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EVOLUTION OF CAIs, Ca, Al-RICH CHONDRULES, AND FERROMAGNESIAN CHONDRULES THROUGH EQUILIBRIUM AND DISEQUILIBRIUM CONDENSATION. H. Nagahara and K. Ozawa. 1Dept. Earth Planet. Sci., University of Tokyo. E-mail: hiroko@eps.s.u-tokyo.ac.jp. 2Dept. Earth Planetary Sci., Univ. Tokyo.

Introduction: Ca-Al-rich chondrules would provide critical information to relate CAIs and ferromagnesian chondrules [e.g., 1]. Here, we quantitatively estimate the formation conditions of those components on the basis of our kinetic evaporation-condensation model [2], and compare them to those for CAIs and ferromagnesian chondrules

Ferromagnesian chondrules: Ferromagnesian chondrules have constant (Ca+Al), wide variation of Si/Mg, and weak correlation between Si/Mg and Fe [3]. These features are most plausibly explained by kinetically controlled condensation of silicate melt with a cooling rate of 1 – 0.01°C/hour at 1800 – 1400K from a gas depleted in refractory component by 30% and Fe by 80% under the dust enrichment of several hundred times solar [2].

Ca-Al-rich chondrules: Glassy Ca-Al-rich chondrules in Semarkona are characterized by strong concentric zoning in terms of major elements [4]. They can be explained by fractionation of spinel from the nearly equilibrium liquid condensates at Ptot~10^-6 bar with dust enrichment higher than 100 times solar and T> 1600K. This is different from the condensation model from fractionated gas [5]. The estimated cooling condition is close to that for ferromagnesian chondrules.

Solar nebula evolution and CAIs and chondrules:

CAIs. Type A and B CAIs are thought to be solid condensates from gas with CI composition, which later have suffered melting and evaporation [6] or liquid condensates from gas of CI-like composition [5]. The estimated formation conditions are Ptot=10^3 – 10^5 bar, T ~ 1500-1400°C, and cooling time of several hundreds to tens of thousands min [5], which is much slower than those for.

Overall evolution. CAIs, Ca-Al-rich chondrules, and ferromagnesian chondrules are thought to record nebular evolution from low P (high T), low dust enrichment, and nearly equilibrium (slow) condensation towards high P (low T), high dust enrichment, and fairly dynamic condensation The difference could be due to temporal (and spatial?) evolution, which is well preserved in the amount of 16O [7].

EXPERIMENTAL HYDROTHERMAL ALTERATION OF ANHYDROUS IDPs. K. Nakamura, S. Messenger & L.P. Keller
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Introduction: Anhydrous IDPs have been linked to cometary sources based on their compositions, spectral properties, and atmospheric entry velocities [1,2]. On the other hand, since no spectral signatures of hydrated minerals have been detected in comets, hydrated IDPs are thought to derive from primitive asteroids [1]. We reported an unusual IDP whose mineralogical and isotopic characteristics are mostly typical of anhydrous cometary IDPs but also contained minor hydrated phases [3]. Two possible origins for this IDP should be considered: (1) primitive (anhydrous) asteroidal material not represented in the meteorite collections, or (2) short-period comet that experienced a brief and incomplete aqueous alteration episode. To test these hypotheses, we carried out a series of hydrothermal alteration experiments on anhydrous IDPs and fine-grained (~80 µm) Allende carbonaceous chondrite.

Methods: Individual IDPs and fragments of Allende matrix were embedded in epoxy and 70 nm-thick sections were obtained by ultramicrotomy then transferred to C-coated Au grids. The sample grids were immersed in aqueous solutions, sealed in teflon containers (7ml), and heated at 120~150˚C for 12 to 72 hours. The sections were observed before and after the hydrothermal experiments by transmission electron microscopy (TEM) for precise mineralogical and crystallographic studies of individual phases.

Results and Discussion: The IDP U2097A19 had mineralogy typical of anhydrous IDPs including olivine, enstatite and Fe-sulfides. GEMS (glass with embedded metal and sulfide) grains are also ubiquitous. The Allende fragment was composed mainly of olivine (Fa50). After 24 hours in 120˚C deionized water (pH not controlled), both samples remained unchanged. After 12 hours in 150˚C deionized water, most of the anhydrous crystals and some amorphous silica in GEMS grains in the IDP were replaced by fine-grained phyllosilicates. The chemical composition and 7Å basal spacing indicate that the phyllosilicates are Fe-rich serpentine. However, most of the GEMS grains showed little reaction. Under the same conditions, much of the Allende olivine was also replaced by serpentine. The serpentine in Allende was better crystallized compared to that in the IDPs. After 72 hours in 150˚C deionized water, both samples were completely hydrated except a few GEMS grains.

Alteration of the IDP proceeded much more rapidly than similar experiments on meteorites [e.g. 4-6]. This is likely due to unique compositions [7] and fine grain sizes of IDPs (~200nm). Further works will be required to constrain parameters of capable of inducing aqueous alteration in cometary materials.

MINERALOGY OF ULTRACARBONACEOUS LARGE MICROMETEORITES.

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Three Antarctic micrometeorites (AMMs), KWP3F5, tt54B397, and to440033 with sizes larger than 200 µm were found to contain a large amount of carbonaceous material. Carbon concentration of the three AMMs is much higher than that observed in CI and matrix of CM chondrites. Carbon Kα line is higher than oxygen Kα line in the SEM/EDS spectra. The three AMMs have some morphological and mineralogical features in common. (1) Carbonaceous material forms a complex framework structure in an entire region of the micrometeorites, (2) Synchrotron X-ray diffraction analysis showed that the carbonaceous material is amorphous, and (3) small, variable compositions of olivine, low-Ca pyroxene, pyrrhotite, and kamacite disperse within the carbonaceous material. The heterogeneous silicate compositions and the presence of sulfides are indicative of pristine mineralogy of the micrometeorites.

KWP3F5 shows unique structure composed of two parts: one part, making up a substantial portion of the micrometeorite, shows wrinkled appearance and consists mainly of framework of carbonaceous material. In contrast, the other part is spherical objects made of silicates and has typical chondritic elemental abundance. The spherical shape clearly indicates that this part was melted during atmospheric entry due to low melting temperature of silicates ~ 1600°C, while the carbonaceous framework was left unmelted due to high melting temperature of carbonaceous material ~3000°C. The framework appears to have served as a heat insulator that has shielded inner silicates and sulfides during the atmospheric frictional heating.

The results of laser-extracted noble gas analysis of KWP3F5 indicate that the micrometeorite is enriched in solar-wind light noble gases. Ne isotopic composition is close to high energy component of solar wind (SEP) and no cosmogenic component is detected, suggesting that the micrometeorite has already been a small particle in the interplanetary space and exposed to solar and galactic cosmic rays for a short period of time. During atmospheric entry, the surface of the micrometeorite was heated to lose low-energy component of solar wind (SW).

Micrometeorite tt54B397 is rich in small low-Ca pyroxene particles with various Mg/Fe ratios less than 1 micron. Nano-sims analysis of this micrometeorite revealed that it contains presolar silicates in high abundance [1].

All of the mineralogical, compositional, and isotope signatures are different from those of matrix of primitive chondrites (e. g., [2]) but analogous with carbon-rich anhydrous IDPs (e. g., [3]). The three micrometeorites, however, are one order of magnitude larger than carbon-rich IDPs and show characteristic framework structure of amorphous carbonaceous material.

ON THE ESTIMATION OF THE STRENGTH OF METEOROIDS. K. Nazarova¹, P.A. Bland¹ and N.A. Artemieva¹. IARC, Department of Earth Science and Engineering, Imperial College London, South Kensington, SW7 2AZ, London, UK; Institute for the Dynamics of Geospheres, Russian Acad. Sci., Leninsky Prospect 38/6, Moscow, Russia 117939

Information on the strength of meteoroids over a range of sizes is rather limited. The strength of the body depends on material, structure, composition, dimension, shape, and its life history. Fragmentation of meteoroids by aerodynamic forces is closely connected with their strength – improving models of meteoroid strength is fundamental to understanding of meteoroid fragmentation and to improving our understanding of impact rates at planetary surfaces [1].

Measurements of the mechanical properties of meteorites are an important source of information on iron and stony meteoroid strength [2]. But this dataset is clearly limited, and extending strength estimates from meteorites to large meteoroids is problematic. To improve our understanding of meteoroid strength, we are comparing results from modelled atmospheric disruptions to fireball data, and modelled cratering events to the size and morphology of small crater fields on Earth (for those cases where impactor-type is known).

There are three main approaches to describing the atmospheric motion of meteoroids which are relevant to estimating the conditions for meteoroid break-up. The first - a hydrodynamic approximation - considers the impactor as a liquid-like object or droplet – so-called ‘pancake’ models [3, 4]. The second approach is based on studying the motion of the finite number of large well-separated fragments, which may be described individually [5, 6]. The third approach describes an intermediate situation when the fragments are not well-separated and move like a swarm of particles [3].

Here we use the model of separate fragments (SF) and a hydrodynamic approximation to estimate the strength of terrestrial impactors. By varying bolide strength in our simulations of atmospheric disruption, or small-asteroid impact, we can achieve a best-fit to specific fireball events and terrestrial crater fields. In this paper, we compare our modelled strength estimates from >20 fireball events, and a number of small crater fields, to laboratory data on meteorite strength [7, 8], to derive a strength model for iron and stony meteoroids extending over a 1-10^6 kg mass range.

**Ti, Al-rich Ca-pyroxene assemblages in CAIs.**

C. E. Nehru, M. K. Weisberg, and D. S. Ebel.

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**Introduction:** We have started a survey of the textures, mineral compositions, and petrology of Ti, Al-rich Ca pyroxene and coexisting melilite in a suite of refractory inclusions (compact and fluffy Type A) from CV (Leoville, Allende, Efremovka, Vigarano, NWA 2364), CO (Lance) and CR (Gao-Guene B and EET92105) Chondrites. We are particularly intrigued by the remarkably high Ti content in some of the pyroxene in CAIs and its significance in understanding CAI formation. These are our preliminary results.

**Results:** The CAIs we studied vary in sizes from a few tens of microns to a few millimeters across with variable shapes - irregular to oval to circular - and provide good evidence for a single, generally concentrically layered sequence of minerals related by successive condensation/crystallization processes. The core to rim sequence generally recorded is: perovskite + MgAl spinel ± hibonite, then melilite + Ca-pyroxene, and finally MgAl-spinel. The complete sequence may be missing or vary in some CAIs, but the general pattern remains. In addition, some contain Wark-Lovering rims.

In *fassaitic pyroxene* the, Ti$^{3+}$ with Ti$^{4+}$ were recalculated as by [1]. Fassaite composition variations from one CAI to another and sometimes within the same CAI are common. TiO$_2$ values vary from a few percent to a maximum of about 14 wt% and Al$_2$O$_3$ up to about 30 wt% are noted. Al and Ti values in a given CAI are positively correlated, and Al is negatively correlated with Mg. Fassaite with up to 13.64 wt % TiO$_2$ and 22.77 wt % Al$_2$O$_3$ occurs in the Type A compact inclusion of CR2 Chondrite EET92105 as reported by Weisberg et al. [2]. Fassaites from EET 92105 are uniform. *Melilite* is the most abundant component in the CAIs we studied. The association of melilite and Mg-Al-spinel with fassaite is most common. Melilite compositions vary, with normal zoning (X$_{Ak}$ increasing towards rims) frequent. The Ak content correlates positively with CaTs in coexisting fassaite.

**Discussions and Conclusions:** The origin of Type A CAIs has been debated for some time now. The current study (limited to CV3, CO3 and CR2 chondrites) adds to the existing textural and mineralogical evidence that points to a high temperature origin with successive layers approaching equilibrium with surrounding vapor. The sequence of minerals observed is in general agreement with the calculated sequence of equilibrium condensation [3]. Our data set is not yet large enough to warrant a blanket statement. For example, Efremovka 101.1 is a rare CAI studied by [4] and we have not come across one like it in our samples of Efremovka. We will be refining our conclusions as we gather more information on the subject.

COMBINING CHASSIGNY AND NWA2737: NEW CONSTRAINTS ON POSSIBLE PARENTAL MAGMAS AND CRYSTALLIZATION HISTORIES.
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Introduction: There are marked similarities between the cumulate mineral assemblages and melt inclusion assemblages of Chassigny and NWA2737 [1, 2]. A primary difference lies in the higher Mg# of the ferromagnesian minerals of the latter [1, 2]. The high Mg# of the ferromagnesian minerals of NWA2737 indicates a less Fe-rich parental magma than has been proposed for the Chassigny [2]. We are investigating the possibility that both NWA2737 and Chassigny crystallized from a similar parental melt with terrestrial Mg# and Al contents and that the NWA2737 assemblage reflects a higher temperature (and perhaps pressure) stage of fractionation. We are comparing experimental data from [3, 4] with the reported mineral compositions and crystallization sequence for both meteorites [1-4]. The Chassigny cumulate assemblage of olivine-augite-orthopyroxene and the polyphase melt inclusion assemblage olivine-augite-clinoxyroxene-orthopyroxene-kaersutite-Ti-biotite-apatite-spinel and alkali-rich rhyolite has been produced experimentally by crystallizing a mildly alkalic hawaiite with bulk water contents between 0.5 and 2 wt% at 9.3 kbar pressure [5, 6]. Mineral compositions of the Chassigny cumulate assemblage are reproduced at 1050°C. The NWA2737 olivine composition was produced experimentally along this path at 1200°C. Experiments are being conducted to evaluate whether the magnesium pyroxene can be produced soon thereafter. The general experimental assemblages matched those of both meteorites at 9.3 kbar, but not at 12.3 or 4.3 kbar, or for water contents below 0.5 wt%. The Al contents of the NWA2737 augite and that of augite in the Chassigny melt inclusions are consistent with elevated pressure of crystallization. The presence of intercumulus high-Al pyroxene and kaersutite suggests that elevated pressures are not the result of overpressure in melt inclusions. Elevated pressures of fractionation are common for such magmas on Earth where the liquids residual to fractionation rise and erupt onto the surface to form intra-plate magmatic suites.

Conclusions: Both NWA2737 and Chassigny contain mineral assemblages that can be produced at least in part from magmas with chemical characteristics similar to those of terrestrial silica-saturated hawaiite but at different stages of fractionation. This result suggests that source regions in the martian mantle need not be as Fe-rich as previously thought. It further suggests the possibility of more terrestrial-like magmas on Mars, results that are in keeping with the new MER results [e.g., 7].

X-RAY COMPUTED TOMOGRAPHY DATA USED TO MEASURE CHONDRULE AND METAL GRAIN SIZE/SHAPE DISTRIBUTIONS. J. W. Nettles and H. Y. McSween Jr.

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Introduction: Variations in sizes and shapes of chondrules are thought to be attributed to a sorting mechanism that existed in the nebula. Sorting by mass and sorting by aerodynamic properties have both been proposed in the literature [1, 2], although neither has been proven. The sorting mechanism should act on both chondrule and metal-troilite components in a similar manner (i.e., if sorting was by mass chondrules and metal grains should have similar mass distributions), but the irregular sizes and shapes of both components makes these parameters difficult to measure. We used X-ray CT data to avoid these complexities and to provide a dataset from which to compare size/shape distributions of both meteorite components.

Methods: Using the University of Texas at Austin’s High Resolution X-ray CT Facility, we acquired tomographic images of Krymka (LL3.1), Semarkona (LL3.0), and Sharps (H3.4). These meteorites are type 3.x meteorites with as little thermal metamorphism possible in order to best represent samples of nebular processes. Scans were acquired with beam currents of 180 kV, 0.133 mA and voltages of 180 kV using a sample-offset cone beam geometry. In-plane scan resolution was ≈10 µm/pixel, and the slice thicknesses were ≈14-17 µm.

Once individual chondrules and metal grains were identified, the ‘blob3d’ software tool developed at the High Resolution X-ray CT Facility was used to extract size and shape measurements for the two components. Parameters include volume, surface area, and maximum diameter, as well as minimum projected area, which we assume to be the face presented to the gas as the particle moved throughout the nebula.

Results and Discussion: Metal grain surface/volume ratios are quite similar, with average ratios within ~20% of the surface/volume ratio of a sphere. Chondrules are also roughly spherical in surface/volume ratio, though the ratio distributions are more skewed to higher values than in metal grains. Full descriptions of the size and shape distributions will be presented at the conference.

ON THE ABUNDANCE OF PRESOLAR SILICATE AND OXIDE GRAINS IN PRIMITIVE METEORITES.

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Introduction: The discovery of presolar silicates in IDPs and meteorites [1-3] has opened new opportunities. Isotopic analyses of elements other than oxygen are expected to provide new information on nucleosynthesis in the parent stars of the grains. [2, 4, 5]. Identification of the mineralogy and chemical composition of the grains can provide constraints on the stellar atmospheres from which the grains condensed, but only limited information exists [2, 6]. Finally, the abundance of presolar grains in different types of meteorites is expected to provide information on conditions in the early solar system.

Results: Using the experimental approach employed in the analysis of a polished section of Acfer 094 [5] we have extended our NanoSIMS search for presolar silicates to the CO3.0 meteorite ALH77307. This search resulted in the discovery of 9 presolar silicates and 5 presolar oxide grains. While based on the NanoSIMS analysis we tentatively identified two grains as corundum and three as spinel, Auger spectroscopy showed that one of the “corundum” grains is actually a hibonite grain [7]. It is quite possible that some grains from other studies thought to be corundum on the basis of their high Al content are also hibonite. Four silicate grains were also analyzed by Auger spectroscopy. Three of them are Mg- and one is Fe-rich [6]. The abundances of silicates and oxide grains are inferred to be ~75ppm and ~40ppm, respectively. This compares to ~180ppm and ~110ppm for these grain types in Acfer 094 [4, 5].

Discussion: There are considerable uncertainties in estimating the abundances of small presolar grains in primitive meteorites. Analysis of tightly packed spinel grains from Murray acid residues by isotopic raster imaging in the NanoSIMS [8] shows that the detection efficiency of presolar grains <0.5 µm is less than 100% and thus the abundances given above are only lower limits. Detection efficiencies are even lower for direct imaging searches with the IMS 1270 equipped with SCAPS and might not be constant for different searches [9]. The fact that presolar silicate abundances in Acfer 094 and ALH77037 are much higher than in Bishunpur (LL3.1) Semarkona (LL3.0) and Murchison (CM2) [10, 11] has been attributed to destruction in the latter, less primitive, meteorites. However, abundances of oxide grains, believed to be less susceptible to destruction by metamorphism and aqueous alteration, in the former two meteorites are also much higher than in CM2 meteorites [12]. Thus, either destruction processes affect both grain species in a similar way or there are large differences in presolar grain abundances between the formation regions of different meteorite classes.

**KALAHARI 008/009 - THE SHORTEST EXPOSURE AGE OF ALL METEORITES.** K. Nishiizumi¹, K. C. Welten¹, and A. Bischoff². ¹Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA. kuni@ssl.berkeley.edu. ²Institut für Planetologie, 48149 Münster, Germany.

**Introduction:** During geological field work in Botswana Kalahari 008 (598 g) and 009 (~13.5 kg) were found roughly 50 m apart in front of a small dune [1, 2]. Cosmogenic nuclide studies provide information on the exposure histories of those objects.

**Sample Description:** Kalahari 008 is an anorthositic breccia having typical clasts of lunar highland breccias. Olivine crystals are typically much less frequent than pyroxene and display a distinct bimodal distribution in composition. Pyroxenes show a wide range of compositions. Most plagioclases in clasts and matrix are a-northites [1, 2].

Compositionally and texturally, Kalahari 009 differs from Kalahari 008. Considering chemical composition and mineralogy Kalahari 009 is compatible with a VLT lunar mare basalt. It is a fragmental breccia consisting of fragments of basaltic lithologies embedded in a fine-grained matrix. Main constituents are pyroxene and plagioclase. Olivine occurs less frequently [1, 2].

**Cosmogenic Radionuclides:** Cosmogenic radionuclides in Kalahari 008 (130 mg) and 009 (157 mg) were measured by AMS at Lawrence Livermore National Lab and the results are shown in Table 1. The cosmogenic nuclide concentrations in Kalahari 008 and 009 are the lowest activities in stony meteorites ever measured. The $^{41}$Ca concentrations in both samples were below detection limit. Cosmogenic radionuclide concentrations of Kalahari 008 are 40-70% higher than that of Kalahari 009 but nuclide ratios are very similar for both objects indicating different shielding conditions in the same object in space. The $^{26}$Al/$^{10}$Be activity ratios of Kalahari 008 and 009 are both 1.0±0.3 that is lower than the production rate ratio of ~4. A large portion of the $^{10}$Be might be meteoric $^{10}$Be contamination, even though both samples were acid leached. The combined $^{26}$Al and $^{36}$Cl 4π exposure ages are 350±120 yr for Kalahari 008 and 220±40 yr for Kalahari 009 that is the shortest exposure age of any meteorite. If both objects are lunar meteorites, the transition time from the Moon to the earth was 230±90 yr and ejection depth was more than >1,100 g/cm² on the Moon. Small amounts of cosmogenic nuclides are also produced in-situ on the Earth’s surface. The $^{26}$Al and $^{36}$Cl concentrations in Kalahari 009 can be explained by ~0.3 Myr exposure time in the Kalahari Desert (1,000 m elevation and 21’S). Long terrestrial ages, 0.3-0.5 Myr, were found for Dhofar lunar and Martian meteorites [3]. For the case of Kalahari 009, cosmogenic nuclides could have been produced on the Earth’s surface, without previous exposure in space. Cosmogenic nuclide results do not exclude that Kalahari 009 is a terrestrial object. However, the $^{36}$Cl concentration in Kalahari 008 is ~15% higher than saturation of $^{36}$Cl production on the Earth’s surface, therefore Kalahari 008 was exposed in space.

**Table 1.** Cosmogenic radionuclide concentrations (dpm/kg) in Kalahari meteorites.

<table>
<thead>
<tr>
<th>Kalahari</th>
<th>$^{10}$Be</th>
<th>$^{26}$Al</th>
<th>$^{36}$Cl</th>
<th>$^{41}$Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>008</td>
<td>$^{0.021±0.001}$</td>
<td>$^{0.020±0.006}$</td>
<td>$^{0.022±0.001}$</td>
<td>$^{0.40±0.37}$</td>
</tr>
<tr>
<td>009</td>
<td>$^{0.014±0.001}$</td>
<td>$^{0.014±0.004}$</td>
<td>$^{0.010±0.002}$</td>
<td>$^{0.03±0.21}$</td>
</tr>
</tbody>
</table>

PRESOLAR CHROMITE IN ORGUEIL. L. R. Nittler¹ C. M. O’D. Alexander¹, F. J. Stadermann², and E. K. Zinner¹. ¹Carnegie Institution of Washington, Washington DC, 20015, USA, email: lrn@dtm.ciw.edu, ²Washington University, St. Louis, MO, 63130, USA.

Introduction: We have previously reported the discovery of presolar Cr-rich oxide (MgAlCrO₄) grains in the Orgueil meteorite [1, 2]. Continued searches of our Orgueil residue have revealed several iron chromite grains with unusual O isotopic compositions, indicating that they are preserved stardust. These results indicate that chromite condenses around some O-rich stars, contrary to predictions of equilibrium condensation calculations.

Methods and Results: The Orgueil acid residue has been described previously [1]. About 2,700 1–5 μm O-rich grains were automatically analyzed for their O isotopic ratios with an ims-6f ion probe [3]. Of these, six grains were identified as presolar grain candidates. SEM-EDS identified five of these as chromite (FeCr₂O₄) with minor amounts of Mg and Al and the sixth as Al₂O₃ with minor Mg. The grains range from 1 to 4 μm in diameter. Four of the chromite grains were reanalyzed by NanoSIMS, confirming the 6f results. In contrast to other known presolar oxide and silicate grain types, the chromites are unusual in that they show a relatively limited range of compositions (δ¹⁷O=200—350‰, δ¹⁸O≈0‰). The Al₂O₃ grain has a typical ¹⁸O-depleted Group 2 signature [4]. Based on the chromite/Al₂O₃ ratio, we estimate the abundance of Orgueil presolar chromite as ~50ppb.

Discussion: The O isotope ratios of the unusual chromite grains are consistent with dredge-up of CNO-cycle processed material in red giant stars of ~1.25M☉ and slightly super-solar metallicity [5]. However, chromite is not expected as a major circumstellar condensate in such stars. Thermodynamic equilibrium models predict that as an O-rich stellar outflow cools from high T, both Fe and Cr condense into a metallic alloy, not as oxides [6, 7]. Chromite can possibly condense before metal under very oxidizing conditions [8], but this is not expected for low-mass stellar outflows. The existence of presolar Cr-rich spinel [1, 2] and presolar Fe-rich silicates [9] suggests that Fe and Cr can in fact condense into oxides in stellar outflows, likely indicating non-equilibrium conditions during circumstellar dust formation. Perhaps the present grains formed originally as mechanical mixtures of Cr-rich metal grains and spinel with subsequent annealing converting the assemblages to Mg, Al-bearing chromite. In any case, the restricted isotopic range of the grains suggests that they might have formed around a single type of star and thus chromite might not be a common circumstellar condensate. NanoSIMS measurements of Mg-Al, Cr and Fe isotopes in these unusual grains are planned for the near future. Resolving ⁵⁴Cr from ⁵⁴Fe will probably require RIMS measurements, however.

EXTENSIVE MICROSCALE N ISOTOPIC HETEROGENEITY IN CHONDRITIC ORGANIC MATTER, L. R. Nittler, P. Hoppe, C. M. O’D. Alexander, H. Busemann, and G. Cody. Carnegie Institution of Washington, Washington DC, 20015, USA, lrn@dtm.ciw.edu, MPI for Chemistry, Mainz, Germany.

Introduction: H and N isotopic anomalies (mainly excesses of D and $^{15}$N) in organic matter from primitive meteorites and IDPs suggest preservation of presolar molecular cloud material [1-3]. However, there have been very few spatially correlated H and N studies for either chondrites or IDPs [4, 5]. We report C and N isotopic imaging data for organic matter from four meteorites and three IDPs. D/H imaging data for many of the same samples are presented in [6, 7] and bulk organic isotope data in [8].

Samples and Methods: We used the Mainz NanoSIMS to acquire C and N isotopic ratio images from matrix fragments of Tagish Lake and Al Rais (CR2), purified insoluble organic matter (IOM) from EET 92042 (CR2) and Bells (CM2) and three IDPs. Except for the Bells IOM, 5-20 µm particles were pressed into Au foil and first analyzed by D/H isotopic imaging [6, 7]. Microtomed (S-embedded) slices of Bells IOM were deposited directly onto a Au mount. NanoSIMS techniques were very similar to those used by [5]. Isotopic ratios were calculated for individual 0.2-1 µm diameter regions within images and data were calibrated using the measured bulk isotopic compositions of the Bells IOM [8].

Results and Discussion: We found few resolvable C isotopic anomalies, most of which appear to be associated with presolar SiC grains. All samples showed mostly homogeneous $^{14}$N/$^{15}$N ratios within 10-20% errors on <0.5 µm scales, with a few percent of the imaged areas showing significantly different ratios (both high – “hotspots” and low – “coldspots”). The highest $\delta^{15}$N values in Tagish Lake, Al Rais, EET 92042 and the IDPs are similar to those previously observed in IDPs and CR2 chondrites ($\geq 1,000$‰ [3, 9]). In contrast, Bells IOM has significantly higher $\delta^{15}$N values. Although its bulk value (+415 ‰ [8]) is comparable to typical bulk IDPs, several regions have values >2,000‰, with one 200 nm region reaching ~3,000‰. Bells also showed a ~3µm diameter cold-spot ($\delta^{15}$N= −65‰). SEM examination revealed no difference in composition or morphology for the isotopically unusual areas, compared to the bulk IOM. Although some D hotspots are clearly associated with enhanced $^{15}$N, there is little spatial correlation between the H and N isotopic ratios. In fact, most of the highest D and $^{15}$N hotspots are not associated with each other, indicating that, for the most part, presolar D and $^{15}$N anomalies are contained in distinct organic carriers. Moreover, Bells reaches $\delta^{15}$N values higher than can be explained by low-temperature interstellar chemistry, perhaps reflecting contributions from stellar nucleosynthesis or UV self-shielding.

CARBONACEOUS NANOPARTICLES IN TAGISH LAKE AND IVUNA: WHY DO THEY IN TAGISH LAKE HAVE NITROGEN-ENRICHED RIMS? T. Noguchi1 and A. Nakazawa1, E. Okunishi2, H. Naraoka3, T. Nakamura4, and K. Nakamura5. 1Department of Materials and Biological Sciences, Ibaraki University. E-mail: tngec@mx.ibaraki.ac.jp. 2JEOL Co. Ltd., 3Department of Earth Sciences, Okayama University, 4Department of Earth and Planetary Sciences, Kyushu University, 5JSC, NASA.

Introduction: Since the discovery of carbonaceous nanoparticles (originally “organic nanoglobules” [1], hereafter CNP) from Tagish Lake meteorite, CNPs are interested as one of the important carriers of the organic compounds in carbonaceous chondrites [2, 3]. In this study, we investigated CNPs in Tagish Lake and Ivuna by using ultramicrotomed samples because their occurrences are important to deduce their formation history. We made sulfur-embedded ultrathin sections and performed EELS and energy-filtering imaging analyses by using JEOL-2010F field-emission TEM equipped with GATAN GIF Tridium.

Results and discussion: In Tagish Lake, CNPs have thin (< 20 nm thick) nitrogen-enriched continuous rims irrespective of their internal structures. For example, a CNP in Tagish Lake has a core with C100N2O7 and a rim with C100N21O12. On the other hand, such N-rich rims are not observed in Ivuna. For example, a CNP in it has a core with C100N4O9 and a rim with C100N6O11. Electron-loss near-edge structure (ELNES) of N K edge of the rims of the CNPs in Tagish Lake has a sharp pre-edge at ~399 eV and an edge at ~406 eV. By comparing their spectra with those in literature [4, 5], the former peak is ascribed to π* and the latter σ*. The similarity of the shapes of ELNES in the rims and those of amorphous CN suggests that N in the rims is in heterocyclic aromatic structures like pyridine and pyrimidine.

It is known that organic compounds in Tagish Lake are enriched in nitriles and cyan-aromatic moieties [6, 7]. And N-bearing organics are rich in free and liable organic matters and they have high δ13C and δ15N [8]. Recently, it is revealed that the surface of the extracted CNPs from Tagish Lake is rich in N and has high δ13C and δ15N [9]. Our data suggest that the N-enriched rims are the major carrier of the liable organic matter and probably have high δ13C and δ15N. We think that the rims were formed around cores consisting of water-insoluble and relatively inert organics during aqueous alteration by consuming water-soluble organics with high δ13C and δ15N. The difference of compositions of the rims in the two meteorites probably resulted from different compositions of aqueous solutions and different physicochemical conditions such as temperature and pH in the late-stage of CNP formation during aqueous alteration.

LIFTING THE VEIL: A PRE-CATAclySM LUNAR IMPACT MELT. M. Norman1,2, L. Taylor2, C. Shih3, Y. Reese4, L. Nyquist4, and J. Bowen-Thomas2. 1Lunar and Planetary Institute, Houston. 2Research School of Earth Sciences, Australian National University, Canberra. E-mail: Marc.Norman@anu.edu.au. 3Planetary Sciences Institute, University of Tennessee, Knoxville. 4NASA Johnson Space Center, Houston.

Introduction: We are conducting geochemical, geochronological, and petrological studies of lunar samples that may represent impact melts formed prior to the KREEP-rich breccias with ages of 3.8-4.0 Ga. Here we report initial results for the age and petrogenesis of highlands rock 67955.

Rationale: 67955 is a 163 g impactite that was collected from the rim of North Ray Crater. It is a noritic anorthosite that was mildly annealed, brecciated and injected with dark veins of shock melt. Its bulk composition is similar to a magnesian component that was incorporated into the feldspathic fragmental breccias (FFB’s), which represent the Descartes terrane of the central nearside lunar highlands. If these breccias represent ejecta from the Nectaris basin, then ages of components in the breccias provide limits on the age of one of the older nearside basins. Our study of the composition and chronology of 67955 will improve our understanding of the impact history of the Moon and the development of the lunar crust.

Methods: We examined 67955 in the JSC lunar curatorial lab, and selected a coherent 3g fragment that was macroscopically crystalline and free of the dark shock melt. A polished thin section was produced from this fragment, and mineral separates prepared for Rb-Sr and Sm-Nd isotopic analyses by TIMS. Mineral compositions were determined by EMP on the thin section and on representative fragments from the mineral separates. Trace element and reconnaissance Pb isotopic compositions were determined on representative mineral fragments by laser ablation using a quadrupole ICPMS.

Results: The texture of 67955 is consistent with crystallization of a melt. Poikilitic pyroxene encloses euhedral to subhedral olivines (Fo77) and plagioclase (An91-96, strong mode at An93-94). Ilmenite, FeNi metal (7% Ni, 0.6% Co), apatite, zirconalite, chromite, and sulfide are present. Pyroxene is predominantly low-Ca (Wo3En78), but a few grains of high-Ca pyroxene were found. Average mineral compositions fall within the field for Mg-suite highlands rocks on a plot of An vs Mg#. Incompatible element concentrations in plagioclase span a broad range (e.g., La 0.6-5.4 ppm) and correlate with Sr/Ba ratios, suggesting contributions of both depleted and enriched components that may correspond to ferroan anorthosite and KREEP or Mg-suite lithologies, respectively. Metal has 5x chondritic abundances of PGE, As, and Au but is highly enriched in W indicating reduction of lunar tungsten. Apatite has 3-6 ppm U and 20-35 ppm Th, whereas zirconalite has 1500 ppm U and 0.5-1% Th. Preliminary Rb-Sr isotopic data for plagioclase, pyroxene, and whole rock separates indicate an age of 4.1 ± 0.2 Ga. Preliminary Pb isotopic data for apatite are consistent with an age of 4.1-4.3 Ga, assuming no common Pb.

Implications: 67955 appears to be an impact melt breccia that predates the 3.8-4.0 Ga nearside basins. The preservation of a large sample of impact melt breccia with an age older than 4.0 Ga shows that the lunar crust was not being continuously resurfaced by impacts after initial differentiation of the Moon, and favors the formation of most nearside basins in a discrete episode of heavy bombardment at ~3.9 Ga.
A NEW PARADIGM FOR ORGANIC CHEMISTRY IN NEBULAE: PROTOSTARS AS CHEMICAL FACTORIES.

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Protostellar nebulae are oxygen rich, yet a significant quantity of organic matter is still evident in meteorites and in comets when one might predict that such materials should have reacted with the silicate dust to form large amounts of CO. We know that nearly all meteoritic material was processed through a series of high temperature events, producing Calcium Aluminum Inclusions (CAIs), chondrules, crystalline silicate dust and amorphous condensates. By analogy a similar proportion of the carbonaceous grains should also have experienced these same conditions, yet macromolecular carbonaceous coatings exist on grains in meteorite matrices and volatile organic molecules are observed in reasonable abundance in comets. We propose that surface mediated reactions on silicate dust grains could have played a major role in the production of both volatile and macromolecular carbonaceous materials in the nebular environment.

This proposal is based on the recognition that both inward as well as outward circulation must occur in protostellar nebulae in order to explain the presence of crystalline silicate grains, and on recent experiments in our laboratory that demonstrate the resilience of surface mediated organic synthesis. We will discuss the basic model of nebular circulation as it related to the production of crystalline mineral grains found in comets and the consequences for the production of organics.

Our recent experiments have demonstrated that almost any free surface will act to catalyze the Fischer-Tropsch-Type conversion of CO and molecular hydrogen to fairly complex hydrocarbons. In addition, we have now discovered that one of the products of these reactions is a macromolecular carbon coating on the grain surface that itself acts as a catalyst to promote the formation of hydrocarbons containing nitrogen if the reaction occurs in the presence of N\textsubscript{2}, H\textsubscript{2} and CO. Far from acting as a poison, these coatings can greatly enhance the reactivity of some grain species such as amorphous magnesium silicate or silica particles that are not themselves very good initial catalysts. The net result of this process should be a relatively uniform composition for the macromolecular carbonaceous materials deposited on meteoritic grains and a significant increase in the quantity of organic materials that may have been produced and then circulated throughout protostellar nebula compared to the quantities produced by previous models.
THE LUNAR Rb/Sr RATIO AND IMPLICATIONS FOR LUNAR HISTORY.

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Introduction: Taylor [1] estimated bulk moon Rb and Sr contents of 0.28 and 30 ppm giving $\mu_{MN} \sim 0.027$ ($\mu = ^{87}\text{Rb}/^{86}\text{Sr}$). Nyquist et al. [2] estimated $\mu_{MN} \sim 0.038$ from ages (T) and initial $^{87}\text{Sr}/^{86}\text{Sr}$ (I$_{Sr}$) of lunar samples, giving bulk lunar Sr ~20 ppm for Rb~0.28 ppm. The lowered Sr abundance may have consequences for geochemical models of the moon. For the chronology of early lunar events, we consider 3 cases for $\mu_{MN} \sim 0.038$, using measured T$_{FAN} \sim 4430$ Ma and I$_{Sr,FAN} \sim 0.699052$ [3].

Case 1: (a) Hi-$\mu_{SN}$ at $-\Delta T_{Hf-W}$: On a Sr-evolution diagram, an extrapolation backward in time from (T$_{FAN}$, I$_{Sr,FAN}$) meets a forward extrapolation from ($-\Delta T_{LMO}$, I$_{Sr,CAI}$) at ($-\Delta T_{LMO}$, LUNI) for $\Delta T_{LMO} \sim 37$ Ma, LUNI ~0.699034. Here $\mu_{SN} \sim 0.91$ is assumed for the solar nebula from CI chondrites, $\Delta T_{Hf-W} \sim 42$ Ma [4], and I$_{Sr,CAI} \sim 0.698934$ from Efremovka CAI E38 [5]. The putative giant impact creating the earth-moon system also occurs at $\Delta T_{LMO} \sim 37$ Ma before FANs. (b) An interval $\Delta T_{PEM}$ is assigned to Proto-(Earth)-Moon during which most of Earth’s mass is accreted before the moon-forming impact. A lower limit for $\mu_{PEM}$ is $\mu_{PEM} > \mu_{E}$ for Earth. $\Delta T_{PEM}$ is constrained within (|$\Delta T_{PEM}$|$ + |\Delta T_{LMO}|) ~42 Ma. A short $\Delta T_{LMO}$ is a possibility, but $T_{FAN} = 4524$ Ma required for agreement with $\Delta T_{Hf-W}$ disagrees with most FAN ages.

Case 2: (a) LUNI = I$_{Sr,Euc}$. In this case $\Delta T_{LMO} < \sim 110$ Ma follows directly from known I$_{Sr,FAN}$ and estimated $\mu_{MN}$. The assumption LUNI ~I$_{Sr,Euc}$ for eucrites follows reasoning that the giant impact must have occurred after planetary accretion had reached a stage when Vesta-sized and larger bodies were numerous. (b) As above, limiting |$\Delta T_{LMO}$|<=$\Delta T_{Hf-W}$ requires $T_{FAN} = 4524$ Ma in disagreement with most FAN ages, and very high $\mu_{MN} < 0.112$.

Case 3: Hi-to-Lo-$\mu_{SN}$ at 4566 Ma, T$_{FAN}$ at ~4430 Ma. Similar to Case 1, but utilizing the absolute ages of CAI and FANs instead of $\Delta T_{Hf-W}$. On a Sr-evolution diagram, an extrapolation backward in time from (T$_{FAN}$, I$_{Sr,FAN}$) for $\mu_{SN} \sim 0.91$ meets a forward extrapolation from (4566 Ma, I$_{Sr,CAI}$) at ($-\Delta T_{LMO}$, LUNI) for $\Delta T_{LMO} \sim 133$ Ma, LUNI ~0.698977. Lower initial $\mu_{SN}$ in the range ~0.26 (CV) to 0.083 (Earth) and lower are permitted for Proto-(Earth)-Moon. Impact times in the range ~4500-4560 Ma are permitted for the moon-forming event for these $\mu$-values.

Discussion: $\Delta T_{LMO}$ marks flotation of the lunar crust, and comparison to thermal models (e.g. [6]) suggests $\Delta T_{LMO} < \sim 100$ Ma. We prefer Case 3 for initially low-$\mu$, a giant impact at ~4500-4560 Ma, crust solidification at ~4430 Ma, and closure of the lunar mantle to Nd-isotopic exchange at ~4320 Ma as determined from a $^{146}\text{Sm}/^{144}\text{Nd}$ mantle isochron [7].

INTRAMOLECULAR CARBON ISOTOPIC DISTRIBUTION OF MACROMOLECULAR ORGANIC MATTER IN CARBONACEOUS CHONDRITES (CM),
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Introduction: Carbonaceous chondrites may be important when considering the origins of life on the Earth, possibly because they provide organic compounds to the early Earth [1]. Kerogen-like macromolecular organic matter is the main component of organic matters in carbonaceous chondrites. It has a highly condensed aromatic structure with many functional groups [2]. The macromolecule shows heterogeneous isotopic distribution, suggesting its multiple origins [3]. In a previous study, acetic acid is generated by hydrous pyrolysis of the Murchison macromolecule [4]. In this study, we measured intramolecular carbon isotope distribution of the macromolecules for carboxyl group.

Samples and Analytical Procedures: Purified macromolecular organic matter from the Murchison and six Antarctic CM chondrites (Y-791198, Y-793321, A-881280, A-881334, A-881458, B-7904) were used in this study. A part of the Murchison macromolecule was subjected to hydrous pyrolysis at 270–330ºC to examine carboxylic acid generation [4]. These macromolecules including the hydrous pyrolytic residues were subjected to intramolecular δ¹³C analysis for carboxyl group by elemental analysis/pyrolysis/isotope ratio mass spectrometry at 750ºC for reactor temperature.

Results and Discussion: For the Murchison, the amount of carboxyl group in unheated macromolecule was 1.42mmol/g. Hydrous pyrolysis made 79-39% of carboxyl group released from the macromolecule. The amount of the acetic acid generated by hydrous pyrolysis accounts for 49-12% of the total carboxyl groups.

δ¹³C of carboxyl group (δ¹³C_{carboxyl}) of the unheated Murchison macromolecule was -2.0‰ (vs. PDB), being much more ¹³C-enriched than bulk macromolecule (-12.7‰). Since the δ¹³C_{carboxyl} of acetic acid generated by hydrous pyrolysis is lower (-22.5 to -32.6‰) than δ¹³C_{carboxyl} of the residual macromolecule (-6.8 to -7.6‰), other ¹³C-enriched organic compounds and/or carbon dioxide must be generated simultaneously with acetic acid.

The amount of carboxyl group in Antarctic macromolecules ranges from 1.79 to 1.05mmol/g, similar to that of Murchison. Even against the solvent-extractable organic acid-depleted chondrites such as A-881280, the amount of carboxyl group of macromolecule is higher (1.79mmol/g), suggesting that the macromolecules have a potential to produce organic acids. The δ¹³C_{carboxyl} of Antarctic macromolecules ranges from +2.3 to -7.6‰, which may suggest a variation of hydrothermal activity on meteorite parent bodies.

A POSSIBLE IMPACT CRATER IN BASALT AT MESETA DE LA BARDA NEGRA, NEUQUEN, ARGENTINA.

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Introduction: Recent efforts to indentify additional impact craters in Argentina, making use of LANDSAT imagery and aerial photographs, have identified a possible new example in this category at Neuquén province, Patagonia. The identified structure is a crater (1.5 kilometers in diameter) located in the southwestern extreme (S 39° 10', W 69° 53') of a large relict basaltic plateau named Meseta de la Barba Negra. The aerial photographs interpretation allow to show close similitudes with Barringer’s meteor crater (Arizona, USA). The crater even resembles Barringer’s in small details as the little squareness of its shape. The depression is surrounded by a raised rim which is mainly developed in the southwestern area. The rim is composed by angular blocks and wide boulders, possibly corresponding to an ejecta blanket. Stratigraphically the crater affects two units, the Basalto Zapala (olivinic basalt flow) which age was established by radiometric data as between 8,6 ± 0,4 and 2,3 ± 0,3 million years (Later Miocene – Early Pliocene) [2]; and the underlie Collón Cura Formation (cineritic tuffs and tuffites) attributed to Middle Miocene [3]. The hole is partially covered by modern eolian sand and colluvial deposits. In the bottom, small expositions of thin diatomitic levels are present (Tula mine). In situ research revealed possible shatter cones and breccias in the middle and highest part of the slope. According to the geological context of the area, the estimated age of Barda Negra’s crater is youngest than Lower Pliocene.

If this crater is in fact a new meteorite impact site then it would be very important and interesting as the second simple-type impact crater in basaltic rocks on Earth. To date, Lonar Lake’s crater in India, (1.8 km), is the only simple-type terrestrial impact crater in basalt known in the world [4].

A mathematical model for the impact was applied in quantum formalism, polynomial elements and Korteweg-DeVries (KDV) soliton theory [5], using a HP 49g, which is a Scientific Programmable Graphing Calculator with 1.5 Mb in RAM. For the impact event are used the following parameters: diameter ~ 1.5 Km, circular shape, basement composition ~ basaltic. According this model the asteroid diameter is ~ 48.65 m, with a velocity and impact angle of ~ 17.91 km/s and 41.78° respectively. The number of rings are calculated in ~ 0.37 with a initial crater profundity of ~ 156.52 m. The total energy in the impact is calculated in ~ 1.01E24 Ergs, i.e., ~ 23.97 megatons. Further investigation of this crater is in progress.

HYDROTHERMAL ALTERATION EXPERIMENTS OF ENSTATITE UNDER VARIOUS pH CONDITIONS: IMPLICATIONS FOR AQUEOUS ALTERATION OF CARBONACEOUS CHONDRITES.
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Introduction: Enstatite has been preferentially replaced by phyllosilicates relative to other major silicates in aqueously altered chondrites. Phyllosilicate replacing enstatite differs among the different types of chondrite. For example, serpentine forms in CM chondrites [e.g., 1], whereas saponite (smectite) forms in CV chondrites [e.g., 2-4]. The differences in phyllosilicate mineralogy may be related to different pH conditions of the fluids that reacted with enstatite. We carried out hydrothermal alteration experiments of orthoenstatite (OEN) powder with aqueous solutions of various pH values (pH 0-14) at 300 C and 1 kb for 1 week. The recovered samples were studied using powder X-ray diffraction (XRD), SEM-EDS and TEM-EDS. Our purposes are to compare the experimentally altered products with those in chondrites and to estimate pH conditions of the fluids that were involved in aqueous alteration of the chondrites.

Results: All the recovered samples in the present experiments contain unaltered OEN. The following descriptions of XRD measurements will be focused on alteration products, and diffraction peaks of OEN will not be mentioned. 

1N-HCl (pH 0) & 1N-NaCl (pH 6): No XRD peaks are detected. However, SEM and TEM observations show that Si-rich amorphous material has formed in the sample altered with 1N-HCl.

H2O (pH 7) & 0.01N-NaOH (pH 12): Small XRD peaks of serpentine are detected. OEN grains have been partially replaced by serpentine along their edge.

0.1N-NaOH (pH 13): Larger XRD peaks of serpentine and smectite are detected. OEN grains have been largely replaced by the phyllosilicates, exhibiting pseudomorph texture.

Discussion: The results of our experiments have revealed that alteration products of enstatite depend on pH values of the aqueous solutions that enstatite reacted with. No phyllosilicates have formed at either pH 0 or 6, although Si-rich amorphous material has formed at pH 0. These results indicate that the alteration of enstatite to phyllosilicate is restrained under acidic conditions. On the other hand, serpentine has formed at pH 7 and 12, and both serpentine and smectite have formed at pH 13 and 14. These results indicate that the alteration of enstatite to serpentine occurs in a wide range from neutral to alkaline conditions (pH 7-14), and the alteration of enstatite to smectite requires relatively high pH conditions. From these results, we suggest that enstatite in CM chondrites has been altered under neutral to alkaline conditions, and enstatite in CV chondrites has been altered under more alkaline conditions than CM chondrites.

THE ORIGIN OF PLATINUM GROUP ELEMENTS IN POLYMICT EUCRITES C. Okamoto¹, M. Ebihara², and A. Yamaguchi³, ¹Graduate School of Environmental Studies, Nagoya University, Furo-cho, Nagoya, 464-8601, Japan, ²Graduate School of Science, Tokyo Metropolitan University, Hachioji, Tokyo 192-0372, Japan, ³National Institute of Polar Research, Tokyo 173-8515, Japan.

Introduction: The HED meteorites are the largest group of achondrites that derived from a large asteroid, probably 4Vesta. Most HED meteorites were brecciated by impacts near the parent body surface during cataclysmic bombardment from ~3.5-4.1 Ga [1]. The abundances of siderophile elements including platinum group elements (PGEs) in unbrecciated eucrites are generally low because metal segregation causes a depletion of siderophile elements during igneous activity [2]. However, some polymict breccias of HED meteorites contain significant amounts of siderophile elements by the incorporation of projectiles during impact events. To better understand the origin of projectiles, we determined the abundances of platinum group elements in eucrites that have relatively high abundances of PGEs.

Analytical: We used three nuclear analytical methods (prompt gamma-ray analysis, instrumental neutron activation analysis and instrumental photon activation analysis) to determine major, minor and trace elements in four eucrites (ALHA76005, EET92003, GRO95633, LEW87026). The contents of PGEs were determined by ICP-MS. Polished Thin Sections of the samples adjacent to the portions used for bulk chemical analyses were observed by an optical and scanning electron microscope, and an electron probe microanalyzer.

Results and Discussion: All four meteorites studied in this study have been observed to have metallic iron having high Ni contents (4–9%). Although CI-normalized PGE (Os, Ir, Ru, Pt, Rh, Pd) patterns of 4 samples are similar to each other (having flat pattern), CI-normalized (Ni/Ir)/(Pt/Ir) ratios of these samples are not equally similar, (Ni/Ir)/(Pt/Ir) ratios of ALHA76005 and LEW87026 (=1) are similar to those of mesosiderites while the ratio of EET92003 is similar to that of IAB iron meteorites. In addition, (Ni/Ir) and (Pt/Ir) values of GRO95633 range within those of IIIAB iron meteorites.

Although some HED meteorites, especially howardites, contain chondritic clasts as a minor component from projectiles [3], we revealed in this study that polymict breccias of HEDs actually contain more varieties of projectile materials than previously thought.

A COMBINATION OF IMPACT EXPERIMENTS AND NUMERICAL MODELING IN THE ANALYSIS OF SPECIAL FEATURES AT WET IMPACTS AND CRATER FIELDS. J. Ormó, A. Lepinette and J. Martinez-Frias. Centro de Astrobiologia (INTA/CSIC), 28850 Torrejon de Ardoz, Spain. Email: ormo@inta.es.

**Introduction:** Centro de Astrobiologia is developing a laboratory that will allow the creation of meter-size impact craters under controlled conditions. Preliminary tests have been carried out in an outdoor test bed [1]. The results from these tests were used in this study as reference for numerical simulations with SALE-B, a 2-D hydrocode modified by Boris Ivanov based on SALES-2 [2]. The goal is to complement the experimental results with numerical simulation. When agreement is achieved between the results from the two methods, we will be able to analyze a greater number of cases more conveniently (i.e., the effect of different water depths in our experiments). The experimental and numerical simulations will help us understand the behavior of different materials and the formation of certain features at, first of all, wet-target craters [see 1] where the water affects the excavation (e.g., concentricity due to layered target), ejecta formation (e.g., rampart), and modification (e.g., collapse and resurge erosion). Of special interest is also the formation of small meteorite impacts (i.e., craters in crater fields formed after atmospheric break-up of the projectile) where the projectile may fragment or penetrate the ground to form a funnel-shaped crater. These examples are types of craters that may show features that provide information on the target properties, which in turn can assist in paleoenvironmental reconstructions.

The experiments were carried out with a CHUTA IB-060 gun loaded with a 0.50 cal cartridge. The projectiles are 4x7 cm and cylindrical. In the cases selected for comparisons with numerical simulations in this study, the projectile was of steel. Results from the experiments were received through filming with high-speed camera as well as direct measurements of the resulting craters. These comparisons are, unfortunately, still suffering from limitations: For instance, 1.) we must use an elliptic shape of the projectile in the numerical simulation instead of the cylindrical used in the experiments, 2.) we have not yet been able to use porous targets in the simulations (We use limestone whereas the experiments were done with sand of different degree of water saturation), and 3.) the impact velocity in the experiments is not well known. However, this will be improved with the new indoor experimental laboratory that will allow better control of the test bed set-up, better velocity determination for the projectile, and updated numerical code allowing simulation of porous and multi-layered targets.

Non-linear O isotopic variations in planetary materials [1] have long been thought to reflect inhomogeneous distribution of nucleosynthetic components, although models relying on chemical rather than nuclear effects [2,3] have recently gained renewed interest. Various models predict that the Sun has relatively more, less, or about the same proportion of $^{16}$O as the Earth, but pending Genesis analyses solar O composition is not yet known well enough to discriminate among the models.

We suggest a model in which the absence of a systematic trend in relative abundance of $^{16}$O in diverse planetary bodies emerges naturally because the compositions reflect only random variations. Suppose that bodies of mass $m_0$ form a population of mean $\Delta_{17}$ (isotopic distance from the terrestrial fractionation line) equal to the solar value but with some standard deviation $\sigma_0$. Larger bodies of mass $m$, postulated to grow by random accretion of the smaller bodies, will form a population of the same mean but smaller $\sigma = \sigma_0 (m/m_0)^{-3/2}$. There would thus be no systematic trend in $\Delta_{17}$ of larger bodies, other than less dispersion about the mean. This model can account plausibly well for chondrite parent bodies and larger. A corollary is that the Earth is sufficiently large that its composition should be indistinguishable from solar, i.e. the Sun should have $\Delta_{17} = 0$.

This model cannot be extrapolated downwards in mass, i.e. it cannot account for the assumption above in terms of O in chondrules, CAI's or presolar grains. It must thus be coupled with another model in which bodies smaller than chondrite parent bodies grow by a different mechanism, e.g. accretion from a local "feeding zone" [4] characterized by a local composition established by grain sorting, chemical or photochemical mechanism, etc.

Recently two datasets for O in lunar metal grains, possibly representing the solar wind, have been reported. Hashimoto and Chausidon [5] conclude solar wind $^{16}$O is enriched (relative to Earth) by at least 20‰ (consistent with Clayton's [2] photochemical self-shielding model), but Ireland et al. [6] report that solar wind $^{16}$O is depleted by at least 50‰ (in a range not predicted by any detailed models).

We suggest that these results might not reflect true solar wind composition because of contamination with terrestrial O. Ozima et al. [7] have called attention to the "Earth wind" effect, whereby when/if the Earth lacked a global magnetic field a significant flux of atmospheric ions could have been picked up by the solar wind and transported to the surface of the Moon, assuming that this may have been a dominant effect for N isotopic composition and perhaps important for light noble gases. It is thought that in earlier times CO$_2$ and perhaps CO were major atmospheric species, and it must be considered likely that their O compositions were affected by non-mass-dependent fractionations [3], so that they could have introduced anomalous O to the lunar surface.

HELIUM AND NEON ISOTOPIC COMPOSITIONS FROM IDPs OF POTENTIALLY COMETARY ORIGIN.
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Introduction: IDP flag U2108 flew for 8.05 hours November 19-23, 2002 shortly after the Leonid meteor shower associated with comet Tempel-Tuttle. Flags L2054, L2055 and U2121 flew together for 7.90 hours on April 30-31, 2003 coinciding with earth's passage through the dust of comet Grigg-Skjellerup. We analyzed He, Ne and Ar isotopic compositions in a suite of 16 of these particles. Distinguishing characteristics of their origin were sought by comparing with previous IDP analyses.

Results/Discussion: Samples were step-heated while monitoring $^4$He and $^{20}$Ne levels [1], and individual IDP weights were estimated from grain sizes [2]. The paucity of gas in these samples is striking. Only 4 had sufficient gas to end heating before reaching maximum T~1400°C. The "empty" IDPs have $^4$He ranging below detection limits ($\sim$1x10$^{-12}$ ccSTP) to ~8x10$^{-11}$ ccSTP. There is no correlation between $^3$He/$^4$He and $^4$He concentration. One U2108 IDP has the heaviest integrated He composition measured in our lab and is heavier than any individual temperature step where both He isotopes could be detected. Four IDPs have undetectable $^3$He despite significant $^4$He concentrations. Given $^3$He detection limits, one of these samples must have a still heavier He composition, and the other 3 could possibly as well. He-Q [3] is seen in two U2108 IDPs, one having an integrated composition equaling Solar Energetic Particle (SEP) He [4], which also appears in individual heating steps of other samples. Solar wind He [4] dominates in two other IDPs.

For the 4 IDPs with multiple heating steps, 3 have <500°C T release fractions and essentially all gas released by 900°C. The other particle has He release beginning at ~800°C and a high T component driven out at 1400°C. One IDP has the pattern of $^3$He enrichment with increasing T observed earlier [2], with the highest calculated $^3$He excess of any measured IDP.

Six of these IDPs have well defined and unusually low $^{22}$Ne/$^{20}$Ne relative to SEP, SW, or atmospheric values. This appears more directly related to low $^{22}$Ne than to high $^{20}$Ne. In general, $^{21}$Ne amounts were insufficient to distinguish between different Ne isotopic compositions on a three isotope plot.

Conclusions: $^4$He in 65 previously measured IDPs averages 0.46 ccSTP/g, compared to 0.069 for the 16 IDPs from these flags (0.029 for the 12 "empty" IDPs). The lower average for "empty" IDPs in this suite is consistent with ablation from the two target comets and subsequent short space exposure time. Alternatively, several L2055 particles were determined to either have extremely low densities or be composed mostly of elements lighter than S [5], which might be less retentive of light noble gases.

The age of the Moon is not well known, although its formation is associated with global melting and differentiation leading to significant parent-daughter fractionations of radioisotopes commonly used for dating. This is because a large fraction of the Moon is covered by younger mare basalts and lunar highland rocks are brecciated and multiply modified by impacts and thermal metamorphism. The best evidence for an old crustal age is provided by the low $^{87}$Sr/$^{86}$Sr of anorthositic rocks [e.g., 1]. This is, however, difficult to transform into an age as the Rb-content of protolunar material is not known.

KREEP is a lunar trace element component enriched in incompatible elements that formed as a residual melt from crystallization of the lunar magma ocean. The KREEP-component is found at all highland sites. KREEP has surprisingly uniform elemental and isotopic compositions and a Rb-Sr age of about 4.42 Gy [2, 3, 4]. The high Ti-mare basalts (A11, A17) have trace element patterns complementary to KREEP suggesting formation after KREEP extraction. The KREEP trace element pattern resembles that of the Earth’s crust and the high Ti A11- and A17-patterns are similar to MORB [5]. In both cases, Earth and Moon, W is the most incompatible element with the highest enrichment in KREEP and strongest depletion in Apollo 11 and 17 mare basalts. Because Hf is less incompatible than W, KREEP has a nearly ten times higher W/Hf ratio than A11 and 17 basalts.

The W-isotope compositions of representative samples of KREEP and A11 and 17 mare basalts have been determined [6]. The cosmic ray production of $^{182}$W by $^{181}$Ta neutron capture [7] has been eliminated by analyzing only metals extracted from these lunar rocks. The $^{182}$W/$^{184}$W of KREEP is significantly less radiogenic than that of A11 and 17 basalts, and the less fractionated low Ti basalts have $^{182}$W/$^{184}$W ratios between the values for these two reservoirs. The differences in $^{182}$W/$^{184}$W ratios of lunar mantle reservoirs indicate that the global lunar differentiation occurred when $^{182}$Hf was still extant, most likely between 40 and 55 Myr after CAI formation. If, as is likely, lunar global differentiation followed closely after the giant impact formation of the Moon, then the Hf-W age provides a close approximation of the age of the Moon.

METEORITE MASS FLUX AND THE DELIVERY OF PREBIOTIC MATERIAL. M. A. Pasek and D. S. Lauretta. Lunar and Planetary Laboratory, University of Arizona. Tucson, AZ 85721, USA. E-mail: Mpasek@lpl.arizona.edu.

Introduction: Meteorites may have played a significant role in the origin or evolution of life especially through the delivery of H, C, N, O, S, and P-bearing compounds and minerals early in Earth’s history. Mass flux estimates of meteoritic material are critical to our studies on the role of meteoritic phosphides on the synthesis of prebiotic chemicals [1]. Some classes of iron meteorites have high concentration of phosphides. Their availability at the surface of the early earth may have been a critical factor in the origin of life [1]. It is commonly assumed that since chondrites comprise the numerical majority of meteorites then they must also be the majority of meteoritic mass. In such a view, large iron falls like Sikhote Alin are considered outliers.

Calculations: We use the MetBase Meteorite Data Retrieval Software (2003) for frequency and mass data for falls and finds. We calculate power law relationships for: all meteorite falls, iron meteorite falls, all Antarctic finds, and Antarctic iron meteorite finds. For both collections of “all” meteorites we calculate the number of meteorites in 102.4-256, 256-640, 640-1600 (factors of 2.5) kg bins and so on, and then calculate log-log relationships for the mass and number of meteorites. For iron meteorite collections, we organize data into bins of factors of 10, due to the rarity of iron meteorites. For meteorite falls, masses below 1 kg are difficult to recover after fall and, as a result, there are few observed falls that are smaller than this mass. Antarctic finds are not limited by this collection bias.

The relationship between number (N) and mass (M, in kg) for all meteorites is: log N = 2.3 - 0.77 log M (R^2 =0.98). For all falls, we have the relationship: log N = 2.8 - 0.74 log M (R^2 =0.88). For Antarctic iron meteorites we obtain log N = 0.96 - 0.39 log M (R^2 =0.87) and for iron meteorite falls: log N = 1.4 - 0.41 log M (R^2 =0.90). Both fall data sets include Sikhote Alin, which lies on the Antarctic mass vs. number relationship.

Conclusions: The similarity between the slopes for Antarctic and Fall collections suggests that these sample the same material. The difference in intercept implies that Antarctic samples contain less massive material and that collection of falls is biased towards larger material. Iron meteorites show significant bias for producing massive meteorites, as indicated by the larger slope of their mass distribution lines. As a result, iron meteorites make up approximately 50% of the mass of meteoritic material reaching the surface of the Earth.

The modern flux of meteorites to the Earth is estimated at ~159 per million square kilometers per year [2]. Using a flux of 81000 meteorites per year over the entire surface area of the Earth coupled with the mass vs. number distribution established by Antarctic and Fall meteorites, we determine the average mass of a meteorite to be 5 kg. Approximately 4 × 10^3 kg of meteoritic material strikes the Earth per year, half as iron meteorites. This would result in ~1000 kg of reduced P impacting the Earth per year. During the late heavy bombardment, this amount may have been a factor of 10^5 larger [3]. Such a huge influx of reactive P may have enabled incorporation into early biosystems.

THE DHALA STRUCTURE, BUNDELKHAND CRATON, CENTRAL INDIA- A NEW LARGE PALEOPROTEROZOIC IMPACT STRUCTURE.

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Introduction: The Dhala structure is centered at 25º17’59.7"; 78º8’3.1" on the Central Indian Bundelkhand craton, Shivpuri district, Madhya Pradesh State. It was earlier described as a "cauldron structure" [1]. It is composed of a clearly defined central uplift, surrounded by Paleoproterozoic crater fill sediments (low lying, thinly bedded, subhorizontal shale of varied composition) followed by an impact melt vein and a large ring of breccia. The central uplift comprises flat-lying alternating argillaceous-arenaceous sediments and a lateritized conglomerate horizon at the top belonging to Vindhyan Supergroup of Paleoproterozoic age. The target rock is a coarse grained pink granitoid of Archean age (~2.5 Ga). The Bundelkhand craton comprises Archean metasupracrustals (TTG, amphibolites, BIF, chert, ultramafites etc.) and, felsic intrusives and volcanics of Paleoproterozoic age in addition to giant quartz veins and mafic dykes (Paleo-Mesoproterozoic age).

Geology of Dhala structure: It is a circular structure with an observed diameter of about 9 km and covering an area of nearly 55 km². A ring of granitoid breccia with an exposed width between 1 and 2.5 km occurs at a distance of 1.9 and 3.3 km from the centre of the structure. The breccia includes clasts of dominantly coarse-grained pink porphyritic granitoid in addition to mylonitized pink granitoid, vein quartz and supracrustals. Between the central uplift and breccia ring occurs a circular area of about 4 km diameter of mainly lithic breccia in a ferruginous matrix with sub-horizontal tectonic dip toward the central uplift. Slump folds with variable orientations are observed along the base of subhorizontal sediments close to the central uplift. Subvertical faults are observed within this horizon. Melt breccia exhibiting flow structure and vesicles is exposed as discontinuous curvilinear outcrop over a length of 6 km with exposed thickness up to 20m in the inner ring of the structure. The melt breccia comprises clasts of shocked quartz, feldspar, carbonate blebs, and zircon, besides opaque phases as well as large granitoid and small amphibolite xenoliths in an aphanitic matrix. Multiple sets of planar deformation features (up to four sets) are observed in quartz and orthoclase, and one zircon grain shows subgrain development with reduced birefringence. Ballen texture is very common in quartz. The melt phase is generally devitrified. Spherulites are ubiquitous. The crater fill sediments (lithic breccia) also contain shocked clasts with PDFs.

Conclusion: The presence of a circular structure, a ring of extensive breccia occurrences, and voluminous melt breccia, presence of PDF in quartz and feldspar, ballen texture in quartz, melting of xenoliths and subgrain development in zircon suggest that the Dhala structure represents a newly discovered impact structure. The large volume of impact melt rock observed suggests that the Dhala structure could possibly be an eroded remnant of an actually much large impact crater.


Acknowledgement: I thank Professor Uwe Reimold for his encouragement and support.

Amoeboid olivine aggregates (AOAs) are a common type of refractory inclusions in essentially all carbonaceous chondrites [1]. They typically consist of forsteritic olivine, Fe,Ni metal and a Ca,Al-rich component mineralogically and chemically similar to some CAIs. This component is composed of Al-diopside, spinel, anorthite and rare remnants of melilite, with the latter being replaced by the former minerals. About 10% of AOAs contain low-Ca pyroxene surrounding olivine in AOAs peripheries. Essentially all minerals of the least altered AOAs, except for some grains of low-Ca pyroxene, are $^{16}\text{O}$-rich ($\delta^{17,18}\text{O} \approx -40$ to $-50 \text{‰}$), implying that they formed in an $^{16}\text{O}$-rich nebular region(s), similar to CAIs. The contorted shapes of AOAs and generally unfractoned or Group II REE patterns along with the lack of appreciable melting point to a condensation origin for AOAs. They represent a relatively undisturbed record of nebular condensation. AOAs contain Fe,Ni metal and olivine which are often used to constrain redox conditions in the solar nebula. The appreciable amounts of refractory Ca and moderately volatile Cr and Mn in some AOA olivine can provide additional constraints on the temperatures, pressures, redox conditions, and the modes of condensation in their nebular source regions.

We used the non-ideal solution model of olivine (Fe, Mg, Ca, Mn, Cr, Ni, Co) built into the CWPI code [2] to model condensation in nebular systems with different redox conditions defined by variable dust/gas ratios. The comparison of the calculated olivine compositions with the FeO-MnO-CaO-CrO systematics of AOA olivine in the CR chondrites [3] shows that both depletions and enrichments of the AOA nebular source region(s) in dust by $\sim 10^\times$ are required to account for the observed range of FeO concentrations ($0.04$ – $1 \text{ wt.\%}$) in olivine. The range of Fa contents ($<2 \text{ mol.\%}$) recorded in the unaltered AOAs from other chondrite groups [1], points to somewhat higher dust enrichments ($\sim 25$–$30\times$) in their source regions. Such high dust enrichments make the nebular gas oxidizing, thus increasing the gap between the condensation temperatures of olivine and metal, which condense at the same temperature at $10^4 \text{ bar}$. The common presence of Fe,Ni metal grains inside the AOA olivine requires an early condensation of metal that is inconsistent with the condensation sequences of dust-enriched systems. Our goal is to resolve this discrepancy as well as to discuss the chemistry of metal and olivine from AOAs of various chondrite groups.

SIMULATION OF CHONDRULE FORMATION BY FLASH MELTING OF POROUS CHARGES AND COOLING DURING FREE FALL  Torsten Poppe¹, Tilman Springborn¹, Jürgen Blum¹ and John Wasson². ¹Institut für Geophysik und extraterrestrische Physik, Tech. Univ. Braunschweig, 38106 Braunschweig, Germany; ²Univ. California, Los Angeles, CA 90095-1567 USA

Chondrules are highly abundant mm-sized spherules found in primitive meteorites. They solidified after an unknown melting process in the early solar nebula. In order to improve the understanding of this process, we are carrying out an experimental study aiming at the transformation of highly porous dust samples into melt spherules by flash melting. The porous samples have morphological characteristics of early solar system dust aggregates which are regarded as first-generation chondrule precursors. For heating, we use intense infrared-laser radiation and electric gas discharges. We will present results including first melt spherules produced in our laboratory.

Later experiments will involve cooling during free fall in the 123-m drop tower at Bremen. These experiments will help determine the sizes of first-generation phenocrysts that would form in meter-scale nebular processes that allow very rapid radiative cooling.

Most chondrules have porphyritic textures. A key question is how much of the observed phenocrysts grew during the last chondrule melting event. Although some researchers hold that the bulk of the phenocrysts now present formed in the last event, others argue that relatively thin layers formed in each event, and that multiple melting events were needed to form common porphyritic chondrules. We have launched a search for chondrules in type-3.0 chondrites that have large amounts of glass and relatively small phenocrysts. Krot and Rubin [2] described several such chondrules, most of which were Al-rich. We are examining large and small chondrules in primitive chondrites to determine the fraction and characteristics of chondrules that have normal compositions and small phenocryst fractions.

Since 1970, there have been 240 field trips to the Georgia tektite strewn field to determine the parent stratum and document new specimens and map out the strewn field. Since that time, the strewn field has been expanded from 500 to 7500 square miles. The total number of Georgia tektites has been increased from 200 to 2000.

Several interesting recent developments have occurred. It was speculated that Native Americans may have worked tektites into artifacts but no really good specimens had been found. In early 2004, I got word that a 12,000 year old Clovis point was found. This delicate 3.5 g specimen showed up in an artifact collection but, at the time was not recognized for its importance.

Shortly after and probably due to the publicity, another spectacular point was brought to my attention. This 7.1 g specimen was found in southern Bleckley County. It was identified as a Cotaco Creek Asymmetrical. This artifact is thought to have been worked about 2500 years before present.

In July 2004, I received word that a 13.7 g half disk, water worn Georgia tektite had been found in Treutlen County. This find was important because the particular geology at the site was right for tektites, and to date, we had tried for 25 years to find one in this county. This was now the fourth specimen, the rest being found in the last several years.

Two new tektites have been found in Emanuel County bringing the total specimens there to seven.

In May 2005, a 4.5 g tektite was found in Wilkinson County. We had tried to find a tektite in this county for 30 years. In January 2004, a 4.15g tektite was found in mine tailings but it was not in situ. This one fit the proper geology. It was found in the extreme southern part of the county between Allentown and Danville near the Twiggs and Bleckley County borders. It is 35.6 x 25.4 x 5.1 mm in size.

The Georgia tektite strewn field is now slightly larger than the Texas bediasite strewn field. The Georgia tektites are now found in 18 documented counties and are thought to have fallen in the upper Eocene approximately 35 million years ago.

ASTEROID (15146) HALPOV - A FAST ROTATOR. Hal Povenmire and Bruce Gary Florida Institute of Technology 215 Osage Drive Indian Harbour Beach, FL 32937 and 5320 E. Calle Manzana Hereford, AZ 85615

At Lowell Observatory, Flagstaff, AZ, there is a program for discovering Comets and Near Earth Asteroids. The 30" Schmidt used in this survey is located at Anderson Mesa about 10 miles southeast of Flagstaff. This program is called "Lowell Observatory Near Earth Asteroid Search" (LONEAS).

On March 11, 2000, a seven mile diameter asteroid was discovered in a nearly circular orbit in the outer part of the main belt. It was given the preliminary designation 2000 EQ130. On March 6, 2004, the International Astronomical Union (IAU) and Minor Planet Center approved the designation (15146) HALPOV suggested by Dr. Ted Bowell, director of the LONEAS project. This was to acknowledge the long term work on Georgia tektites, lunar grazing occultations and asteroidal-stellar occultations by Hal Povenmire.

Prediscovery images were found dating back to 1996. Asteroid (15146) HALPOV has now been observed on seven oppositions and the orbit is securely known. It was last observed on April 7, 2005. The orbital elements of this typical main belt asteroid are as follows: The orbital period is 4.79 years or approximately 1749 days. The nearly circular orbit has an eccentricity of only 0.0685601. The inclination is very low, only 2.92758 degrees. The semi-major axis is approximately 2.8428418 A.U. The argument of perihelion is approximately 196.39975 degrees. The longitude of the ascending node is approximately 133.03544 degrees. The perihelion is 2.6438 and the aphelion is 3.038 A.U.’s. The slope parameter is 0.15, M=173.16100 degrees.

Retired NASA-JPL scientist, Bruce Gary observed this asteroid during the April 2005 opposition from his private observatory near Hereford, AZ. His data follows: The absolute magnitude or (H) is approximately 14.16. If this is a C type asteroid, then the albedo is about .04 and the diameter is approximately 11 km. The shape is not spherical as there is a magnitude variation of 0.13. The preliminary value of the B-V=0.54 +/-0.06. The preliminary rotational period is 3.86 hours. The average is approximately 7.0 hours. There is no indication of this asteroid being a binary. This data was obtained at a distant opposition where the magnitude was approximately +18.5. At more favorable oppositions, the magnitude may be as bright as +17.0. Regardless of what classification this asteroid is, it would be classified as a fast rotator.

NEW I-Xe AGES OF CHONDRULES FROM THE NWA267 (H4) METEORITE. O. V. Pravdivtseva, C. M. Hohenberg, and A. P. Meshik, McDonnell Center for the Space Sciences and Physics Department, Washington University, CB 1105, Saint Louis, MO 63130, USA, E-mail: olga@wustl.edu

The NWA267 (H4) chondrite was studied as part of ongoing investigation of the I-Xe record, preserved in chondrules from the different types of meteorites.

Each chondrule was split into a few fragments to be used in the Pb-Pb and I-Xe studies. Since chondrules are complex objects and can potentially contain multiple iodine-host phases, one fragment from each chondrule was saved for mineralogical studies and identification of iodine host phases by in situ laser extraction. Fragments designated for I-Xe analyses were irradiated by thermal neutrons in evacuated quartz ampoules. The Xe isotopic composition in each chondrule was measured in step-wise heating extractions following the same protocol to ensure proper comparison of the results.

All three NWA267 chondrules contained significant quantities of radiogenic $^{129}$Xe (Table) with the inferred abundances being lower limits, since iodine carrier phases probably constitute for only part of each fragment. I-Xe system in first two chondrules closed at nearly the same time as the Shallowater internal standard 4562.3 ± 0.6 Ma [1] (negative relative ages mean younger). I-Xe system in chondrule #3 apparently was disturbed, with higher temperature extractions forming an isochron corresponding to closure time slightly after the formation of CAI’s [2].

The I-Xe age of chondrule #3 is probably the formation age, although the uncertainty is rather high.

<table>
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<tr>
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<th>weight, mg</th>
<th>age, Ma</th>
<th>$^{129}$Xe 10^{-12} cm^3STP/g</th>
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<tr>
<td>#1</td>
<td>1.33</td>
<td>-0.3 ± 0.7</td>
<td>88.8</td>
</tr>
<tr>
<td>#2</td>
<td>1.50</td>
<td>0.2 ± 0.4</td>
<td>161.2</td>
</tr>
<tr>
<td>#3</td>
<td>1.77</td>
<td>3.5 ± 3.4</td>
<td>22.3</td>
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I-Xe ages of NWA267 (H4) and Richardton (H5) [3] chondrules are in good agreement, with the lower metamorphic grade NWA267 being slightly older. A similar trend in I-Xe ages was observed in the LL3.0 – LL3.6 meteorites [4], with chondrules of higher metamorphic grade being younger and characterized by apparently longer evolution times between closure in high- and low-temperature iodine host phases. Although mineralogy of NWA267 chondrules is not investigated yet, the release profiles of radiogenic xenon suggest a single major iodine carrier for chondrule #1 and multiple iodine-carriers for chondrules #2 and #3. Simultaneous closure of I-Xe system in different phases in NWA267 chondrules points towards relatively fast cooling.

All three NWA267 chondrules required corrections for small amounts of fission-produced xenon from $^{235}$U which indicates that they may be good candidates for Pb-Pb studies and direct comparison of I-Xe and Pb-Pb chronometers.

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HIGH PRECISION W ISOTOPE MEASUREMENTS (180, 182, 183, 184, and 186) OF IRON METEORITES. L. Qin1,2,4, N. Dauphas1,2,4, P. E. Janney4, M. Wadhwa1, and A. M. Davis1,3,4.

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Introduction: The $^{182}$Hf–$^{182}$W short–lived chronometer ($t_{1/2}$=9 My) has proven to be very useful for evaluating the relative timing of metal-silicate differentiation in the Earth and meteorite parent bodies. The W isotopic composition of iron meteorites was initially used as a proxy of the initial solar system $^{182}$W/$^{183}$W composition [1], and has been extensively characterized in different iron meteorite groups [2–4]. Recent studies have found that Tlacotepec, a type IVB iron meteorite, has an $\varepsilon^{182}$W (~4.5) that is resolvably lower than the initial $\varepsilon^{182}$W in chondrites and CAIs [3–5]. Exposure to galactic cosmic radiation (GCR) can influence the W isotopic compositions of iron meteorites by spallation and neutron capture reactions [6, 7]. Thus, the extremely negative $\varepsilon^{182}$W values observed in some iron meteorites may reflect burn out of $^{182}$W relative to other W isotopes during long term exposure to GCR. In this study, we report some of the most precise analyses to date of $\varepsilon^{180}$W, $\varepsilon^{182}$W, and $\varepsilon^{184}$W in iron meteorites. Data for tungsten–180 have not been reported before because of its very low abundance (0.13 %), which makes it difficult to measure precisely and accurately.

Results: We analyzed the Gibeon IVA iron meteorite because it has a low exposure age and a high shielding, such that W isotope variations in this sample relative to chondrites can entirely be attributed to $^{182}$Hf decay. The results (normalized to $^{183}$W/$^{186}$W) for this meteorite are, $\varepsilon^{180}$W=$-0.16\pm0.79$, $\varepsilon^{182}$W=$-3.25\pm0.09$, and $\varepsilon^{184}$W=$0.04\pm0.07$, where the errors represent a 95% confidence interval. Assuming an initial $\varepsilon^{182}$W for the solar system of ~3.5, this indicates that the parent body of Gibeon underwent metal-silicate differentiation 1.76±0.93 My after solar system formation. To demonstrate our ability to measure W isotopic compositions accurately and precisely without having to introduce isotopic spikes in the laboratory, we also studied the W isotopic compositions of mixtures of terrestrial W NIST standard with varying amounts of Gibeon. The $\varepsilon^{182}$W values in the mixtures with 8% and 2% Gibeon are $-0.16\pm0.11$ and $-0.05\pm0.07$. These values are identical with the expected values within error and demonstrate our ability to resolve $\varepsilon^{182}$W depletions of less than 0.1ε. Also, the mixtures yield $\varepsilon^{180}$W of ~3.71±0.52 and ~3.33±0.31, and $\varepsilon^{184}$W of 0.05±0.06 and 0.04±0.07. Our goal in the near future is to improve the precision on $\varepsilon^{180}$W, which may allow us to document and, therefore, correct for the effect of GCR exposure on tungsten isotopes, notably on $^{182}$W.