THE BLUE ANGEL REVISITED. G. J. Wasserburg[1], G. R. Huss[2], and D. A. Papanastassiou[1,3] [1]The Lunatic Asylum, Division of Geological and Planetary Sciences 170-25, Caltech, Pasadena, CA 91125; isotopes@gps.caltech.edu; [2]Department of Geological Sciences and Center for Meteorite Studies, Arizona State University, Tempe, AZ 85287-1404 USA; [3]Earth and Space Sciences Division, Jet Propulsion Laboratory, 183-335, Caltech, 4800 Oak Grove Dr. Pasadena, CA 91109-8099

The Blue Angel is a brilliant, light-blue hibonite-rich inclusion found in Murchison (CM) by R. Becker in 1979, who presented it to the Lunatic Asylum for investigation. It was subject to an extensive petrochemical examination [1] and a preliminary study of ^{26}Al–Mg systematics [2]. Our current interest in the inclusion is due to the fact that the hibonite appears to resemble a vapor condensate (Figs. 1-3) and is certainly distinct from the typical hibonites found in CAIs that were crystallized from a melt. The Blue Angel has a diameter of ~1 mm and has very porous and friable regions. It consists dominantly of hibonite (~45% by volume), calcite (~45%), spinel (~6%), and perovskite (~2%). Minor and trace phases are diopside, melilite, FeNi metal and gypsum. The inclusion can be divided into three zones: 1) a core of dark bluish-grey hibonite; 2) a mantle of intermixed light-blue (hibonite) and white patches (calcite); and 3) the spinel rim. The core, with extensive void spaces, is almost entirely composed of hibonite crystals, which are randomly oriented hexagonal plates with poikilitic perovskite blebs and rare FeNi. Mantle hibonites are particularly loosely packed and that region is very porous. The ^{26}Al–Mg study by [2] was done on individual crystals using the direct-loading technique (DLT). It was shown that there were clear excesses of ^{26}Mg of 13.6‰. Using the average Al/Mg ratio determined by the SEM, a value of $^{26}\text{Al}/^{27}\text{Al} \approx 5\text{x}10^{-5}$ was estimated. In order to obtain a better estimate of the ^{26}Al–^{26}Mg systematics, we have conducted an ion probe study of the Blue Angel.

Ion probe measurements were conducted with the new Cameca ims 6f ion microprobe at Arizona State University using standard techniques [e.g., 3, 4]. The ability of the new instrument to generate very small beam spots made these measurements possible. The results for hibonites from the core and mantle and for spinels from the rim are shown in Fig. 4. All data fall on a single array which is consistent with $(^{26}\text{Al}/^{27}\text{Al})_0 = 5\ \text{x}10^{-5}$. While there is not a large spread in $^{27}\text{Al}/^{24}\text{Mg}$ in the hibonites, there appears to be an excellent correlation. Rim spinels give $^{26}\text{Mg}/^{24}\text{Mg}$ indistinguishable from normal Mg. The only other data set is from Papanastassiou and Wasserburg [2, 5]. These workers used DLT to measure the isotopic compositions of individual grains after measuring Al/Mg using x-ray analysis with an SEM. Their earlier results [2] established the radiogenic nature of Mg in the hibonite and the normal value of Mg in the spinel. While the DLT ^{26}Mg/Mg measurements of hibonites [5] were quite precise they did not correlate with Al/Mg, but had an essentially constant value over the range of the Al/Mg measured values. The results that we report here indicate that there is a real correlation of $^{26}\text{Mg}/^{24}\text{Mg}$ with $^{27}\text{Al}/^{24}\text{Mg}$ and that the earlier results may reflect large uncertainties in Al/Mg by the SEM X-ray measurements on individual grains.

The inferred $(^{26}\text{Al}/^{27}\text{Al})_0$ of $(5.3\pm0.5)\text{x}10^{-5}$ presented here is based on the hibonite and spinel data. It follows that the Blue Angel, a friable object with a mantle impregnated with calcite and enclosed in a rim of spinel, perovskite, aluminous pyroxene, and calcite (all distinct from the adjoining matrix), formed with the same canonical $^{26}\text{Al}/^{27}\text{Al}$ [6, 7] as that with which many/most CAIs. Any proposed mechanism of formation of the Blue Angel must involve a first stage in which the refractory oxide phases (as well as the FeNi blebs) were produced as a vapor deposit followed by deposition of calcite. While the first stage might conceivably be attributed to a nebular process, we consider [*cf*, 1] that the whole object might instead be produced in a planetary environment. Here an ^{26}Al heat source could produce extremely high temperatures, causing explosive volcanism from high-temperature vents. This volcanism would mix material from the interior of the protoplanet with its exterior, which consisted of a more hydrated debris heap. The high-temperature source may well have produced abundant CO_2 from oxidation of an original carbon inventory. The impregnation of the calcite presumably occurred at this time. This object was then included in the Murchison meteorite. We wish to emphasize that all chondritic samples are aggregates of materials having diverse origins and metamorphic histories and that they had to be accumulated in bodies of sufficient size in order to be preserved.

We will obtain more-complete Al-Mg isotopic data on separated individual crystals using SIMS techniques. Measurements of oxygen on both hibonite and calcite will be carried, out as well as a search for ^{41}Ca.

References: [1] Armstrong J. T. *et al.* (1982) *GCA* **46**, 575-595. [2] Papanastassiou D. A. and Wasserburg G. J. (1980) *Meteoritics* **15**, 348-349. [3] Huneke J. C. *et al.* (1983) *GCA* **47**, 1635-1650. [4] Fahey A. J. *et al.* (1987) *GCA* **51**, 3215-3229. [5] Papanastassiou D. A. and Wasserburg G. J. (1982) Unpublished MS. [6] Lee T. *et al.* (1977) *Ap.J.* (Letters) **211**, L107-L110. [7] MacPherson G. J. *et al.* (1995) *Meteoritics* **30,** 365-386. Supported by NASA NAG5-4083 (GJW) and NAG5-8158 (GRH). Caltech Division Contribution #8762 (1071).

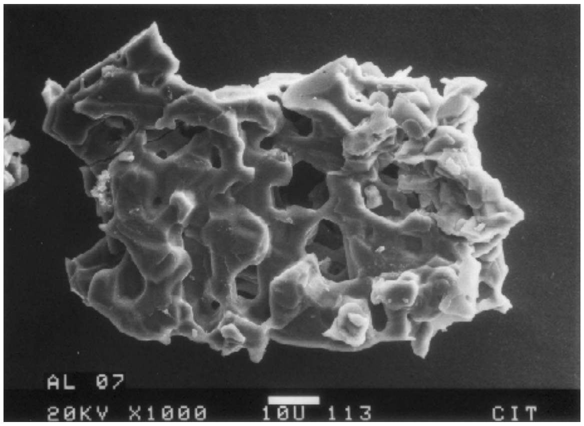

Fig. 1: An SEM image of a fragment of the hibonite core of Blue Angel showing the extensive void spaces with hexagonal or trapezoidal outlines [after 1].

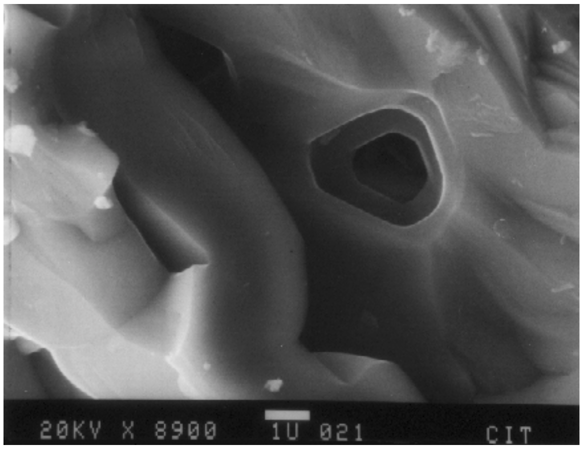

Fig. 2: High magnification SEM image of a hibonite crystal from the core showing a characteristic trigonal hole, strongly suggestive of vapor growth [after 1].

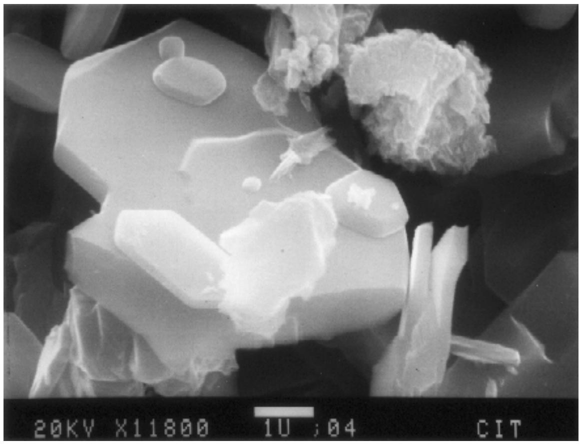

Fig. 3: High magnification image of a portion of the blue mantle region showing euhedral hexagonal plates of hibonite [after 1].

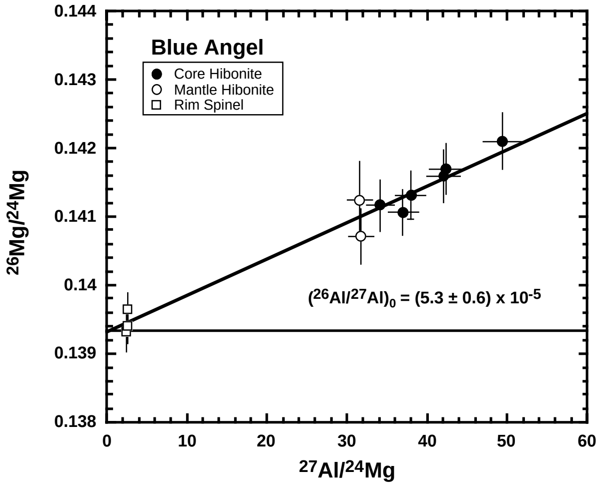

Fig. 4: Mg-Al evolution diagram for the Blue Angel. Data for core hibonite, mantle hibonite, and rim spinel fall on a single array. The slope (2 sigma errors) determined by least-squares regression is shown.