

**DIAMONDS FROM THE POPIGAI IMPACT STRUCTURE, RUSSIA.** Christian Koeberl<sup>1</sup>, Victor L. Masaitis<sup>2</sup>, Falko Langenhorst<sup>3</sup>, Dieter Stöffler<sup>3</sup>, Marcus Schrauder<sup>1</sup>, Christian Lengauer<sup>4</sup>, Iain Gilmour<sup>5</sup>, and Robert M. Hough<sup>5</sup>. <sup>1</sup>*Institute of Geochemistry, University of Vienna, UZA II, A-1090 Vienna, Austria (a8631dab@vm.univie.ac.at)*; <sup>2</sup>*Karpinsky Geological Research Institute, Sredny prospekt 74, 199026 St. Petersburg, Russia*; <sup>3</sup>*Museum für Naturkunde, Humboldt-Universität, Invalidenstr. 43, D-10115 Berlin, Germany*; <sup>4</sup>*Institute of Mineralogy and Crystallography, University of Vienna, UZA II, A-1090 Vienna, Austria*; <sup>5</sup>*Department of Earth Sciences, Open University, Milton Keynes MK7 6AA, U.K.*

**Summary and Introduction.** Impact diamonds form as a result of shock-metamorphism during impact. Although diamonds in meteorites are relatively well-known, the study of diamonds at terrestrial impact craters has largely been confined to Russia (see, e.g., [1,2]). Masaitis [2] found that diamonds form from carbon in the target rocks, mainly graphite-bearing (e.g., graphitic gneiss) or coal-bearing rocks. The first crater, at which abundant impact diamonds have been found since 1971 is the 100-km-diameter Popigai crater in Russia [1]. Subsequently, impact diamonds have been recovered from a number of other craters, e.g., Kara, Puchezh-Katunki, and Ries. The distribution of impact diamonds in impactites is a function of the initial distribution of coal- or graphite-bearing rocks among the target rocks, as well as the shock zonation. No impact diamonds are recovered from the central part of the crater (e.g., a hot melt body), because temperatures were too high and led to a combustion of the carbon. However, in the zone immediately following, the temperatures were low enough and the pressures high enough to form abundant impact diamonds. The highest abundances are found in impact melt rocks (tagamites) and suevites. Some diamonds are found *in situ* in the target rocks (Fig. 1). In this report, we discuss preliminary results of our studies of six impact diamonds from the Popigai crater. We have used electron microscopy (SEM, TEM), neutron activation analysis, infrared spectroscopy, x-ray analysis, and isotope analyses for characterizing the samples. Our results show that some of the samples contain the hexagonal diamond modification lonsdaleite. TEM images show microcrystalline units of <5  $\mu\text{m}$  in size with a layered structure (possibly a remnant of the graphite structure). Infrared (IR) spectroscopy indicates the presence of solid  $\text{CO}_2$  and water in microinclusions in the diamonds, with  $\text{CO}_2$  being under a pressure greater than 5 GPa (at room temperature).

**Samples and Techniques.** We studied six impact diamonds of up to 2 mm in size that were obtained from impactites of the Popigai crater, Russia (see also [2]). Three of the samples were of a black, and three of a white-yellowish color. The samples were studied by electron microscopy (SEM) and infrared absorption (IR) measurements. The IR spectra were obtained on the uncut samples to avoid alteration (e.g., decrepitation of inclusions) due to the polishing process, during which the samples reach up to 1000°C. The three black samples were too opaque to obtain IR spectra. Spectra were collected on the three yellowish samples (PY1-3), as well as on one other, much smaller Popigai diamond (MSPOPI), using a Nicolet 740 Fourier-transformed Infrared (FTIR) spectrometer. The spectra were recorded with 4  $\text{cm}^{-1}$  resolution between 400-4000  $\text{cm}^{-1}$  using a Glowbar source, KBr beam-splitter and HgCdTe-B detector, and a 1000  $\mu\text{m}$  aperture. Subsequently, the samples were cut or broken into several pieces for Transmission Electron Microscopy (TEM), neutron activation analysis (INAA), x-ray, isotopic, and other studies. TEM was done with a Philips CM20-STEM at 200 kV after about 100 hours of ion thinning.

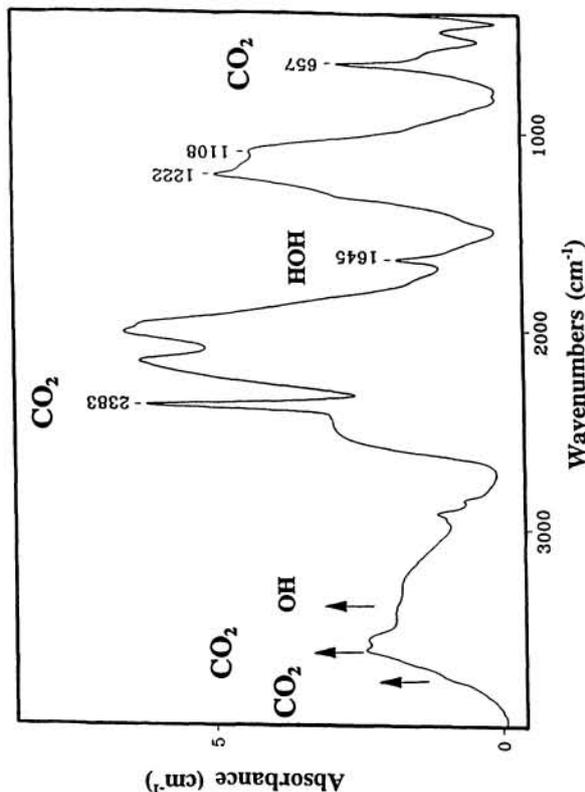
**Mineralogy and Spectroscopy.** Impact diamonds commonly preserve the crystal habit of their precursor, which is mostly graphite. The diamonds that formed after graphite are called "apographitic" diamonds. SEM photographs show an indication of some remnant crystal structure (Fig. 2,3). X-ray diffraction analysis (using a Gandolfi camera) show that some sample contain up to about 10 vol% lonsdaleite. The IR raw spectra of all diamonds examined exhibit the intrinsic diamond absorption bands. In addition, two of the transparent diamonds (PY1, PY3) show strong bands at around 655 and 2385  $\text{cm}^{-1}$ , which are identified as the  $\nu_2$  and  $\nu_3$  bands of  $\text{CO}_2$ , respectively (Fig. 4). Close examination of these spectra reveals also the combination bands ( $\nu_3 + 2\nu_2$  and  $\nu_3 + \nu_1$ ) of  $\text{CO}_2$ . All the four absorption bands are shifted from their one atmosphere positions. Comparison with high-pressure spectra of solid  $\text{CO}_2$  (dry-ice; [3]) reveals that the positions these peaks in the spectra of two samples fit the spectrum of solid  $\text{CO}_2$  at a pressure >5 GPa. The spectra are similar to those of  $\text{CO}_2$ -bearing diamonds previously reported [4]. The two  $\text{CO}_2$ -bearing samples also show absorption bands at 1645 and 3420  $\text{cm}^{-1}$ , which are due to the presence of water. As the bands are very broad and the peak positions cannot be determined exactly, the pressure for the trapped water cannot be constrained. Water concentrations were estimated from the peak heights of their main absorption bands at 3420  $\text{cm}^{-1}$ . We used the 1 atm absorption coefficient of pure water as given in [5]. For the samples PY1 and PY3 water contents of about 64 ppm were estimated (the smaller MSPOPI sample contains about 250 ppm  $\text{H}_2\text{O}$ ). All samples also show bands at 480, 1222, and 1108  $\text{cm}^{-1}$ , which are probably due to nitrogen absorption (and-or silicates). However, the spectra of the impact diamonds clearly differ in this region from mantle-derived diamonds; they are different from Ib diamonds (with dispersed N) and IaB diamonds. The bands are more similar to, but not identical with, type IaA diamonds (with paired N-centers) bands [6]. A further examination whether N is present in the structure of these diamonds and in which form is needed. It is also remarkable to note that these diamonds contain no carbonates. SEM and TEM studies show that the raw diamonds are partly covered by a melt film, which may be the result of their extraction from the target rocks. The preliminary TEM investigations show a layered structure, which may be the remnant of the graphite structure.

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**References:** [1] Masaitis, V.L., et al., *Meteoritika* 49, 180-196, 1990 (in Russian). [2] Masaitis, V.L., *Regionalnaia Geologia i Metallogenia* 1, 121-134, 1993 (in Russian). [3] Davies, G., Collins, A.T., and Spear P., *Solid State Communications* 49, 433-436, 1984; [4] Schrauder, M., and Navon, O., *Nature* 365, 42-44, 1993; [5] Navon O., Hutcheon I.D., Rossman G.R., and Wasserburg G.J. *Nature* 335, 784-789, 1988; [6] Davies, G., *Chem. Phys. Carbon* 13, 1-143, 1977.



**Fig. 1.** Popigai impact diamond (diameter about 200  $\mu\text{m}$ ), *in situ* in gneiss (in recrystallized plagioclase). Crossed nicols.



**Fig. 4.** IR absorption spectrum of impact diamond PY-1. In addition to the intrinsic diamond modes (double feature around 2000  $\text{cm}^{-1}$ ), four peaks due to  $\text{CO}_2$  are visible. The position of all  $\text{CO}_2$ -bands is shifted compared to their room temperature and pressure values. Furthermore, the stretching and bending absorption modes of water are indicated at 1645 and 3420  $\text{cm}^{-1}$ . The absorptions at around 1222 and 1108  $\text{cm}^{-1}$  can be due to either nitrogen or silicate minerals.



**Fig. 2.** SEM photograph of black impact diamond PB5.



**Fig. 3.** SEM photograph of transparent impact diamond PY2.