OBSERVATIONS ON A 10-KG GRAPHITE NODULE FROM THE CANYON DIABLO (IAB-MG) IRON METEORITE.

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Introduction: The Canyon Diablo (CD) iron meteorite is unusual in that it contains large, to decimeter-sized, nodules dominated by graphite and veins of metal. They were mentioned as early as 1906 by Tassin [1], and described as a septarian nodule composed of graphitic carbon and metal. They are usually found around Barringer Crater as caliche-covered masses and only rarely insitu in irons, e.g., Fig. 488 in [2]. In addition, the large nodules do not contain significant troilite, unlike the abundant smaller examples [2]. Despite their size and unusual structure, there have been few petrographic descriptions of these masses [e.g., 1,3]. Here is given a preliminary account of a 10-kg CD graphite nodule.

Sample and Methods: Several years ago, a large graphite-rich mass was found about eight miles SW of Barringer Crater at a depth of four feet. The mass was covered by thick caliche, which the finder subsequently removed with a hammer and acid, leaving a 10 kg graphite nodule (fig. A). Additionally, there was no meteoritic shale associated with the nodule suggesting that the mass had an independent flight during breakup of the incoming CD mass. The Center for Meteorite Studies at ASU acquired a 4.12 kg end-piece of the nodule (fig. B) and a complete 330 g slice measuring 18 x 15 cm from the center of the mass. This slice was flat lapped, polished, and examined by optical microscopy.

Eighteen areas of the nodule were sampled and analyzed for $\delta^{13}C$ at the Environmental Isotope Laboratory, University of Arizona, on a continuous-flow gas-ratio mass spectrometer (Finnigan Delta PlusXL). Samples were extracted with a diamond core drill. The extracted 2-mm diameter x 3-mm long cores were crushed and ~0.3 mg used for $\delta^{13}C$ analysis. Areas for analysis were chosen at random across the sample from the edge of the slice to the center. Approximately 0.3 mg of sample was combusted using an elemental analyzer (Costech) coupled to the mass spectrometer. Standardization is based on acetanilide for elemental concentration, NBS-22 and USGS-24 for $\delta^{13}C$. Precision is better than ± 0.08 for $\delta^{13}C$ (1s), based on repeated internal standards.

Results and Discussion: Visually, the large slice shows an anastomosing network of metal veins (to 4-mm thick), which divides the graphite into angular blocks (fig. B). Microscopic examination shows that the metal veins are dominated by polycrystalline kamacite, with a grain size typically <100 um, with lesser schreibersite (fig. C), and rare troilite. Cliftonite, defined as euhedral grains of twinned graphite [4,5], is common as single and clustered grains concentrated in a central band in the thicker (>2 mm) metal veins. Cliftonite also borders the metal veins, forming compact checker-board-like masses (fig. D). Away from the veins, the graphite forms a compact aggregate of graphite "books", typically <20 μm long, with occasional mm-sized grains, and fan-shaped aggregates. Also present are scattered <50 μm kamacite grains, with anhedral to euhedral outlines, and rare troilite. Troilite show abundant shock lamellae. Silicates are rare and largely restricted to scattered grains near the edge of the slice.

The $\delta^{13}C$ values for the large CD range from -7.91 to -10.27 ‰, with a mode of -9.7 ‰ (fig. E). There is no apparent pattern to this range with respect to location within the nodule. These values are lighter than those previously measured for CD nodular graphite [6], which range from -4.89 to -9.36 ‰, and other IAB-MG nodular graphites [6,7], but heavier than that for C in cohenite or taenite [7]. In addition, [6] shows a range of 1.31 ‰ within a single 2-cm-sized CD graphite nodule.

Formation of the large graphite nodules is contentious. One interpretation is that the metal veins within the nodules are the product of shock melting of the host meteorite with metal bing injected at high T into the graphite, which subsequently cooled quickly [8]. However, [3] suggests that the nodules formed at relatively low T as the veins show areas rich in refractory PGEs that coexist with those depleted in these elements at the sub-mm scale. They suggest the recrystallized texture of the metal is indicative of a "brief and moderate thermal event" and that the iron did not form from a metal melt. As such, [3] proposed the formation of CD via a chemical vapor deposition mechanism. Similarly, [9] measured primordial noble gases within a graphite nodule and deduced from the HL/Q ratio that the graphite-metal inclusion was heated to 600° C at most. However, iron formation at low T is inconsistent with the more commonly held view of their crystallization from a high T melt that cooled through the austenite region of the Fe-Ni phase diagram.

Currently, the relationship between the carbon and its characteristics in the large nodules (containing polycrystalline kamacite and cliftonite) and the more common cm-sized nodules of carbon±troilite and mantled by schreibersite±cohenite is unknown. It is possible that the graphite in the larger nodules represent "fossil" carbon accumulations [6], and as such has the potential to give insights into previous stages of their formation history.

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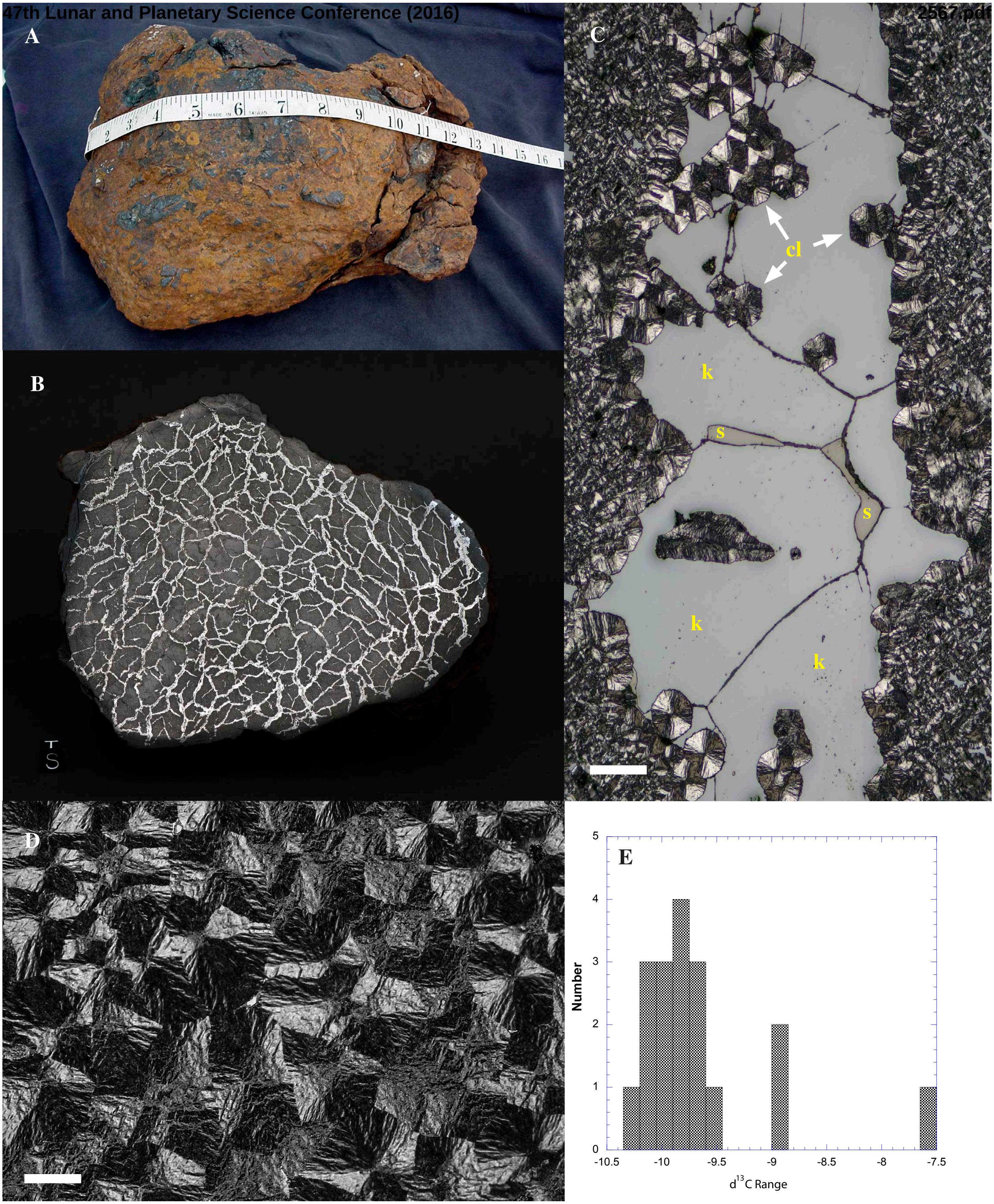

A) Photograph of the 10-kg Canyon Diablo graphite nodule. Tape measure is in inches. **B**) Photograph of the cut and polished face of the 4.12 kg end-piece (1-cm scale cube at the bottom left) showing graphite (grey) and metal veining (white). ASU#34_133. **C**) Reflected-light image showing a typical metal vein of kamacite (**k**), with minor schreibersite (**s**), bordered by graphite (mottled black-grey-white). The graphite within and bordering the metal is composed of twinned grains (typically 20 to 30 µm) called cliftonite (**cl**). Away from the vein the graphite is typically finer grained, with randomly oriented books in the 5 x 2 µm size range. Scale bar = 50 µm. **D**) Coalesced cliftonite grains forming a checker-board pattern. Scale bar = 20 µm. **E**) Histogram of the 18 $\delta^{13}C$ values.