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FTIR mapping of diamond plates of eclogitic and peridotitic xenoliths from the Nyurbinskaya pipe, Yakutia: genetic implications

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Abstract

Results of studies of IR absorption and photo- and cathodoluminescence of diamonds from peridotitic and eclogitic xenoliths from the Nyurbinskaya pipe are presented. The internal structure of diamonds of different genesis and the changes in their impurity composition throughout the crystals are analyzed. A comparison is made for the spectral parameters of crystals from xenoliths of different genesis and from kimberlites of this pipe. The internal structure of 38 eclogitic and 4 peridotitic diamond (class –4 to +2 mm) crystals is examined on their 0.4–0.8 mm thick plane-parallel plates. We present results of a detailed study of diamonds with different characteristics from four eclogitic and two peridotitic xenoliths from the Nyurbinskaya pipe. Areal mapping of diamond plates from xenoliths showed varying contents of total nitrogen, its aggregates, and hydrogen and their zonal distribution in the investigated crystals. Peridotitic diamonds are characterized by low and medium nitrogen contents, a high degree of nitrogen aggregation, and low contents of hydrogen and seldom show signs of growth interruption. Eclogitic diamonds have high contents of nitrogen and hydrogen; there are many zoned diamonds with signs of multistage growth among them, which indicates that they are of several growth generations. The composition of inclusions, the distribution of nitrogen impurity, and the degree of nitrogen aggregation in diamonds testify to a predominance of eclogitic paragenesis crystals in the Nyurbinskaya pipe. The internal structure of eclogitic paragenesis crystals, the arrangement of diamonds in eclogitic xenoliths, and other facts argue for their later, compared with peridotitic xenolith diamonds, formation from fluid or fluid-melt during metasomatism. This determined the typomorphism of diamonds and high productivity of the pipe.

Keywords: diamond; mantle xenoliths; eclogites; peridotites; nitrogen and hydrogen impurities

Introduction

Eclogites, parental diamond-bearing rocks, were earlier not given proper attention. They were shortly described only after their finding in the recently discovered South African kimberlite pipes (Bonney, 1989; Williams, 1932). But a systematic and comprehensive research into these unique rocks started only after the discovery of kimberlite pipes in Yakutia. The first studies were performed by V.S. Sobolev (Sobolev, 1960; Sobolev et al., 1969, 1972) and then were continued by other researchers (Bartoshinskii, 1960; Bobrievich et al., 1959; Ponomarenko and Spetsius, 1976; Ponomarenko et al., 1973; Sobolev, 1977; Sobolev and Kuznetsova, 1966; Sobolev et al., 1998). Note that diamond-bearing peridotites were first found and described by Russian scientists (Pokhilenko et al., 1977; Ponomarenko et al., 1980; Sobolev et al., 1969).

Though kimberlite pipes were discovered more than a hundred years ago, first in South Africa and then in Russia, Canada, and other world provinces, and there are tens of books and hundreds of research papers concerned with study of kimberlites and diamonds, the problem of diamond genesis has not been completely solved and is still the subject of discussion (Bulanova, 1995; Cartigny, 2005; Ireland et al., 1994; Meyer, 1985; Sobolev, 1960; Sobolev et al., 1984; Spetsius and Taylor, 2008; Stachel and Harris, 2008; Taylor et al., 1998, 2000; Thomassot et al., 2009). At the boundary between the 20th and 21st centuries, the researchers reached great success in studying mantle xenoliths (first of all, diamond-bearing) from kimberlites as well as diamonds from different deposits, as demonstrated at the last four International kimberlite conferences (1982–2012) (Anand et al., 2004; Navon, 1999; Pearson et al., 1999; Shirey et al., 2004; Spetsius, 1999, 2004; Spetsius et al., 2009, 2012). Infra-red spectroscopic and photo- and cathodoluminescence investigations showed an intricate internal structure of most kimberlite diamonds and yielded new data on the age of diamonds and

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mantle rocks, which testify to a long period of their formation, especially for eclogitic paragenesis diamonds (Bulanova et al., 2014; Shirey et al., 2013).

Mantle rock xenoliths are undoubtedly parental diamond-bearing rocks. They were found in kimberlite pipes in the Yakutian diamondiferous province, both among ultramafic rocks and among eclogites of different types (Sobolev et al., 1984; Spetsius, 2008; Spetsius and Taylor, 2008). This work also deals with study of diamonds from eclogites of different types. It is based on the comprehensive research into the physical properties of diamonds from a unique collection of xenoliths (160 samples) from the Nyurbinskaya pipe, whose mineralogical composition was considered earlier (Spetsius et al., 2006, 2008).

The Nyurbinskaya pipe is one of the richest primary deposits of high-grade diamond in Yakutia. It is located in the upper reaches of the right tributary of the Nakyn River, along the axis of the Diagonal'nyi Fault, at a depth of 60–80 m from the day surface and is overlain by Late Triassic–Early Jurassic deposits (T_3–J_1dh and J_1uk). Its intrusion is dated at 364 Ma (Agashev et al., 2004), which corresponds to the time interval D_3 established for the main diamond deposits of Yakutia: Mir, Internatsional'naya, Yubileinaya, Sytykanskaya (Davis et al., 1980), and Udachnaya (Kinny et al., 1997) pipes. Kimberlites of the Nyurbinskaya pipe differ seriously from those of other diamond fields, first of all, in ultralow content of picroilmenite and low contents of Ti, Fe, K, Rb, P, and other impurity elements. In Nb–Sr isotope characteristics they are similar to kimberlites of group I, but in mineralogical, petrographic, and some geochemical features they can be assigned to group II (Kornilova et al., 2001). Mantle xenoliths 2 to 25 cm in size were found in all types and phases of kimberlites, and many of them are diamond-bearing. Diamonds from the Nyurbinskaya pipe, like those from other kimberlite pipes of the Nakyn field, are unique in morphologic and structural characteristics. This is evidenced from our research data on more than 11,000 crystals from geological collections and samples taken during the earlier exploration of diamond deposits and during our prospecting works as well as from literature data (Bogush and Kedrova, 2009; Bogush et al., 2001; Spetsius et al., 2006). Among these diamonds, there are many nitrogen-rich octahedra and crystals of transitional habits with violet photoluminescence caused by the combination of blue and red luminescence. A specific feature of the kimberlite diamond population from the Nakyn field is the presence of crystals with a fine greenish coat ("coated diamonds"), a predominance of eclogitic diamonds (Mityukhin and Spetsius, 2005), and the abundance of diamonds with pink–violet photoluminescence and green phantoms inside. Mapping of structural defects in diamond plates from mantle xenoliths of known paragenesis from the Nyurbinskaya kimberlite pipe can help to examine the diamonds, including their internal structure, which is of important practical and scientific interest. The established specific typomorphic and physical features of diamond crystals from different types of mantle xenoliths will permit the crystal separation by the types of parental rocks and the estimation of the portion of diamonds of different parageneses in kimberlites of the Middle Markha and other districts of the Yakutian province. Study of the internal inhomogeneity of crystals and the concentration and volume distribution of structural defects, directly related to the crystal growth and post-growth conditions, will give an insight into the growth history of the crystals and the mantle processes at high temperatures and pressures. All this is demonstrated in our paper.

Samples and methods

To solve the set-up problem, unique rock xenoliths of different compositions from the Nyurbinskaya pipe were crushed to extract diamonds (Spetsius et al., 2006). The xenoliths were oval nodules composed of relatively unaltered garnet and scarce pseudomorphs of completely altered clinopyroxene; some of them resembled megacrysts (Fig. 1). Most of the diamonds were localized as occasional crystals or twins at the surface of xenoliths; four diamonds were present only in the sample N-60. The rock was referred to as eclogite or peridotite based on the chemical composition of garnet (Spetsius et al., 2006). The detailed characteristics of the samples and the chemical compositions of garnets, including the oxygen isotope composition, are given in our earlier paper (Spetsius et al., 2008). The composition of rock-forming garnets was determined on a Superprobe JXA-8800R electron microprobe under standard conditions at the ALROSA Geological and Scientific Research Enterprise, Mirnyi. Operating conditions: resolution 133 eV, accelerating voltage 20 kV, beam current 10 nA, and beam size 1–2 μm. The internal structure of diamonds was studied on 38 colorless crystals (class –4 to +2 mm) from eclogites and 4 crystals from peridotites, which were used to prepare 0.45–0.85 mm thick plane-parallel plates passing via the geometric center of the crystals. The diamond morphology was examined using a Leica binocular microscope. The specifics of the internal structure of crystals were revealed by luminescent spectroscopy. Photoluminescence (PL) of diamonds was induced by an LGI-505 nitrogen laser at a wavelength of 337 nm. The PL spectra were not recorded; only the luminescent light was analyzed. Cathodoluminescence (CL) of diamonds was studied on a Zeiss scanning microscope at the GEMOC Center of Macquarie University, Sydney.

The impurity composition of diamonds was studied by FTIR spectroscopy. The FTIR spectra of the prepared plates were recorded by a detailed mapping (~800 points) at ~50 μm intervals with a resolution of 1 cm^{-1} on a VERTEX-70 (Bruker) Fourier spectrometer equipped with a Hyperion 2000 microscope. Concentrations of A-, B1-, and B2-defects in diamonds were measured from the FTIR spectra normalized to the two-phonon absorption (Boyd et al., 1994, 1995). The spectra of diamonds of mixed type IaAB were computed by decomposition of the total FTIR spectrum into individual absorption band systems of natural diamonds of pure types IaA and IaB. The total content of nitrogen (N_{tot}) was estimated by summation of the contents of its impurities in the C-, A-, and B-forms, because the content of B2-form nitrogen (platelets) has not been determined. Defect B2 is assumed to form