

0.12 ε and -0.02 ± 0.12 ε). We note that none of the meteorite classes studied earlier in our lab [6] have a Cr-isotopic signature similar to that of the K/T samples. Moreover, it is not clear at present whether the measured deficit of <sup>53</sup>Cr is real or if it is the result of an elevated <sup>54</sup>Cr/<sup>52</sup>Cr ratio in the sample. (The <sup>54</sup>Cr/<sup>52</sup>Cr ratio is used for the second-order fractionation correction [6].) There are indications [8] for an elevated <sup>54</sup>Cr/<sup>52</sup>Cr ratio in the bulk carbonaceous chondrites. For this reason we have measured the isotopic composition of Cr in bulk samples of Allende and Orgueil. Treated in the same way as the K/T samples, preliminary data for Allende and Orgueil (<sup>53</sup>Cr/<sup>52</sup>Cr ~ -0.40 ε and ~ -0.44 ε respectively) show that their Cr-isotopic signature is very similar to that of the K/T samples. Thus, regardless of what the "negative" <sup>53</sup>Cr/<sup>52</sup>Cr ratio actually will translate into (i.e., deficit of <sup>53</sup>Cr or excess of <sup>54</sup>Cr), the obtained results strongly suggest that the K/T boundary impactor was comprised of carbonaceous-chondrite-type material.

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**IMPACT DIAMONDS IN GLASS BOMBS FROM SUEVITE OF THE RIES CRATER, GERMANY: NEW OBSERVATIONS.** M. Siebenschock, R. T. Schmitt, and D. Stöfler, Institut für Mineralogie, Museum für Naturkunde, Invalidenstrasse 43, D-10115 Berlin, Germany (matthias.siebenschock@rz.hu-berlin.de).

Impact diamonds are an indicator of cratering processes on planetary surfaces. They have formed *in situ* by shock transformation from graphite in C-bearing target rocks [1]. There is still a discussion about whether some impact diamonds could be formed by condensation of vaporized C-bearing target rocks [2]. Impact diamonds have been known to exist in the Ries Crater (24-km diameter) since the studies by [1]. They were found in glass bombs [1,3] or highly shocked C-bearing clasts [4,5] of the suevite.

Impact diamonds were found in glass bombs of the fallout suevite of three new localities of the Ries crater: Aumühle (48°58'N 10°38'E, 11 km north-northeast of the crater center), Seelbronn (48°44'N, 10°28'E, 18 km south-southwest of the crater center) and Zipplingen (48°56'N, 10°24'E, 11.5 km west-northwest of the crater center). Aumühle and Zipplingen are located in the so-called megablock zone between the inner ring and crater rim of the crater, whereas Seelbronn is located outside of the crater rim in the ejecta blanket. To separate the diamonds from the glass bombs, acid-dissolution techniques as described in [3] were used. Contamination by industrial diamonds or SiC-grains was eliminated by avoiding sawing and cutting procedures during the separation.

Impact diamonds were found in the glass bombs Au-G (diameter 30 cm) and SIE-9781 (diameter 20 cm) from Aumühle, SIE-9721 (diameter 20 cm) from Seelbronn, and Zi-G1 (diameter 10 cm) from Zipplingen. For the separation glass bomb Au-G was divided into a core sample (rich in vesicles) and a rim sample (poor in vesicles). Both samples of Au-G contain impact diamonds. The whole-rock chemistry of the glass bombs was determined by X-ray fluorescence spectroscopy (Table 1). The impact diamonds appear as polycrystalline aggregates and reach sizes up to 300 μm. They appear in pseudohexagonal plates and show parallel intergrowth of platelets as a common morphological feature. They contain impurities of graphite often orientated in lamellae. Their color varies from colorless-yellowish and green to grayish-black. Under the optical microscope, the diamonds are transparent and birefringent as reported previously [4,5]. Some of the diamond grains from SIE-9721 show a transition from graphite to diamond. The abundance of diamonds in the analyzed glass bombs is in the lower part-per-billion range. All of these samples contain additional graphite, and the abundance of graphite is much more common in comparison to impact diamonds. All of the extracted diamonds seem to have formed by solid state transformation of

TABLE 1. Chemical composition of diamond-bearing glass bombs.

wt%	Au-G (core)	Au-G (rim)	SIE-9781	SIE-9721	Zi-G1
SiO <sub>2</sub>	65.70	65.80	65.30	64.20	64.10
TiO <sub>2</sub>	0.80	0.79	0.82	0.73	0.68
Al <sub>2</sub> O <sub>3</sub>	16.90	16.80	16.90	14.80	14.70
Fe <sub>2</sub> O <sub>3</sub> *	2.46	2.45	2.51	4.99	4.74
MnO	0.05	0.05	0.03	0.10	0.10
MgO	0.73	0.78	0.56	2.63	2.44
CaO	3.83	3.74	4.29	4.08	4.11
Na <sub>2</sub> O	3.25	3.24	3.46	3.06	3.17
K <sub>2</sub> O	3.22	3.11	3.02	2.75	2.67
P <sub>2</sub> O <sub>5</sub>	0.34	0.35	0.58	0.27	0.24
L.O.I.	1.90	2.00	1.60	1.80	2.20
Total	99.18	99.11	99.07	99.41	99.15

\* Total iron given as Fe<sub>2</sub>O<sub>3</sub>.

graphite. Large SiC grains as reported by [6] could not be found in any of our analyzed glass bombs.

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**HIBONITE IN ALLENDE AND MURCHISON REFRACTORY INCLUSIONS AND IMPLICATIONS OF THE ABSENCE OF CERIUM DEPLETIONS.** S. B. Simon<sup>1</sup>, A. M. Davis<sup>1,2</sup>, and L. Grossman<sup>1,2</sup>, <sup>1</sup>Department of the Geophysical Sciences, 5734 South Ellis Avenue, University of Chicago, Chicago IL 60637, USA (sbs8@midway.uchicago.edu), <sup>2</sup>Enrico Fermi Institute, University of Chicago, Chicago IL 60637, USA.

**Introduction:** We have studied two hibonite-rich fluffy type A (FTA) inclusions, ALH2 and ALH3, from Allende and SH-6, a fluffy, hibonite-spinel inclusion from Murchison. Although it is very likely that these types of inclusions are primary condensates [1,2], their trace-element abundances have not been thoroughly studied. We analyzed hibonite and melilite in the two FTAs and hibonite in SH-6 with the ion microprobe to determine the trace-element abundances of (presumed) condensates; to compare the trace-element contents of Allende hibonite with those of Murchison hibonite; and to see if Allende hibonite exhibits negative Ce anomalies, as would be expected if its very low Ti<sup>3+</sup>/Ti<sup>4+</sup> ratios and orange color reflect condensation under oxidizing conditions rather than later equilibration [3].

**Samples:** Inclusion ALH2 has melilite up to 200 μm across and hibonite plates up to ~50 μm across. Allan Hills 3 has coarser melilite (up to 700 μm) and is less altered than ALH2. The outer ~400 μm of ALH3 consist of melilite with sparse spinel and perovskite, but the interior has zones that are very rich in hibonite and spinel. Melilite is very aluminous (Åk<sub>0.5-20</sub>) and hibonite has 2-7 wt% TiO<sub>2</sub>. Most hibonite plates are 20-40 μm across and are subhedral to anhedral. Sample SH-6 has a porous core of blue, euhedral hibonite plates that are 2-10 μm across, and an ~10-μm-thick rind of spinel. It was described by [2].

**Results:** Both SH-6 and ALH3 have group II chondrite-normalized REE patterns. This is seen in both the hibonite and melilite of ALH3, indicating a common source for these phases. Allan Hills has a flat pattern, probably a group I. The hibonite in ALH2 and ALH3 has no Ce anomalies, supporting the previous suggestion [3] that the oxidizing conditions inferred for Allende hibonite reflect re-equilibration rather than condensation under extremely oxidizing conditions. The ALH2 and ALH3

hibonite REE patterns are quite different from each other and from most Murchison hibonites that have been analyzed [4]. While Murchison hibonite commonly has flat, light REE (LREE) abundances at  $\sim 100\times$  CI, hibonite in ALH2 has very low LREE abundances, at  $\sim 5\times$  CI. In ALH3 hibonite, LREE abundances are not flat but instead fall by 2–3 $\times$  from La (40–80 $\times$  CI) through Sm, then drop off even more sharply, at least through Gd, at 2–10 $\times$  CI. As is typical of group II patterns, Tm is enriched relative to the refractory heavy REE (HREE), but the latter could not be measured accurately because of interferences due to the high LREE/HREE ratios and low concentrations. Yttrium, an element that is as refractory as Lu, is also very low, at  $\sim 1\times$  CI.

**Discussion:** Most hibonite-, spinel-bearing inclusions are thought to have last equilibrated with the nebular gas at 1200°–1230°C [5]. Under conditions sufficiently oxidizing to form orange hibonite, Ce is quite volatile relative to the other REE at these temperatures [6]; yet no Ce depletions are observed in ALH2 or ALH3. It is unlikely that the Allende hibonite formed under oxidizing conditions and that Ce eventually completely condensed into it, because equilibration temperatures much lower than those found by [5] would be required. It is also unlikely that Ce condensed into another phase and was later redistributed within ALH2 and ALH3 in just the amounts required to erase anomalies. We agree with the previous suggestion [3] that Allende hibonite formed under "normal," reducing conditions (i.e., without Ce depletions) and was later altered at higher O fugacities to produce its orange color. Experiments [3] have shown that blue, Ti<sup>3+</sup>-bearing hibonite can become orange in 1 hr at 1430°C at an  $f_{O_2}$  of  $10^{-8}$ , indicating that Ti<sup>3+</sup> in hibonite can oxidize easily at high temperatures. From the above observations, we conclude that it is likely that Allende hibonite was altered under oxidizing conditions at elevated but subsolidus temperatures, probably in the nebula. In contrast, Murchison inclusions, which contain oxidized secondary phases such as Fe-bearing phyllosilicates yet retain blue hibonite, must have experienced much lower alteration temperatures than did Allende inclusions. A study of the time required at various temperatures for the blue-to-orange transition in hibonite would likely place valuable constraints on the alteration conditions experienced by all hibonite-bearing inclusions.

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**LOHAWAT HOWARDITE: CHEMICAL AND MINERALOGICAL CHARACTERISTICS AND COSMOGENIC RECORDS.** U. K. Singh<sup>1</sup>, M. S. Sisodia<sup>1</sup>, A. D. Shukla<sup>2</sup>, S. Chakraborty<sup>2</sup>, K. M. Suthar<sup>2</sup>, M. H. Dixit<sup>2</sup>, P. N. Shukla<sup>2</sup>, and N. Bhandari<sup>2</sup>, <sup>1</sup>Department of Geology, J. N. V. University, Jodhpur 342 005 (bhandari@prl.ernet.in), <sup>2</sup>Physical Research Laboratory, Navrangpura, Ahmedabad 380 009, India.

Three rare stony meteorites (an enstatite chondrite, a howardite and an eucrite) have fallen in a period of 5 yr within a distance of about 180–210 km from each other in the semidesert region of western Rajasthan, India. Statistically, this is a strange coincidence, first because of the nature of these meteorites, which belong to rare groups, second because of the proximity of the falls, and third because of the short interval of time during which they fell. Normally, one meteorite is expected to fall over a 15,000 km<sup>2</sup> area in about 2000 yr, and the most probable, i.e., abundant, group of meteorites is that of ordinary chondrites. In addition, it may be noted that howardites and eucrites (HED) have related origins and it is believed that they belong to different depths of the same asteroidal bodies. The Didwana-Rajod enstatite chondrite and Piplia Kalan eucrite, which fell in 1991 and 1996 respectively, have been described previously [1–3]. Here we describe the howardite, a single fragment weighing about 40 kg that broke up on impact, at Lohawat village in Western Rajasthan on October 30, 1994, about 11 p.m. IST [4]. It is a heterogeneous polymict regolith breccia with a large variety and number of lithic fragments in a finely comminuted material, having an appearance similar to Kapoeta.

Two lithologies are prominent, one consisting of a fine-grained light-ash-colored angular and rounded fragment and the other, less abundant, of a dark glassy material having dominantly feldspars. A dunitic fragment, probably of a diogenite, was also found and some fragments have eucritic mineral composition, which is consistent with the models that howardites are mixtures of eucrite and diogenite components. Many of these fragments and single mineral grains are rounded and some of them have well-developed glassy rims. Several glassy (pyroxenitic) chondrule-like objects, ranging in size from 1 to 7 mm, were also found. Some minerals show definite shock effects as expected in impact breccias.

Chemical analysis gives concentrations of Fe (15.15%), Mg (9.28%), Al (4.22%), Ca (4.73%), K (0.0267 to 0.0366%), and Na (0.26%). These are similar to the values reported earlier [4].

Cosmic-ray tracks and some radionuclides have been measured. The track density is found to range between 0.7 and  $6 \times 10^6/\text{cm}^2$  in olivine and feldspar grains, which were etched for 9 hr in boiling WN solution and for 30 min in boiling 1:2 NaOH respectively. Solar-flare-irradiated grains are extremely rare ( $\ll 1\%$ ). Sodium-22 and <sup>26</sup>Al activities, measured, using whole-rock  $\gamma$ -ray spectrometry, are  $46 \pm 5$  dpm/kg and  $77 \pm 4$  dpm/kg.

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**MAGIC-ANGLE-SPINNING NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY OF SHOCKED LIMESTONES FROM THE STEINHEIM CRATER.** R. Skála<sup>1</sup> and J. Rohovec<sup>2</sup>, <sup>1</sup>Department of Mineralogy, Czech Geological Survey, Geologická 6, CZ-15200 Praha 5, Czech Republic (skala@cgu.cz), <sup>2</sup>Department of Inorganic Chemistry, Faculty of Science, Charles University, Hlavova 2030, CZ-12843 Praha 2, Czech Republic.

**Samples:** Five samples of Malmian and Dogger limestone and marlstone lithologies from the Steinheim Basin, Germany [1], experiencing various degrees of impact metamorphism associated with the Ries-Steinheim event at  $\sim 15$  Ma, were selected for study. A sample of lithographic limestone from Solnhofen represents an unshocked standard studied together with the set of shocked materials. The degree of shock in the specimens that were used for this research varied from virtually none, in the case of bedded limestones from the outside the crater, to low and middle levels of shock expected in monomict breccia from the crater rim and shatter-cone limestones from the central feature, up to relatively highly shocked materials in breccia drilled out from beneath the apparent crater floor. Characteristics of the samples studied are given in Table 1 below.

**Experimental:** All samples were X-rayed prior to the collection of nuclear magnetic resonance (NMR) spectra. X-ray powder diffraction has revealed that in all samples, the main constituent is represented by calcite. In addition, minor amounts of quartz were found in the samples. In the case of fallback breccia, the powder pattern indicated the presence of calcite, quartz, feldspar, and kaolinite. In thin sections, sedimentary textures and structures seen in unshocked samples are at least partially preserved in monomict breccia ("Gries") clasts and in shatter cones, while they are highly altered to completely missing in fallback breccia.

Approximately 2 ml of powdered sample was used to acquire <sup>13</sup>C NMR spectra under magic-angle-spinning (MAS) conditions. The spectrometer used was Varian Unity I Nova 400. Spectra were obtained at a frequency of 100.575 MHz. Magic-angle-spinning frequency was 5 kHz, preacquisition delay 150 s, flip angle 90°, and rotor 7 mm. A pulse Fourier transform method was used to obtain the NMR spectra by first detecting signals in the time domain, then transforming the data to yield spectra in the frequency domain. No lb factor was utilized. Each sample was characterized by the values of chemical shift and half-width of chemical shift peak. These values are listed in Table 1.