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Plastic deformation in natural diamonds: Rose channels associated to mechanical twinning

M. Schoor [a], J.C. Boulliard [b], E. Gaillou [c,*], O. Hardouin Duparc [d], I. Estève [b], B. Baptiste [b], B. Rondeau [e], E. Fritsch [f]

[a] Association Jean Wyart, Case 73, UPMC, 4 place Jussieu, 75232 Paris Cedex 05, France
[b] Collection de Minéraux de l'Institut de Minéralogie, et de Physique des Matériaux et Cosmochimie, UPMC, Case 73, 4 Place Jussieu, 75232 Paris Cedex 05, France
[c] MINES ParisTech, PSL Research University, Musée de Minéralogie, 60 Boulevard Saint-Michel, 75006 Paris, France
[d] LSI, École Polytechnique, CNRS, CEA, Université Paris-Saclay, 91128 Palaiseau, France
[e] Laboratoire de Planétologie et Géodynamique, CNRS-UMR 6112, 2 rue de la Houssinière BP92205, 44322 Nantes Cedex, France
[f] Institut des Matériaux Jean Rouxel (I.M.N.), CNRS UMR 6502, 2 rue de la Houssinière BP32229, 44322 Nantes cedex, France

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ABSTRACT

Hollow channels in diamond are well acknowledged to be the result of dissolution processes. In this article we demonstrate that some hollow channels in natural diamonds are the consequence of intense plastic deformation by mechanical twinning. Two mixed-habit diamonds presenting numerous geometrical hollow tubes were studied. X-ray Laue analyses showed the presence of microtwins. At the intersection of microtwins, displacements and cracks are generated, creating the hollow channels observed. The presence of the cracks seems to have released the internal stress, as there was less to no signs of deformation at and around them. Further dissolutions are sometimes but not always seen within the cavities. Mechanical twinning, so far mostly identified in pink to purple diamonds, might be more widespread than originally thought in natural diamonds.

1. Introduction

Narrow and hollow channels are uncommon defects in natural diamonds. They were first observed and sketched by Orlov [1] on Russian diamonds. Since that work, there has been little research on channels, most of which were mainly descriptive [2–8]. The main conclusions are that these open tubes occur in diamond from various geographic localities and that they are found in both types I and II diamonds.

The most complete work was reported by Lu et al. [8]. This study analyzed channels in seven natural diamonds. The channels were examined with optical microscopy, scanning electron microscopy (SEM), ultraviolet (UV) fluorescence images and UV–Visible (Vis) and Infrared (IR) (300–850 nm) spectroscopies. The authors noticed that channels were elongated parallel to the ⟨110⟩ directions. From their observations on surface appearance, elongation orientation, internal microstructures and relationships between the channels and other lattice defects they concluded that the channels were due to dissolution processes. They proposed that the formation of etch channels is most likely related to crystal defects like dislocation bundles perpendicular to {111} planes or dislocation dipoles elongated along <110> directions. Let us recall that, for a long time, growth dislocations and dislocation bundles in diamond have been revealed by X-ray diffraction topography [9,10].

Moreover it is well acknowledged that most natural diamonds have undergone one or more processes between their nucleation and their transport at the surface of the Earth. The most common are dissolution processes which leave etched trigonal depression figures on the {111} octahedral faces and which also give rise to dissolution crystal habits with many rounded faces (like pseudo-dodecahedral or even pseudo-trioctahedral shapes) [11–13].

Later reports on hollow channels agreed with these conclusions. So far, it is well admitted that they are systematically etched channels induced by dislocations [16].

2. Materials and methods

We have examined two crystals that exhibit channels visible macroscopically. Both specimens were acquired from the *gem* market and are reportedly from Zimbabwe. They were purchased already sliced and polished to show off a grey three-fold star.

Sample MSC19 consists in a thin slice with two large polished faces and additional smaller facets a little inclined, 10 to 16° from the upper large face (Fig. 1). It measures approximately 5 by 6 mm and 0.39 mm thick.

Sample MSC67 is cut the same way and measures 7.5 by 8.5 mm and are 0.45 mm thick. This sample was not characterized by X-ray.

The crystals were first observed with an optical microscope Leica DM 2500P, equipped with polarizers, coupled with a camera.

* Corresponding author.
E-mail address: eloise.gaillou@mines-paristech.fr (E. Gaillou).

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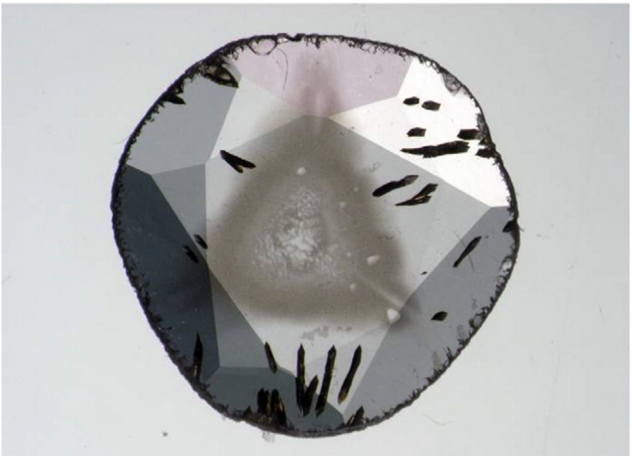

Fig. 1. Images of sample MSC19, a mixed-habit diamond (the diameter is close to 6 mm). Notice the dark geometric channels throughout the sample. This diamond has mixed-habit growth, with grey cuboid sectors and colorless octahedral sectors.

Fig. 3. Photomicrograph of a channel under crossed (linear) polarizers of sample MSC67. There is less to no abnormal birefringence next to the channels, while the rest of the diamond is strained (especially around the disk-crack-like defects).

Transmission infrared spectra were acquired using a Bruker Vertex 70 Fourier-Transform infrared (FTIR) spectrometer, with a spectral resolution of 4 cm^{-1}, accumulating 100 scans per spectrum.

High resolution surface images were taken with a Scanning Electron Microscope (SEM) FEG Zeiss Ultra 55 of the Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie, IMPMC Laboratory in Paris. Accelerating voltage varied between 5 and 15 kV and the samples were cleaned and carbon-coated before analyses.

Structure studies were conducted with an Xcalibur E (Agilent Technology) single-crystal diffractometer with Mo wavelength (0.71073 Å). The beam diameter used was 500 μm. The data were analyzed with Crysalis Pro software.

3. Results

Both diamonds are type IaAB, with high concentration in nitrogen, mostly in the form of A-aggregates; they are also rich in H. Both are natural mixed-habit diamonds. They show the typical colorless sectors (octahedral growth) and brownish to grayish sectors (cuboid growth) in a three-fold symmetry (e.g. [14,15]). The cuboid areas contain high density of graphitized disk-crack-like defects that appear black, which might be responsible for the overall grey color of these sectors. In this paper, we will focus on the large dark needle-like defects visible macroscopically in both cuboid and octahedral sectors. Under optical microscope, they look very similar to the previously described hollow channels [1–9]. Some of these defects reach the surface of the polished diamonds. The cross-sections of these channels have the shapes of quasi-rhombs or quasi-parallelograms (Fig. 2). The rhomb acute angles are close to 60°. These angles agree with channels with square (or rectangular) perpendicular section. The inner wall orientations agree with {100} orientations. Orientations of the channels deduced from the X-ray Laue method show that they are near the [*hkk*] directions. Additional measures with a goniometric device (Fedorov's four-axis universal stage) and geometrical measures agree with directions close to ⟨100⟩ .

Fig. 2. Photomicrograph in transmitted light of the channels and their rhombic shaped openings.

Examination under crossed polarizers revealed abnormal birefringence throughout the diamonds, especially around the disk-crack-like defects. Abnormal birefringence is always present in natural diamond, and represents remaining strain [e.g. 17]. Interestingly, no (to little) abnormal birefringence, therefore no remaining strain, was observed in the vicinity of the geometrical channels (Fig. 3).

Thanks to the use of SEM, high resolution images of the channels were obtained. They revealed that the channel sections are a little concave (Fig. 4). In specimen MSC1, the inner walls are smooth even under a field of view of about few dozens of microns the highest available magnification. In specimen MSC67, some dissolution figures in the inner walls exhibited a four-fold symmetry which confirmed that inner wall orientations are close to {100} orientations (Fig. 5). Moreover the channels are systematically observed at the intersection of the walls

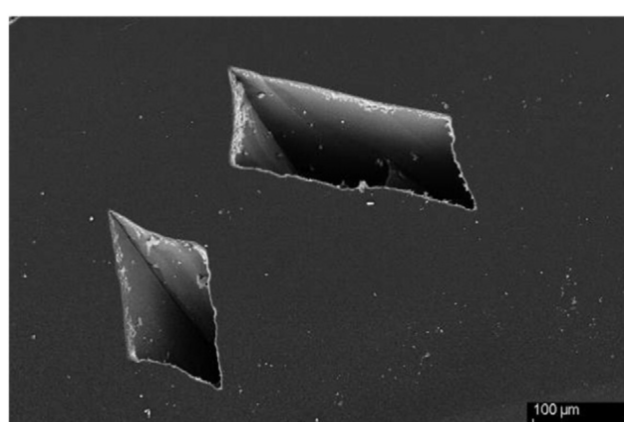

Fig. 4. Close view by SEM of the channel openings of sample MSC19.