THE STRUCTURE OF CANYON DIABLO "DIAMONDS". Laurence A.J. Garvie, Center for Meteorite Studies, Arizona State University, Tempe, Arizona 85287-1404, USA, lgarvie@asu.edu, Péter Németh, Department of Surface Modifications and Nanostructures, Chemical Research Center of the Hungarian Academy of Sciences, H-1025 Budapest, Pusztaszeri út 59-67, Hungary.

Introduction: The first reports of "hard particles" in the Canyon Diablo meteorite dates to 1891 [1], and they were identified as diamond by X-ray diffraction in 1939 [2]. More recent X-ray diffraction studies showed that the Canyon Diablo "diamonds" are composed of various proportions of diamond, lonsdaleite, and graphite [2, 3]. Lonsdaleite is a hexagonal polymorph of diamond [3-5], which under certain conditions plays a central role in diamond formation [4, 6]. The majority of the "diamonds" isolated from Canyon Diablo are black, similar in appearance to carbonado (Fig. A, B). The "diamonds" are most commonly associated with troilite, within metal that shows evidence of shock [7]. Similar "diamonds" also occur in the Chuckwalla, Magura, and ALHA77283 iron meteorites. It is argued that the diamonds in Chuckwalla and ALHA77283 formed preterrestrially, whereas the Canyon Diablo "diamonds" formed as the result of shock-induced transformation of graphite (or cohenite) at the moment of terrestrial impact [7, 8].

Despite the many early reports on meteoritic diamonds in iron meteorites, there are few recent studies of these "diamonds". In an effort to understand the structures of meteoritic diamonds, we used high-resolution transmission electron microscopy (HRTEM) to reveal the structure of Canyon Diablo "diamonds".

Materials and Methods: A diamond-bearing piece of Canyon Diablo meteorite was added to a flask of dilute HCl for two days and allowed to react. The resulting insoluble material was washed several times in distilled water and then dried. The residue consisted primarily of phosphides, carbides, sparse euhedral light-blue moissanite, graphite, and black grains recognized as diamond by their adamantine luster. The adamantine grains were concentrated by centrifuging the residue in a lithium heteropolytungstate (density of 2.9 g/mL) solution. Several hundred grains were concentrated with the heavy liquid then washed in distilled water. A portion of the separate was crushed with a pestle and mortar and the powder x-rayed with a powder diffractometer employing Cu Kα radiation. A small droplet (ca. 2 μl) of the crushed adamantine grains in suspension with water was dried on a lacy-C coated Cu TEM grid. HRTEM images and selected-area electron-diffraction (SAED) patterns were acquired with a JEOL JEM 4000EX TEM (400 *kV*; LaB_6 filament, top-entry, double-tilt stage; C_s = 1 mm; point resolution = 0.17 nm).

Results: *Optical and SEM.* The grains range in size from 50 μm to near 1 mm. Most grains are anhedral with rounded or curved surfaces. Several euhedral grains with rhombohedral and cubic forms were found. Many of the larger grains show a crude layering. The luster and roundness varies between grains. The less lustrous grains are softer and have a more graphitic appearance.

X-ray diffraction. The powder X-ray pattern shows a series of broad reflections with d-spacings that match those for graphite, diamond, and lonsdaleite. Modeling of the pattern suggests average grains sizes for diamond and lonsdaleite near 5 nm.

TEM. The HRTEM images show grains with various proportions of graphite interspersed with crystallites that reveal a 0.2-nm spacing consistent with diamond and lonsdaleite. Some grains show an abundance of 10 to 30-nm sized regions with high diffraction contrast (Fig. C). These grains are typically poor in graphite. The SAED patterns from these high-contrast regions reveal rings belonging to diamond and lonsdaleite (Fig. D). HRTEM images from such high-contrast areas (Fig. E) show spacings and angles consistent with diamond and lonsdaleite. The layers of the two polymorphs are transition to each other. They have a common orientation, with the [0-11] zone axis of diamond parallel to [010] of lonsdaleite. No large, or isolated crystals of lonsdaleite were found, instead lonsdaleite occurs as small regions intimately associated with diamond.

Conclusions: Though there are early reports of transparent octahedral crystals of diamond in the Canyon Diablo meteorite (see discussion in [3, 9], the question as to whether true diamonds occur in iron meteorites remains unresolved. Instead, the HRTEM imaging shows the atomic-scale structural complexity of the black "diamonds" from the Canyon Diablo meteorite. The presence of lonsdaleite in faulted regions of the sample indicates the significance of the hexagonal polymorph during the diamond formation of the Canyon Diablo meteorite.

References: [1] Foote, A.E. (1891) Amer. J. Sci. **42**, 413-417. [2] Ksanda C.J. and Henderson E.P. (1939) Amer. Min. **24,** 677-680. [3] Frondel C. and Marvin U.B. (1967) Nature, **214,** 587-589. [4] Lonsdale K. (1971) Amer. Min. **56,** 333-336. [5] Yoshiasa A. et al. (2003) Jap. J. App. Phys. **42,** 1694-1704. [6] Erskine D.J. and Nellis W.J. (1991) Nature **349,** 317-319. [7] Lipschutz M.E. and Anders E. (1961) Geochim. Cosmochim. Acta **24,** 83-105. [8] Clarke Jr R.S. et al. (1981) Nature **291,** 396-398. [9] Farrington O.C. (1915) *Meteorites. Their Structure, Composition, and Terrestrial Relations.* Chicago: The Lakeside Press. 233.

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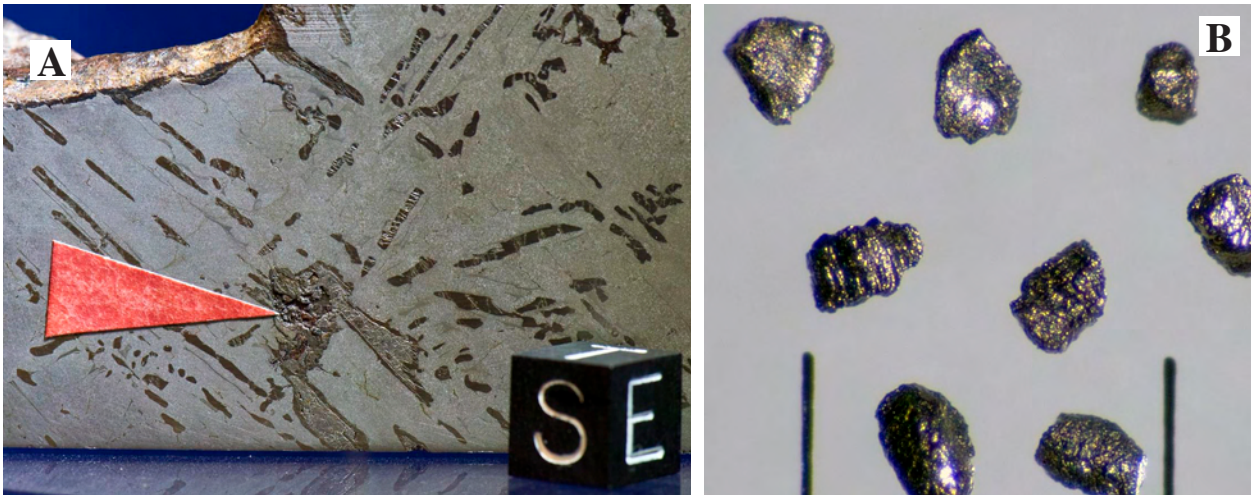

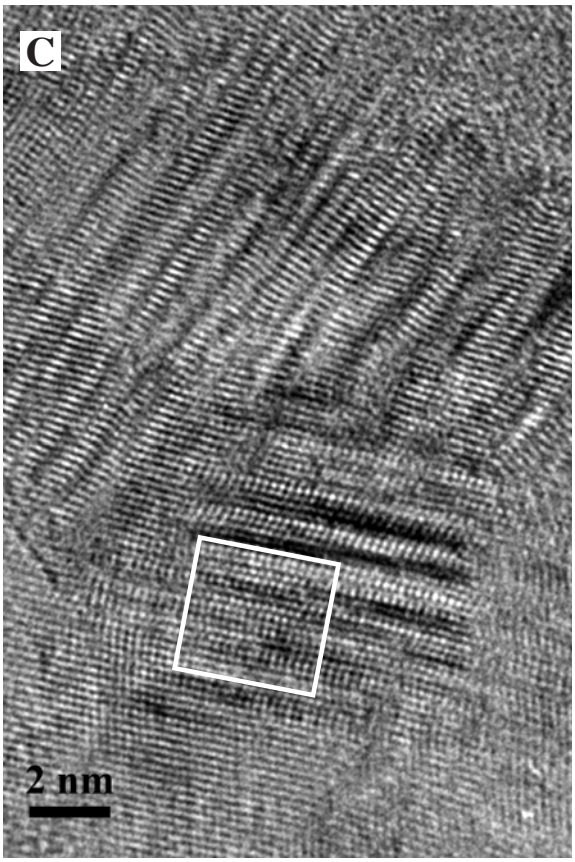

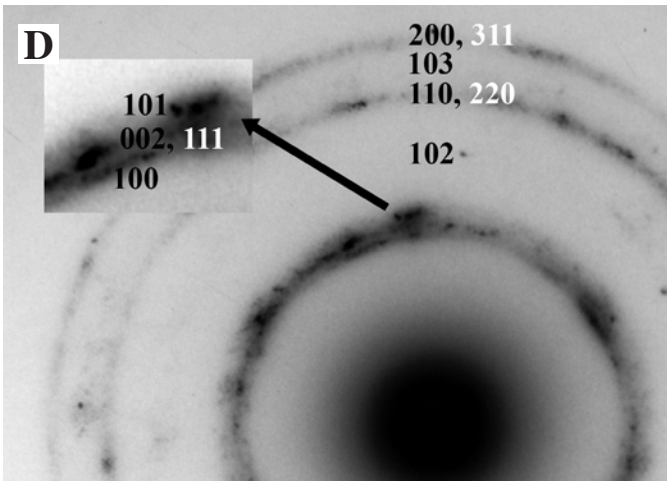

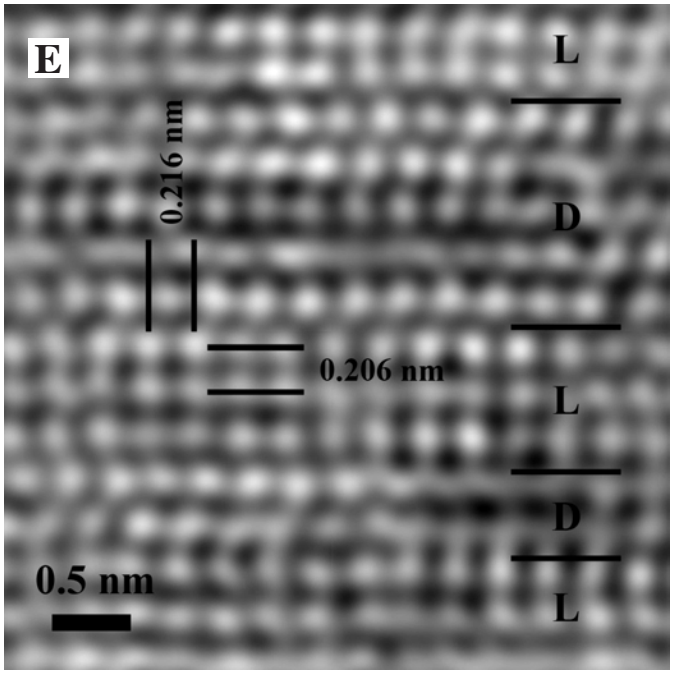

A) Polished section of a shocked Canyon Diablo meteorite with a diamond-bearing region indicated by the arrow (specimen ASU34.364). Scale cube is 1 cm. B) Individual Canyon Diablo "diamonds". Distance between scale markers is 1 mm. C) TEM image of a highly faulted region of diamond showing diamond and lonsdaleite. D) SAED pattern from a region with faulted diamond showing rings for diamond (white indices) and lonsdaleite (black indices). E) Back-ground filtered HRTEM image of the area indicated by the white box in (C) showing layers of diamond (D) and lonsdaleite (L).