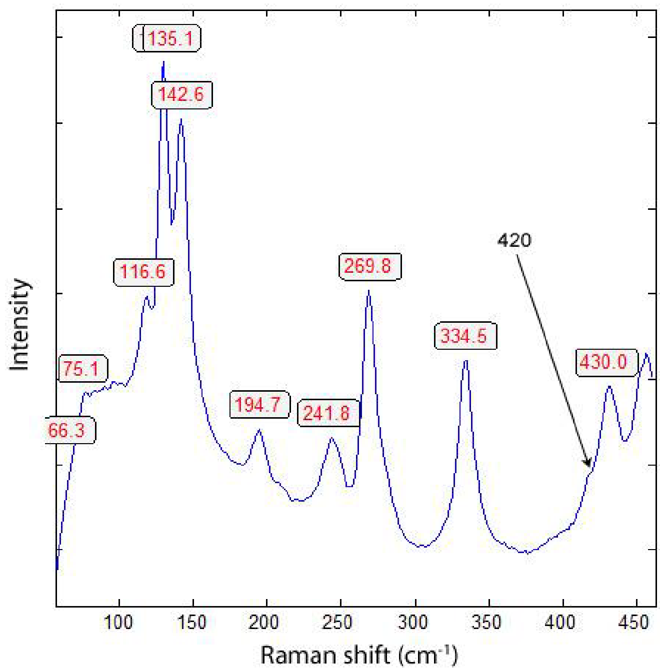

Figure 1: Raman spectrum of quartz, tridymite, and cristobalite in the low-frequency region (η=50-450 cm^{-1}). The shoulder at 420 cm^{-1} is a hidden band of cristobalite.

of Fe-Ni metal and, tridymite and other silicates. In our minette sample, remnants of the MX-1 modification [6] are present too. This modification is formed by quenching high-temperature tridymite modifications. Typical bands are 456.9 (band quite right in Figure 1), and 789.3 cm^{-1}.

Besides quartz, cristobalite, and high-tridymite modifications, there are in Figure 1 also indications of coesite present: 116.6, 175.3, 269.8, and 430 cm^{-1} [8]. However, the unambiguous proof is difficult because of the presence of fine-distributed microcrystals of orthoclase in the bulk quartz and also many lonsdaleite whiskers (Figure 2). Some whiskers are up to 100 µm long. The number of lonsdaleite whiskers > 20 µm is about $5.5 \cdot 10^6/cm^3$. These whiskers appear not only in quartz and feldspar but also in other darker minerals, which demonstrate that the whole rock has seen a high-pressure history. Micro-diamonds in the larger black lath-shaped graphite crystals will also support that [1].

The lonsdaleite whisker in quartz proves that the SiO_2 polymorphs are at least clearly related to the coesite field. According to Frondel [2], the 1470°C corresponds to a pressure of about 5.25 GPa and a depth of about 165 km (however, that is a minimum), as we will see later (Figure 3).

Most lonsdaleite whiskers are in quartz polymorphs and transparent K-feldspars. After 20 measurements, lonsdaleite shows a strong Raman band at 1322.6 ± 2.7 cm^{-1} (mode $\eta = E_{1g}$) and a FWHM = 68.6 ± 12.3 cm^{-1} (see also Thomas and Recknagel 2024) [1]. FWHM means Full Width at Half Maximum. The weaker bands at 1266.9 ± 31.5 and 1528 cm^{-1} (modes $\eta = E_{2g}$ and A_{1g}, respectively, are also present) – see Yang et al. [9].

Interpretation

The presence of tridymite and other remnants of SiO_2 polymorphs

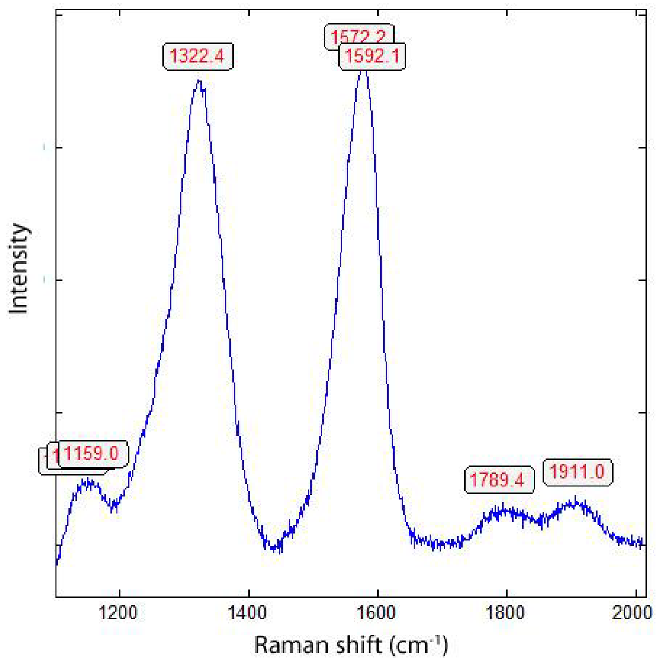

Figure 2: Raman spectrum of lonsdaleite whisker in quartz of the E-Thuringia minette.

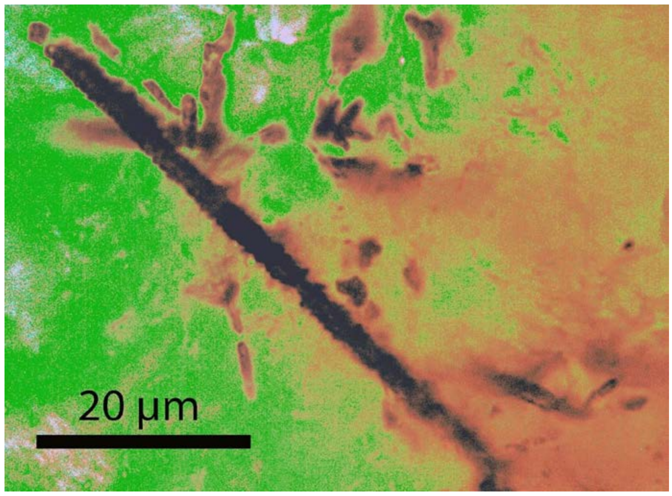

Figure 3: Black lath-shaped anatase crystal in orthoclase of the minette from E-Thuringia. In this needle, there are micro-diamonds and/or lonsdaleite whiskers.

show that during the ascent of the minette lamprophyre at high temperatures, these polymorphs with the lonsdaleite whiskers were subject to steady changes. According to Gigl and Dachille [10] and Hemley et al. [11], the stability of, for example, stishovite is strongly limited at high temperatures and low pressures. The survival of lonsdaleite and diamond under such conditions is a surprise. That means at least that lonsdaleite is more stable than the quartz polymorphs. The formation of lonsdaleite in the earth's mantle is up to now unclear. Greshnyakov et al. [12] wrote that the formation of lonsdaleite from hexagonal graphite takes place at 56 GPa, corresponding to a depth of about 1400 km and a temperature of about 1730°C. The involvement of supercritical fluids or melts during the lamprophyre ascent can reduce the origin depth of lonsdaleite and can also accelerate the lamprophyre ascent.

Acknowledgment

The studied minette sample 2210 from Cunsdorf near Elsterberg/ E-Thuringa is from Kramer. Wolfgang Kramer wrote: The Minette from Cunsdorf bei Elsterberg is a very fascinating rock.

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