<table>
<thead>
<tr>
<th>Title</th>
<th>Authors</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Spatial Resolution 3D Local Tomography of Particle Tracks and Fragmentation in Aerogel</td>
<td>D. S. Ebel and M. L. Rivers</td>
<td>5299</td>
</tr>
<tr>
<td>A Mathematic Model for the Monturaqui Impact Crater, Chile, South America</td>
<td>J. C. Echaurren, A. C. Ocampo, and M. C. L. Rocca</td>
<td>5004</td>
</tr>
<tr>
<td>Two Distinct Olivine-Ringwoodite Phase Transition Mechanisms in Shocked L-Chondrites: Genetic Implications</td>
<td>A. El Goresy, M. Chen, Ph. Gillet, and L. Dubrovinsky</td>
<td>5010</td>
</tr>
<tr>
<td>Improving the Record of the Petrophysics and Paleomagnetism of the Yaxcopoil-1 Core, Chicxulub</td>
<td>T. Elbra and L. J. Pesonen</td>
<td>5229</td>
</tr>
<tr>
<td>UV Irradiation of Aromatic Nitrogen Heterocycles in Interstellar Ice Analogs</td>
<td>J. E. Elsila, M. P. Bernstein, and S. A. Sandford</td>
<td>5066</td>
</tr>
<tr>
<td>Development of a Nondestructive Technique Using Raman Spectroscopy to Measure the D/H Ratio of Extraterrestrial Water</td>
<td>M. E. Elwood Madden, R. J. Bodnar, K. Cheung, and M. Zolensky</td>
<td>5107</td>
</tr>
<tr>
<td>Weaubleau Structure, Missouri: Field and Core Evidence for a Possible Impact Origin</td>
<td>K. R. Evans, J. F. Miller, and G. H. Davis</td>
<td>5117</td>
</tr>
<tr>
<td>Silica Spherules in the EH3 Chondrite ALHA81189</td>
<td>T. J. Fagan, K. Nagashima, and S. K. Sharma</td>
<td>5162</td>
</tr>
<tr>
<td>Model Simulation of Mineralogical and Chemical Changes During Isothermal, Free Evaporation of a Reduced Chondritic Precursor in Pure H2</td>
<td>A. V. Fedkin, M. S. Ghiorsio, and L. Grossman</td>
<td>5227</td>
</tr>
<tr>
<td>X-Ray Flares in Young Suns and Implications for Meteoritics</td>
<td>E. D. Feigelson</td>
<td>5339</td>
</tr>
<tr>
<td>Zoning in K/T Boundary Spinel</td>
<td>L. Ferriere and E. Robin</td>
<td>5263</td>
</tr>
<tr>
<td>Are the SNC Meteorites Clearly Distinct from Terrestrial Rocks?</td>
<td>J. Filiberto and H. Nekvasil</td>
<td>5189</td>
</tr>
<tr>
<td>On the Correlation Between $\delta^{15}$N and Nitrogen Content in Nanodiamonds from Meteorites</td>
<td>A. V. Fisenko, A. B. Verchovsky, and L. F. Semjonova</td>
<td>5037</td>
</tr>
<tr>
<td>High Fe Contents in Presolar Silicate Grains: Primary Feature or the Result of Secondary Processing?</td>
<td>C. Floss, F. J. Stadermann, A. Nguyen, E. Zinner, and A. S. Lea</td>
<td>5093</td>
</tr>
<tr>
<td>Micrometeorites from Frontier Mountain (Antarctica)</td>
<td>L. Folco, P. Rochette, J. Gattacceca, and N. Perchiazzi</td>
<td>5156</td>
</tr>
<tr>
<td>Meteorites: Chronostratigraphic Markers of the Frontier Mountain Blue Ice Field (Antarctica)</td>
<td>L. Folco, K. C. Welten, K. Nishizumi, and A. J. T. Jull</td>
<td>5109</td>
</tr>
</tbody>
</table>
Cr, Mn, and Ni on 433 Eros: Further Evidence of Ordinary Chondrite Composition
   C. N. Foley, L. R. Nittler, M. R. M. Brown, T. J. McCoy, and L. Lim ................................................................. 5233

Elemental Signatures of Nebular and Alteration Processes in CV, CO, and CR CAIs
   J. M. Friedrich, K. P. Jochum, and D. S. Ebel ........................................................................................................ 5112

Contamination in Meteorites Stored Since 1977 — Preliminary Results of Antarctic Meteorite Contamination Study (AMCS)

Carbon and Mineral Phase Distribution in Inter-Grain Spaces and Inclusions Within Chondrules
   M. Fries, A. Steele, and T. McCoy .......................................................................................................................... 5302

Carbon and Mineral Phase Distribution on a CV3 Dark Inclusion Boundary — A Confocal Raman Imaging Study
   M. Fries, A. Steele, and A. Ruzicka .......................................................................................................................... 5236
HIGH SPATIAL RESOLUTION 3D LOCAL TOMOGRAPHY OF PARTICLE TRACKS AND FRAGMENTATION IN AEROGEL. D. S. Ebel¹ and M. L. Rivers². ¹Dept. of Earth and Planetary Sciences, American Museum of Natural History, Central Park West at 79th St., New York, NY 10024. (debel@amnh.org) ²Consortium for Advanced Radiation Sources, Univ. of Chicago.

Introduction: Synchrotron x-ray computed micro-tomography (XR-CMT) non-destructively yields 3-Dimensional images of bulk volumes, that we applied to meteorites [1-4], and lunar glass spherules [5]. We’ve succeeded in imaging, at high spatial resolution, particle tracks and fragmentation histories in aerogel tile (25mm deep) shot with Allende (CV3) dust (into the 7x40mm top surface) using a gas gun (F. Hörz, pers. comm.). STARDUST mission will return samples like these, but optical methods are non-optimal for full 3D imaging before destructive slicing and particle removal.

Methods: Samples rotate on a highly automated high-precision stage, about a chosen center. X-rays (µW) do not heat the sample. From X-ray images taken on a CCD at successive angles, we make a 3-dimensional (3D) array, 650x650x515 centered on the rotation center, of equidimensional volume elements (voxels), each with an x-ray attenuation represented by a 12-bit integer. High-attenuation (denser) particles are bright, aerogel brighter than air in tracks. 3D arrays can be ‘sliced’, sub-sampled, thresholded, contrast-enhanced. 2D ‘slices’ are pixels representing a plane of voxels in the sample.

To image a large aerogel tile at high spatial resolution, portions of the tile must rotate in and out of the field of view of the x-ray beam/CCD collector. For rocky materials with high attenuation, large samples are impractical, and our work has been confined to samples under 1cm maximum cross-section. With low-density aerogel, however, we were able to image portions (interior volumes) of the above tile (7x40mm cross-section) at both 14.49 and 3.66 micron/pixel resolution. This imaging is the first application of ‘local’ or ‘lambda’ tomography to aerogel of which we are aware. Further discussion of technique, and results of this work can be found at:

http://research.amnh.org/users/debel/tomo2/aerogel1.html

Results: Particles, tracks, and sintered aerogel are easily observed in orthogonal planes through volumes. We cropped one carrot-shaped track from the larger 14.5µm/pixl volume. Two particle fragments are visible, separated by tens of µm, but at the ends of laterally downward branching tracks that stem from the main track. In software, we spliced together sequential volumes at 3.66 µm/pixl, and follow individual tracks downward into the tile.

Conclusion: Synchrotron x-ray ‘lambda’ microtomography can successfully produce 3D density maps of analogs of the expected STARDUST comet sample return tiles. Rotation centers can be spaced evenly through the tile volume, to image the entire tile at very high spatial resolution (e.g., 1.5 µm/pixl). Alternatively, tracks can be followed downward by imaging selected volumes. Resulting volumes can be stitched together, cropped, etc. as desired. This non-destructive imaging will recover maximum information content from aerogel tiles prior to cutting, particle extraction, and other invasive investigations. XR-CMT is versatile and applicable to initial characterization for low-density samples from future missions [6]

A MATHEMATIC MODEL FOR THE MONTURAQUI IMPACT CRATER, CHILE, SOUTH AMERICA.

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Synopsis: The Monturaqui impact crater, Atacama, Chile (S23\textdegree 56' W68\textdegree 17') is a simple-type impact crater and was discovered in 1962 by examination of aerial photographs. Later, in situ geologic research confirmed its meteoritic impact origin. Diameter: 460 meters, Depth: 31 meters. The crater lies in an area of desert hills of the Monturaqui range and it is located in the high Atacama Desert (altitude of 3500 meters). The Monturaqui crater is emplaced in Jurassic granite rock, overlain by a thin Tertiary-Quaternary ignimbrite sheet.

The impacting asteroid was metallic: an Iron-Nickel object. Meteorite specimens have not been recovered, but, meteoritic iron shale was found on the outer rim of the crater and highly vesicular impact glass material was abundant on the South and SE flanks of the crater. The impactites have shocked minerals and rock fragments as well as tiny Fe-Ni-Co-P sherules, all bound in glass.

Analysis of the mixed matrix glasses indicated extreme compositional differences compared to granite country rock. Glass shows enrichment in Fe, Ni and Co. These metallic elements came from the impacting metallic asteroid no doubt. The age of this crater has been estimated in about 1 Ma, \cite{1, 2}.

The mathematical model is applied in quantum formalism, polynomial elements and Korteweg-DeVries (KDV) soliton theory \cite{3}, 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 ~ 460 meters, circular shape, basement composition ~ granitic.

Analytical Method and Results: According this model \cite{3}, the asteroid diameter is ~ 14.92 m, with a velocity and impact angle of ~ 17.82 km/s and 41.12\textdegree respectively. The number of rings are calculated in ~ 0.21 with a initial crater profundity of ~ 53.85 m, this quantity could be altered across the passage of time to ~ 31 m, the melt volume is ~ 6,763,699 m\textsuperscript{3} or ~ 0.0068 km\textsuperscript{3}. The number of ejected fragments are estimated in ~ 7,401.1 with average sizes of ~ 0.77 m, and a cloud of dust with diameter of ~ 23.61 km. The total energy in the impact is calculated in ~ 4.77E22 Ergs, i.e., ~ 1.14 megatons. Before of the erosion effects the transient crater is estimated in ~ 226.43 m, the hydrothermal zone (hydrothermal systems) is of ~ 14.92 m to 113.21 m from the nucleus of impact. The lifetimes estimated are of ~ 2,244 years to 3,503 years with uncertainties of ~ +/- 0.9639 % to +/- 2.7286 %, i.e., from +/- 22 years to +/- 96 years. Hydrothermal temperatures from 0.25 years to 1,400 years are estimated in ~ 97.95\textdegree C to 21.79\textdegree C respectively. The fragments are ejected to ~ 11.49 km from the impact center, with a velocity of ejection of ~ 1.12 km/s, ejection angle of ~ 2.58\textdegree and maximum height of ~ 129.59 m. The density of the asteroid is calculated in ~ 6.31 g/cm\textsuperscript{3} and the combined density (maximum and minimum) for the ejected fragments is estimated in ~ 2.63 g/cm\textsuperscript{3}. Finally, the temperature peak in the impact is estimated in ~ 0.76 times the temperature of the solar nucleus, by a space of time of ~ 0.09 ms (9E -5 s).

TWO DISTINCT OLIVINE-RINGWOODITE PHASE TRANSITION MECHANISMS IN SHOCKED L-CHONDRITES: GENETIC IMPLICATIONS.
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Introduction: Natural ringwoodite occurs in chondritic meteorites as fine-grained polycrystalline aggregates mainly in shock-melt veins [1-3]. Multianvil experiments on fine-grained olivine resulted in incoherent nucleation and growth of the product phase on grain boundaries by interface controlled mechanism [4]. Intracrystalline coherent olivine-ringwoodite phase transformation was experimentally induced in San Carlos olivine at 18-20 GPa and 1173-1373 K [5]. The nucleation mechanism involved four stages commencing by formation of (100)α stacking faults in olivine [5]. We investigated Shock-melt veins and surrounding chondritic matrix in the Sixiangkou L-6 chondrite to search for lamellar intracrystalline ringwoodite formation and to assess the P-T conditions and spatial distribution of both inter- and intracrystalline transformation mechanisms inside and outside the shock-melt veins.

Results: Both phase transformation mechanisms were encountered in distinct settings inside and outside the veins. Polycrystalline ringwoodite aggregates with triple junctions were confined to porphyroclastic grains <100 µm in size inside the veins. Pressure and temperatures in the veins are constrained by the assemblage majorite + magnesiowüstite at 20-23 GPa and T~2273 K [3]. Large olivine grains (>100 µm) inside and outside the veins display in contrast intracrystalline lamellar intergrowth of ringwoodite. Large olivines inside the veins and in a 50 µm zone bordering the veins depict two sets of ringwoodite lamellae along their {101} planes. Olivines in this 50 µm zone contain troilite veins intersecting the ringwoodite lamellae thus indicating that the pressure and temperature in this zone were P > 16 GPa and T > 1463 K. Olivine grains with lamellar ringwoodite extend up to a distance of 250 µm beyond the 50 µm zone into the chondritic matrix. In this assemblage only one set of ringwoodite lamellae along (100) of olivine occurs and no troilite melting. This constrains temperature as: 1173 < T < 1463 K, since nucleation of ringwoodite lamellae is inhibited < 1173 K [5]. Laser microRaman profiles across the ringwoodite lamellae reveal Raman bands at 714 and 918 cm⁻¹ of wadsleyite at the ringwoodite olivine interface and the bands 298, 798 and 844 cm⁻¹ characteristic of ringwoodite in addition to the bands 822 and 852 cm⁻¹ characteristic of olivine.

Conclusions: The results allow a reliable estimate of the pressure-temperature gradient from the shock veins to the surrounding chondritic matrix. Pressure dropped only slightly (~23 to ≥ 16 GPa) from the vein interior to the shocked meteorite matrix 300 µm from the vein wall. In contrast, the temperature magnitude dropped from 2273 K in the vein interior to > 1464 K in the 50 µm zone then to ≥ 1173 K 300 µm from the vein walls.

We have previously reported petrophysical and paleomagnetic data [1] from the Yaxcocoil (Yax-1) drill core. However, results have been difficult to interpret due to scarcity of samples down the core. For example the record of the pre- and post-impact layers has a lot of gaps. Hence, many questions arise from the results of previous studies: (i) are some of the N- and R-polarities artifacts or are they true, (ii) have hydrothermal effects or other processes been affecting the physical properties of the samples, (iii) how precise is the paleomagnetic dating tool and can it really reveal the impact age, etc.

In order to get more dense record, to improve data quality and to find answers to these questions, we carried out more detailed sampling of the Yax-1. Measurements of petrophysics (e.g. density (fig.1), susceptibility, porosity) and paleomagnetism (AF and TH demagnetization), coupled with rock magnetic studies were carried out. Results of the new samples reveal improved correlation between petrophysics, paleomagnetism and rock magnetic data. These new results will be presented in terms of K/T paleogeography, magnetostratigraphy and current ideas of Chicxulub impact processes.

UV IRRADIATION OF AROMATIC NITROGEN HETEROCYCLES IN INTERSTELLAR ICE ANALOGS.

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Introduction: Aromatic molecules are thought to be ubiquitous in the interstellar medium and are among the most common organic compounds in the universe [1]. The infrared spectra and possible interstellar ice chemistry of polycyclic aromatic hydrocarbons (PAHs) have been investigated, and it has been shown that a variety of side groups can be added to PAHs under simulated interstellar conditions [2,3]. However, there is little information on the corresponding properties of aromatic nitrogen heterocycles (ANHs), chemical structures in which one or more of the C atoms in the skeleton of a PAH are replaced with a N atom. ANHs are of astrobiological interest both because of the central role that they play in biochemistry on Earth (e.g., nucleobases, flavins) and because several ANHs have been identified in the Murchison meteorite [4].

Here, we present information on the properties of the ANH quinoline frozen in interstellar water-ice analogs. Quinoline is a two-ring compound structurally analogous to the PAH naphthalene. In this work, binary mixtures of water and quinoline were frozen to create interstellar ice analogs, which were then subjected to ultraviolet photolysis. We will present the infrared spectra of the resulting ices at various temperatures, as well as chromatographic analysis of the residues remaining upon warm-up of these ices to room temperature.

This research project was supported by the NAI (grant NNA04CC05A).

DEVELOPMENT OF A NONDESTRUCTIVE TECHNIQUE USING RAMAN SPECTROSCOPY TO MEASURE THE D/H RATIO OF EXTRATERRESTRIAL WATER. M.E. Elwood Madden, R.J. Bodnar, K. Cheung, and M. Zolensky.

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Introduction: Our current knowledge of D/H ratios in the solar system and beyond comes from gas chromatography of volatiles released through heating of bulk meteorite samples and separated phases, in situ analyses of hydrous phases in meteorites, remote spectroscopic observations of comets, asteroids, planets, and nebula, and analyses of terrestrial water and rocks [1]. Unlike these previous techniques, fluid inclusions, such as those trapped in halite in the Monahans [2] and Zag [3] H-5 chondrites, provide direct samples of extraterrestrial water that was present on meteorite parent bodies. A nondestructive analytical technique for measuring the D/H ratio of extraterrestrial water trapped in fluid inclusions in meteorites using Raman spectroscopy is currently being tested and calibrated using synthetic fluid inclusions.

Fluid Inclusion Standards: Fluid inclusion standards with D/H ratios varying from 10% D₂O to near SMOW composition have been synthesized in halite. Using a sealed pressure vessel, ~32 wt% NaCl solutions with varying D/H composition were cycled repeated from 298-525K, then slowly cooled to promote precipitation of large halite crystals. The mass of the sealed pressure vessel was measured before and after the synthesis to ensure that no water had leaked from the system to produce isotopic fractionation. Large crystals of halite (1-5mm) containing two phase (liquid + vapor bubble) and single phase fluid inclusions were formed. These fluid inclusion standards have been used to test and calibrate the analytical technique.

Raman Spectroscopy: Raman is a vibrational spectroscopy and differences in atomic mass can be observed through their different vibrational frequencies, allowing molecules of different isotopic composition to be distinguished from one another and their relative proportions determined. While the Raman spectrum of liquid water is relatively broad, making quantitative analyses difficult, the Raman spectrum of ice is much sharper and better defined. Therefore, analyses were conducted on samples cooled to 77K. Fluid inclusions in the Monahans and Zag meteorites and the synthetic standards are contained in halite, therefore water ice and hydrohalite (NaCl•2H₂O) crystallize as the NaCl-saturated fluids freeze. The D/H composition of the brine can be estimated by measuring the ratio of the integrated O-D vibration peak areas (~2300-2700 cm⁻¹) to the integrated O-H vibration peak areas (~3000-3600 cm⁻¹) in the ice + hydrohalite spectrum. Initial testing of this technique suggests a linear relationship between the integrated peak area ratio and the D/H composition of the standards.

WEAUBLEAU STRUCTURE, MISSOURI: FIELD AND CORE EVIDENCE FOR A POSSIBLE IMPACT ORIGIN.
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Introduction: The Weaubleau structure in southwest Missouri is one of the 38th parallel structures [1]. These also include Decaturville and Crooked Creek, which are widely regarded as impact structures [2]. Although, the complex geology around Weaubleau Creek has been known since the 1950’s [3], it has not been re-examined in detail until recently.

Possible Impact Origin: Computer mapping using digital elevation model (DEM) and shuttle radar topography mapping (SRTM) data has revealed a 9-km diameter ring-like circular topographic feature in the vicinity of the structurally complex area. Subsequent field and drill-coring investigations have shown that this feature has many of the hallmarks of an impact: (1) the relict topography is coincident with the main outcrop area of the “Weaubleau Breccia,” an informal stratigraphic unit with several facies that may be related to different impact processes; (2) ~ 300 m of uplift of brecciated granitic basement is recorded in drill core from the inner margin of the ring; and (3) strata are intensely deformed near the periphery of the ring and progressively less so 8-10 km distant. Such deformation is unusual in a stable cratonic setting, where there is no indication of volcanic activity and surrounding strata are essentially flat lying. We provisionally interpret the circular feature as a central uplift.

Detrital quartz grains in the “Weaubleau Breccia” have abundant planar fractures (PFs) and rare planar deformational features (PDFs), Petrographic analysis of shock-metamorphic features or geochemical studies are needed to confirm an impact origin. These studies are currently underway.

Age Constraints: The “Weaubleau Breccia” includes megabreccia blocks, fractured parautochthonous rock, and polymict lithic breccia. The latter occurs in two varieties: an injection breccia that was emplaced at depth and a thick crudely sorted unit that overlies deformed or heavily fractured strata. We provisionally interpret this crudely sorted unit as a resurge deposit.

Fossils from the resurge facies include bryozoans, brachiopods, corals, echinoid spines, crinoids, blastoids, and conodonts of mixed ages. Blastoids are of middle Mississippian (middle and late Osagean) age. Crinoids include middle Mississippian (middle through late Osagean) forms. Conodonts are of early Ordovician (Ixobrychusian) and lower to middle Mississippian (Kinderhookian through Osagean) ages. Two conodont species have biostratigraphic ranges that extend from late Osagean to Meramecian, but no other fossils typical of the Meramecian occur in this unit.

The “Weaubleau Breccia” subsequently was karsted prior to deposition of Middle Pennsylvanian (Desmoinesian) terrigenous sediments that partially cover the structure. A conservative view places the age somewhere between middle Mississippian and middle Pennsylvanian. The faunal record suggests an age closer to middle Mississippian Osagean-Meramecian boundary.

SILICA SPHERULES IN THE EH3 CHONDRITE ALHA81189

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Introduction: Enstatite chondrites (ECs) are characterized by formation under low fO₂ and high Si/Mg in comparison to other chondrite groups. Because EC chondrule formation and gas-solid reactions were distinct from those of other groups, ECs provide unique constraints on the full set of conditions that were extant in the solar nebula. In this study, we report the presence of silica spherules in a primitive EH3 chondrite ALHA81189.

One possible origin for the spherules is by gas-liquid condensation, suggesting that silica may have condensed as a liquid in the EC-forming region.

Analytical Methods: Silica spherules in ALHA81189 were identified by thin section-scale elemental X-ray mapping during previous studies of enstatite chondrites [1,2]. The spherules were characterized subsequently using petrographic microscopes, a JEOL JSM-840A scanning electron microscope with an EDS detector and a JEOL JXA-8900 electron microprobe at the Smithsonian Institution, Washington, DC. Raman spectra of silica spherules were collected using a focused Ar⁺ laser with spatial resolution of 2-5 µm in width and ~20 µm in depth [3].

Oxygen isotopic compositions were determined by point analyses (spot size ~ 5 µm) using the CAMECA ims-1270 ion microprobe at TiTech under conditions described previously [4]. Oxygen isotope images were collected from one spherule and one chondrule with a silica rim using the isotope microscope system at TiTech configured with the CAMECA ims-1270 ion microprobe and the SCAPS [5,6].

Results and Discussion: The silica spherules range from 50 to 100 µm in apparent diameter in thin section. Highly undulatory extinction indicates very fine grain size. The Raman spectra indicate that they consist of the cristobalite polymorph, consistent with formation at high temperatures and low pressures. The oxygen isotopic analyses fall near bulk values for ECs, indicating that the spherules did not form from isotopically foreign oxygen. SCAPS imaging of one spherule did not reveal any heterogeneities within analytical uncertainties.

The spherical shapes suggest that these objects formed from liquids, but because of eutectic relationships it is difficult to produce a silica liquid by melting of solid grains. One condensation model suggests that fractional removal of solids from gas in the EC-forming region could result in condensation of silica [7]. It is possible that the spherules formed by this process with pressure high enough to result in gas-liquid condensation, or that gas-solid condensation was followed shortly thereafter by melting. The spherules require some means of enrichment and isolation of SiO₂.

MODEL SIMULATION OF MINERALOGICAL AND CHEMICAL CHANGES DURING ISOTHERMAL, FREE EVAPORATION OF A REDUCED CHONDritic PRECURSOR IN PURE H₂. A. V. Fedkin1, M. S. Ghiorso1 and L. Grossman1,2. 1Dept. of the Geophysical Sciences, Univ. of Chicago, 5734 S. Ellis Ave., Chicago, IL 60637. avf@uchicago.edu. 2Also Enrico Fermi Institute.

Introduction: Using the MELTS thermodynamic model [1] to compute the equilibrium phase assemblage and activities of all components in the liquid phase, a model has been developed for calculating equilibrium vapor pressures over multicomponent, iron- and alkali-bearing systems. In [2], this model was applied to published experimental measurements of evaporation rates of Mg, Fe, Na, K and Si for chondrule-like systems in H₂ to obtain evaporation coefficients (α_i) for the dominant evaporating species of these elements using the Hertz-Knudsen equation. The evaporation reaction of an oxide from a silicate liquid produces free oxygen or H₂O in vacuum or in H₂, resp. The vapor pressure of a volatile element like Na may generate a vapor pressure of O₂ or H₂O too high to be compatible with the valence of iron in the evaporating source material. Thus, the actual volatilization residue may be more reduced than the equilibrium assemblage for which vapor pressures are calculated. In our model, free oxygen otherwise released during each vaporization step in such a case is used to oxidize the residue until its oxidation state matches that of the equilibrium assemblage.

Technique: The model chondrule precursor was assumed to contain chondritic proportions of Si, Mg, Fe, Ni, Ca, Al, Na, K, Ti and Cr with enough oxygen to convert only 2.56% of the total Fe to FeO. The only evaporating solid phase was assumed to be metallic NiFe, for which we assumed α_Ni = α_Fe, which is nearly unity [3]. For silicate liquid, α_i for SiO(g), MgO(g), FeO(g), NaO(g) and KO(g) were taken from [2], and it was assumed that α_Cr = α_Ni = α_Fe and that lnα_i = −7787/T(K) + b_i for all species. The initial radius was 0.5 mm and, at each evaporation step, the fractional surface area occupied by each phase was assumed equal to its volume fraction.

Results: For P_H₂ ≈ 10^-4 bar, at all temperatures from 1500-1900K, metallic NiFe falls in abundance both by direct evaporation and by oxidation, the latter using oxygen released initially mostly by alkali loss and then mostly by

\[ \text{Fe}_2\text{SiO}_4(\text{l}) \rightleftharpoons 2\text{Fe}(g) + \text{SiO}_2(g) + O(g) \]

X of olivine (ol) first increases by several mole % (from ~0.02 to 0.05 or 0.06) until the oxidation state of Fe is equal in both the real and equilibrium assemblages, and then falls as Fe evaporated from silicate liquid cannot be replenished by further oxidation of metal (met) due to falling f(O₂). At 1900K, the initial assemblage contains 51 wt% silicate liquid and ol+met+spinel (sp), the initial equilibrium log f(O₂) = IW + 3.5, all alkalies are lost in ~0.2 min, all metal in 11 min, and 10% of the total Fe in 0.8 min. At 1600K, there is initially only 24% silicate liquid (lowering evaporation rates) and ol+opx+sp+met, the initial log f(O₂) = IW + 1.1, all alkalies are lost in 80 min, all metal in >300 min, and 10% of the total Fe in 29 min.

X-RAY FLARES IN YOUNG SUNS AND IMPLICATIONS FOR METEORITICS.
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Introduction: X-ray astronomical studies of young stellar populations have established that solar-type stars exhibit their highest levels of magnetic activity during their pre-main sequence phases when planet formation occurs. Our understanding of this activity, and particularly violent magnetic reconnection flares, has been greatly advanced by the recent Chandra Orion Ultradeep Project (COUP) based on a 13-day exposure of the Orion Nebula by NASA’s Chandra X-ray Observatory [1].

Trends in magnetic activity: COUP shows that all young solar analogs are magnetically active at levels far above main sequence levels: \( <\log L_x > \sim 30.5 \) erg/s (0.5-8 keV band) during the planet formation epoch compared to \( <\log L_x > \sim 27 \) erg/s for the Sun today. Mass-stratified X-ray luminosity functions of stellar populations show a secular decline in magnetic activity from \( 10^5 \) to \( 10^{10} \) years [2]. While age, size and mass are statistical predictors of pre-main sequence X-ray emission, it is surprising that rotation is not [3].

Flares: Nearly all Orion stars observed with strong signals show solar-like flares during the 13-day COUP observation [4, 5]. The physical and statistical properties of Orion flares are similar to, but far more powerful than, contemporary solar flares. Flare peak luminosities can reach \( \log L_x \sim 32 \) erg/s, and strong flares recur every few days in Orion stars.

X-rays and protoplanetary disks: COUP provides three lines of evidence that young stellar X-rays efficiently illuminate the protoplanetary disks. First, the strongest flares are likely produced in magnetic loops 3-10 times bigger than the star; these may be the hypothesized star-disk field lines [5]. Second, a fluorescent iron line is seen in a few COUP spectra which is best explained as reflection by disk gases [6]. Third, soft X-ray absorption is seen in the COUP spectra of stars with inclined and edge-on disks, directly indicating absorption of X-rays by disk gases [7].

Together, these results reduce earlier uncertainty regarding the magnetic geometry and efficiency of X-ray disk irradiation [8]. COUP thus provides empirical support for X-ray heating and ionization of disk gases [9], in situ production of spallogenic isotopes in disk solids by flare MeV particles [10], and CAI or chondrule melting by X-ray or shock heating.

ZONING IN K/T BOUNDARY SPINEL. L. Ferriere¹ and E. Robin². ¹LEME, Muséum National d'Histoire Naturelle, Paris (France). E-mail: ferriere@mnhn.fr. ²LSCE, CEA, Gif sur Yvette (France).

Introduction: Previous studies have revealed the existence of Ni-rich spinel crystals in K/T boundary clays [1,2]. K/T spinel is characterized by a high Ni²⁺ and Fe³⁺ content and also contains Fe²⁺, Mg²⁺, Al³⁺ and Cr³⁺ with abundances varying from site to site [3]. It has been shown that the composition of spinel depends primarily on ambient oxygen fugacity and the initial composition of the crystallizing material [4,5].

Here we report the compositional zoning in K/T boundary spinel from Bidart (France) and Caravaca (Spain). X-ray maps and compositional profiles were performed by EDS on a JEOL JSM 840.

Results: We found a tenth of the crystals with compositional zoning from core to rim. These have a Cr-rich (Cr₂O₃ ~14-18 wt%) and Fe-poor (Fe₂O₃ ~ 48-52 wt%) core with respect to a Cr-poor (Cr₂O₃ ~4-8 wt%) and Fe-rich (Fe₂O₃ ~ 60-64wt%) rim. The core is also slightly depleted in Ni and Ti and enriched in Al and Mg. and has a lower Fe³⁺/Fe total ratio. The contact between the Cr-rich core and the Fe-rich rim is very well defined.

Discussion: Ni depletion in the core indicates that the zoning is primary rather than the result of alteration. The variation of the Fe³⁺/Fe total ratio from core to rim may indicate oxygen fugacity (fO₂) increase during crystallization, accounting for reduced chromite precipitation at low fO₂, with subsequent magnetite overgrowth at higher fO₂. Alternately, it may reflect the presence of relic chromite with subsequent magnetite overgrowth. Relic chromite with similar magnetite overgrowth has been reported in experimental melting of meteorites [5].

Oxygen isotopic analyses on a CAMECA NanoSIMS 50 are currently in progress.

Introduction: It is generally accepted that there are distinct geochemical differences between the SNC Martian meteorites and terrestrial rocks. Element/element ratios, such as the Fe/Mn, Ga/Al, and Na/Al ratios, have been used to distinguish the SNC meteorites from terrestrial rocks [1-3]. These ratios in the SNC meteorites differ from those of the terrestrial mantle peridotites used to develop the terrestrial geochemical fractionation line [4]. Should the SNC meteorites reflect primary Martian mantle assemblages, these differences could reflect first-order differences between the Martian magmatic source regions and those of terrestrial igneous rocks. However, the possibility exists that the SNC meteorites, particularly those with significant cumulate characteristics, arose by accumulation during fractionation and are not reflective of primary martian mantle melts. We are investigating the implications for SNC parental magmas if the cumulate SNCs represent fractionation-derived assemblages from chemically-evolved magmas. We have initiated this by evaluating if parental magmas of the partly cumulate SNCs could have had more terrestrial characteristics than commonly accepted by looking for terrestrial analogs in intra-plate cumulate xenoliths. We have focused on Mg/Si, Al/Si, Fe/Mn, Ni/Mg, Na/Ti, K/La, and Al/Ti ratios; two examples of results are given below.

Mg/Si vs. Al/Si ratios: One of the often-cited differences between the Martian meteorites and terrestrial rocks lies in the ratio of Mg/Si and Al/Si. The robustness of this difference has been questioned by the new Gusev basalt data (MER Spirit), which indicates terrestrial Mg/Si vs. Al/Si values [5, 6]. Comparisons of these ratios in cumulate intraplate magmatic nodules with those of the SNC meteorites shows that the former lie off of the terrestrial geochemical fractionation line and into the SNC field purely because of the accumulation of evolved minerals.

Fe/Mn ratio: The Fe/Mn (FeO/MnO) ratio is commonly used to discriminate between terrestrial and Martian materials. A value of ~40-45 is often considered representative of the meteorites [1, 3], and therefore, of their source regions. Among the SNCs, this ratio is actually quite variable, ranging from 28-51. Terrestrial intra-plate basalts and cumulate xenoliths also show the same range in Fe/Mn ratio, thereby suggesting that the SNC source regions may not systematically differ from terrestrial intra-plate source regions in this ratio.

Conclusion: The geochemical uniqueness of the SNC meteorites and the implications for a unique Martian magmatic source region and parental liquids requires re-consideration. Commonly used element/element ratios do not significantly distinguish the SNC’s from terrestrial rocks.

ON THE CORRELATION BETWEEN $\delta^{15}$N AND NITROGEN CONTENT IN NANODIAMONDS FROM METEORITES.

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Correlation between $\delta^{15}$N and N/C (Fig.) for bulk analyses of meteoritic nanodiamonds can be explained if we suggest that a) diamonds consist of two main populations, b) in one of the populations (denoted as $C_N$) nitrogen is volume-correlated (i.e. is chemically bounded with carbon) and isotopically light ($\delta^{15}$N=−350‰), and c) both population contain surface-correlated nitrogen with $\delta^{15}$N=0. The relative abundance of the populations depends on the grade of metamorphism of meteorites the diamonds come from. The theoretically calculated (under these conditions) curve (Fig.) is in a good agreement with the experimental data.

Suggesting that both populations have similar grain-size distribution, one can conclude that the concentration (Z) of the surface-correlated nitrogen calculated for the bulk of nanodiamonds is a constant for all the meteorites. In this case Z is determined as: $Z = A*(350-\delta^{15}N)/(350+A*\delta^{15}N)$, where $A=N/C$. Indeed, the calculated Z turned out to be similar with the average value of $1.7x10^{-4}$ (1$\sigma=0.8x10^{-4}$) for all the meteorites. We consider this fact as an evidence for reality of the proposed model.

There is no correlation between concentration of HL noble gases and N/C in the nanodiamonds indicating that none of the above populations is the carrier of the HL component. Therefore it must exist another, minor grains population (likely diamond as well) which contains the HL noble gases. Perhaps only this population should have a presolar origin; the other populations could be formed within the Solar System.

HIGH FE CONTENTS IN PRESOLAR SILICATE GRAINS: PRIMARY FEATURE OR THE RESULT OF SECONDARY PROCESSING?
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Introduction: Silicate grains are the newest addition to the collection of presolar minerals found in extraterrestrial materials [1,2]. However, although close to a hundred presolar silicate grains have been found to date, little information exists about the mineralogy and/or elemental compositions of most of them. Such knowledge is crucial for understanding the stellar environments in which these grains formed. Auger spectroscopy is unique in its ability to provide compositional information on a spatial scale of 10s of nanometers without requiring difficult sample preparation [3]. It is, thus, the ideal analytical technique for determining the elemental compositions of presolar silicate grains, which are typically less than half a micron in size.

Experimental and Results: We used scanning Auger spectroscopy to acquire Auger elemental image maps of areas in IDPs and primitive meteorites containing circumstellar silicate and oxide grains [3]. These grains had previously been identified with the NanoSIMS as being presolar, on the basis of their anomalous oxygen isotopic compositions [4,5]. Elemental maps of five presolar silicate grains, ranging in size from ~160 to 350 nm, show that three grains are distinctly enriched in Mg and contain little to no Fe. The remaining two grains are Fe-rich and Mg-poor. Spot analyses, which are planned for the future, will allow us to quantify the elemental compositions and establish the mineralogy of the silicates.

Discussion: Fe-Mg silicates, such as olivine and pyroxene, are expected to have Mg-rich compositions under conditions of equilibrium condensation in the stellar winds of oxygen-rich RGB and AGB stars [6]. The three Mg-rich presolar silicates are consistent with such an origin, but not the two Fe-rich grains. Enrichment of Fe in presolar silicates has been considered to be of secondary origin, due to nebular or parent body processing [e.g., 2], but this could also be a primary feature. Non-equilibrium condensation in stellar outflows is expected to produce silicates with higher Fe contents than equilibrium condensation [7], and amorphous silicates observed around oxygen-rich stars are thought to be Fe-rich in order to explain their higher absorptivity in the near-infrared [8]. Indeed, TEM analysis of a FIB lift-out section of one presolar silicate shows it to be an amorphous silicate containing abundant Fe [9]. One of the Fe-rich grains observed here occurs in an anhydrous IDP, which is unlikely to have experienced significant secondary processing. This grain may represent a primary Fe-rich silicate condensate that formed under non-equilibrium conditions.

In December 2003, hundreds of cosmic spherules and micrometeorites in the 100-800 µm size-range were collected by a PNRA party from sand deposits on a glacially eroded surface at the top of Frontier Mountain (northern Victoria Land, Antarctica) that may be as old as a few Myr [1].

The collection includes both cosmic spherules and micrometeorites (Fig. 1). At the conference, we shall report on concentration of cosmic spherules and micrometeorites in the sediment, frequency distribution by particle size and type. In addition, we shall show details on the mineralogy and bulk chemical compositions by EDS-SEM and EMPA of a representative sample of the Frontier Mountain population.

The comparison of this data set with those from other well-characterized collections [e.g., 2, 3, 4, 5] will allow us to establish the potential of the Frontier Mountain population in yielding new information on the main part of the extraterrestrial matter accreting to Earth.

Fig. 1. Selected back-scattered electron images of sectioned cosmic spherules and micrometeorites from Frontier Mountain. Top left: barred olivine cosmic spherule; top right: coarse grained, olivine and pyroxene micrometeorite; bottom left: CI-type micrometeorite; bottom right CM-type micrometeorite.

**METEORITES: CHRONOSTRATIGRAPHIC MARKERS OF THE FRONTIER MOUNTAIN BLUE ICE FIELD (ANTARCTICA).** L. Folco¹, K. C. Welten², K. Nishiizumi³ and A. J. T. Jull¹. ¹Museo Nazionale dell’Antaride, Siena, Italy Email: folco@unisi.it. ²Space Sciences Laboratory, University of California, Berkeley, CA 94720, USA. ³NSF-Arizona AMS Laboratory, University of Arizona, Tucson, AZ 85721, USA.

**Introduction:** Absolute dating of Antarctic ice is problematic. Meteorites can provide chronological constraints on the age of the ice cropping out at the Frontier Mountain meteorite trap when their terrestrial age is placed in a glaciological context.

**Glaciological setting:** A detailed description of the glaciology of the Frontier Mountain blue ice field (Fig. 1) is given by [1]. Four meteorites, FRO 8401 (L6), 99028 (L6), 93005 (L5) and 93054 (H6), were found along a stretch of ice where an ideal section of the Frontier Mountain blue ice crops out (Fig. 1). The section extends for about 5 km across “the scatterfield” [1] in a roughly SE-NW direction. As indicated by the geometry of tephra layers embedded in the ice, the structure of the ice along the section is essentially a SE-dipping monocline with increasingly older layers moving northwards. Since the four meteorites have much heavier masses (from 772 and 1665 g) than the 200 g wind transport threshold [1], they were most likely not wind-drifted across the ice field.

**Terrestrial ages:** The $^{14}$C terrestrial age of FRO 8401, 99028 and 93005 are 13±2, 21±3 and 27±2 kyr respectively [2]. The $^{41}$Ca/$^{36}$Cl age of FRO 93054 is 40±10 kyr [2].

**Conclusion:** The terrestrial age geographic distribution of the four large meteorites (Fig.1) is best explained by delivery of meteorites at the ice surface through the “ice-flow model” rather than direct fall. As a consequence, such distribution indicates that the age of the ice under ablation at Frontier Mountain is up to 40±10 kyr.

Cr, Mn, AND Ni ON 433 EROS: FURTHER EVIDENCE OF ORDINARY CHONDRITE COMPOSITION. C. N. Foley¹, L. R. Nittler¹, M. R. M. Brown²,², T. J. McCoy⁺, L. Lim⁺.

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Introduction: The NEAR mission provided both mineralogical data from infrared spectroscopy and chemical data from the x-ray (XRS) and gamma-ray (GRS) spectrometers (see [1-3] for XRS instrument descriptions) in order to investigate a potential match for Eros to known types of meteorites. The XRS abundance ratios previously reported for magnesium, aluminum, calcium and iron to silicon match those of ordinary chondrites (OC) [2]. Furthermore, the infrared and GRS data from the orbiter support an OC composition based on mineralogy and bulk surface chemistry, respectively [4, 5]. However, the observation that Eros appears to have a sulfur abundance at least a factor of two lower than OCs, suggests either sulfur loss from the surface of Eros by impact and/or radiation processes (space weathering) or that its surface is comprised of a somewhat more differentiated type of material than an OC, namely something which has undergone limited partial melting and loss of a S-rich melt [2, 3].

We report Cr/Fe, Mn/Fe, and Ni/Fe ratios determined for regions of Eros imaged during two solar flares which occurred during May and December of 2000. These minor element ratios are potentially diagnostic of whether the observed S depletion is due to space weathering or to partial melting. In the latter case, non-OC abundances of Cr, Mn and/or Ni might be expected, even if no silicate melting occurred. Space weathering is not expected to significantly affect these elements.

Results and Discussion: Our basic methodology and preliminary Cr results were described in [6], but we have extended the analysis to Mn and Ni as well. We find broadly chondritic Cr/Fe (0.023 ± 0.007; OCs=0.013—0.019) and Ni/Fe (0.11 ± 0.05; OCs=0.06) ratios for the two flare XRS spectra. Based on simulated spectra, Mn cannot be detected at chondritic levels, due to overlap with the main Fe x-ray line, but our Mn/Fe upper limit (<0.017) is consistent with OCs (0.009—0.014). Coupled with the previously documented major element abundance ratios [2,3] the chondritic Cr, Mn, and Ni abundances relative to Fe strongly favor a space weathering origin for the S depletion. Although some partially melted achondrites (e.g., some lodranites) are observed to have chondritic abundances of these elements, the chondritic Mg/Si and Al/Si ratios rule out a match to such meteorites for Eros.

ELEMENTAL SIGNATURES OF NEBULAR AND ALTERATION PROCESSES IN CV, CO, and CR CAIs.


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Introduction: Calcium-, aluminum-rich inclusions (CAIs) generally display the chemical and mineralogical compositions thermodynamically-predicted for the earliest, high-temperature condensates in a solar nebular gas [1, 2]. Trace element patterns in CAIs and their constituent minerals are the result of not only these initial formation conditions, but also the result of later events including post-accretionary melting and, in some cases, secondary aqueous alteration within the host parent body [3].

We have quantified 46 trace elements (by increasing putative volatility: Hf, Lu, Zr, Y, Er, Th, Ho, Tm, Dy, Tb, Gd, U, Nd, Pr, Sm, La, Ce, Ta, Ca, Nb, V, Yb, Eu, Sr, Ba, W, Ni, Mo, Pt, Co, As, Cu, Sb, Ge, Sn, Ga, Rb, Cs, Sc, Te, Pb, Zn, In, Bi, Ti, Cd) by the LA-ICPMS method of [4] and 10 major and minor elements (by increasing z: Na, Mg, Al, Si, K, Ca, Ti, Cr, Fe) by EMPA in 92 CAIs from CV3 ox, CV3 red, CO, and CR chondrites.

With our 80µm-120µm LA-ICPMS spot size, we have collected either CAI bulk compositional data or compositions of individual melilite, fassaite, and (secondary) anorthite in them.

With our CAI-element database, we will address two issues: First, are there identifiable chemical signatures of secondary alteration and can these be rationally decoupled from primary nebular signatures predicted for moderately volatile elemental concentrations? Second, are there correlations between REE pattern, a known indicator of early thermal history [2], and other moderately volatile and refractory lithophile trace elements?

Chemical Signatures of CAI Alteration: Siderophile and chalcophile elemental abundances in our CAIs are commonly 2-100× higher than might be expected for pure primary nebular condensates [5]. Examples include the trace elements As, Cu, Sb, Ge, Sn, In, Bi, Ti, and Cd; which can be mobilized in aqueous solutions under suitable redox conditions. These trace elements, predicted to condense with Fe alloys or into FeS, were likely transported into CAIs during the aqueous processes known to have affected many CAIs. We will discuss results of investigations of relationships between degree of host-chondrite alteration and contents of the above elements.

Refractory Lithophile Contents: REE abundances in our CAIs range from slightly below 5× CI to greater than 100× CI and contain representatives of Group I, II, III, and V REE patterns [6]. In addition to the REE, we have quantified refractory lithophile trace elements that can be difficult to comprehensively analyze with other microprobe techniques. We will discuss observed and calculated relationships among refractory lithophiles based on volatility, thermal history, and mineral chemistry.

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Introduction: Anthropogenic and microbial contamination of meteorite samples represents a persistent problem in meteorite research, especially with respect to studies performed on meteoritic organic carbon. The Antarctic Meteorite Contamination Study (AMCS) seeks to characterize the extent and effects of these types of contamination [e.g. 1-3] through a three-phase program of study. The three phases are field measurements on newly collected meteorites, meteorite samples immediately following curation, and on other samples from storage. The resulting body of data will track changes in the extent, type, and effects of contaminants from Antarctica, through the curation process, and over time in dry storage. Preliminary results from measurements performed on three samples from the 1977 ANSMET collection season are presented here.

Methods: Three ordinary chondrites collected during the 1977 ANSMET field season were selected on the basis of their mass, high metamorphic grade, and relatively low weathering grade. Ordinary chondrites were chosen primarily for their abundance in order to facilitate collection during the later field study phase. The three samples were divided into meteorite surface and interior portions and stored separately in plasma-cleaned aluminum storage containers. At all times during collection, storage and shipping of the samples, exposure to plastics and plasticizers was minimized. Witness plates were included with the samples and were subsequently analyzed to determine the degree of contamination accrued during sample handling.

Microbial abundance was measured using limulus amoebocyte lysate (LAL) assay, and adenosine triphosphate (ATP) luminometry was used as a measure of microbial metabolic activity. Functional gene analysis of microbe samples was utilized to ascertain the nature of metabolic activity employed by contaminating microbes (e.g. aerobic vs anaerobic). Organic carbon present in the meteorites was characterized using pyrolysis-GC-MS for bulk analysis and ToF-SIMS to add correlating spatial information. Stable isotope analysis of the carbon-bearing phases was also performed, and all data are compared to terrestrial age measurements performed using 14C accelerator mass spectrometry. Data from these measurements will be presented, and when expanded in the larger AMCS study can be used to provide a baseline for a wide variety of studies performed on Antarctic meteorites.

CARBON AND MINERAL PHASE DISTRIBUTION IN INTER-GRAIN SPACES AND INCLUSIONS WITHIN CHONDRULES. M. Fries\textsuperscript{1}, A. Steele\textsuperscript{1}, and T. McCoy\textsuperscript{2}.
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Introduction: Mineral species and reduced carbon have been investigated within chondrule mineral grains and in the inter-grain spaces of porphyritic chondrules using confocal Raman spectroscopy, SEM, and electron probe methods. Imaging Raman is especially useful for this type of research since it can analyze materials embedded within transparent mineral grains such as olivine and pyroxene, and is very sensitive to the presence and structure of carbon. A class of inclusions has been found in CV chondrite chondrules that consists of metal oxide spinels + carbon + void space ± fayalitic olivine ± sulfides ± reduced Fe,Ni (Ni-rich) ± whitlockite. These inclusions are typically \(\approx 10 \mu m\) in diameter and spherical or nearly so, and are distinct from carbon-containing glass inclusions [1]. Examination of inter-grain spaces in porphyritic chondrules reveals the same set of minerals, and both features are surrounded by locally Fe-enriched olivine.

Discussion: Examination of chondrules in the CV3 chondrites Allende, LAP 02206 and QUE 94366 has revealed the consistent occurrence of small inclusions containing the mineral species described above. A search for similar inclusions in the ordinary chondrites EET 96188 (L3.2), GRO 95596 (LL3) and GRO 95658 (LL3) showed that mineral inclusions in these meteorites are commonly glassy inclusions and carbon is uncommon. This suggests a link between the chemical environment for type-specific chondrule formation and the environment for accretion of the meteorite itself. Examination of material filling cracks between olivine grains in a POP chondrule in QUE 94366 was found to consist of the same set of minerals and carbon as the small inclusions. This similarity suggests that the small inclusions and inter-grain material share a common genesis. Since small inclusions tend to contain a larger relative volume of metal oxide spinels than the inter-grain material, it is proposed that the small inclusions are former inter-grain material trapped by olivine grain growth during prolonged heating. The same heating would preferentially drive off the lower melting-point sulfides, carbon, and whitlockite and concentrate spinels.

It is further noted that reduced carbon within the small inclusions occurs in void spaces around their exterior. It has been proposed that carbon played an important role in chondrule reduction [2], and shown that even at low ambient pressures a significant amount of carbon exists as CO and CO\textsubscript{2} gases [3]. The presence of reduced carbon with metal oxides and sulfides concurrently here is explained as the presence of CO/CO\textsubscript{2}-rich gas at high temperature that converted to CO\textsubscript{2} and reduced carbon upon cooling. This provides an explanation for both the co-location of carbon with void space and the concurrent presence of metal oxides and sulfides with reduced carbon.

CARBON AND MINERAL PHASE DISTRIBUTION ON A CV3 DARK INCLUSION BOUNDARY – A CONFOCAL RAMAN IMAGING STUDY. M. Fries¹, A. Steele¹, and A. Ruzicka². ¹Geophysical Laboratory, Carnegie Institution of Washington. E-mail: m.fries@gl.ciw.edu. ²Cascadia Meteorite Laboratory, Portland State University.

Introduction: A large dark inclusion (DI) in the CV3 meteorite NWA 3118 was examined using confocal Raman imaging with an emphasis on the DI-CV matrix boundary. The confocal Raman imaging technique used here is particularly sensitive to the presence and structure of carbon, which provides a set of data not obtainable through SEM, optical microscopy, or other commonly used characterization methods.

Methods: Confocal Raman images were collected across the DI-CV matrix boundary using a WITec α-SNOM with a 532 nm excitation laser operating at an output power of 20 mW prior to entry into the microscope optics. Imagery was collected by rastering the sample under a low magnification (20x) objective lens to produce images with a spatial resolution of 810 nm². Images were produced by selecting spectral features of interest within individual Raman spectra.

Results: Raman data reveals 5-10 µm band of pyroxene along the boundary between the dark inclusion and the CV matrix [1]. The pyroxene is further divided into a high-Mg band on the DI side and a low-Mg band adjacent to the CV matrix. There is also a sulfide-depleted zone on each side, but the sulfides overall do not show a composition difference. Fine-grained olivine in each material, likewise, shows no measurable difference in composition. Hematite is also present in both materials and is relatively depleted at the intersection, but it is unclear if this phase represents native material or terrestrial alteration.

The distribution of carbon in the DI shows a layered appearance that parallels the DI-CV matrix interface. This morphology suggests that DI material was relatively unmixed since formation although it underwent some plastic deformation during incorporation into the meteorite. Raman spectra of reduced carbon contain features that indicate the extent of its graphitic domain component [2]. This parameter shows that carbon in the dark inclusion is demonstrably more graphitic than the adjoining CV matrix, indicating a higher degree of thermal metamorphism. This is consistent with previous observations that dark inclusion material is heavily altered [3] relative to the matrix. Raman measurements made in fresh fractures confirms the more highly graphitic nature of DI carbon.

Discussion: Dark inclusion material exhibits a more extensive history of thermal alteration than adjoining CV matrix material, as evidenced by the micro- and macro-scale morphology of reduced carbon. The depletion of sulfides, with their relatively low melting point, and formation of pyroxene at the interface hint at high temperature processing that is especially prominent on a scale of microns at the DI-CV matrix interface.