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Introduction: Approximately 1/6th of the near-Earth objects (NEOs) are binaries [1]. This is much higher than the proportion of binary objects in the asteroid belt [2]. Since NEO dynamical lifetimes are relatively short (~10⁶-10⁷ years), some active mechanism must be forming new NEO pairs [2]. Proposed formation mechanisms invoke close flybys of the Earth or Venus and involve either tidal disruption [3] or rotational spin-up and disruption [4]. In either case, the parent NEO bodies were either composed of physically weak material (e.g., strengths similar to CI or CM chondrites) or were strengthless rubble piles.

Observational Constraints: If binary NEOs are generated primarily by disaggregation of km-scale NEO parent bodies during close planetary flybys, then the two models of parent body weakness predict different compositional patterns for NEO binaries. If NEO binaries form primarily from physically weak materials, they should be dominantly CM- or CI-type materials. If they form primarily from strengthless rubble piles, one wouldn’t expect any particular compositional preference. We have obtained near-infrared spectra of several NEO binaries, including 1998 ST₂ [5], 2003 YT₁ [6] and (66063) 1998 RO₁ [7]. The first binary NEO studied (1998 ST₂) was identified as a CM-type assemblage supporting the first option. However, subsequently 2003 YT₁ was identified as an HED assemblage, while 1998 RO₁ appears to be a moderately metamorphosed L-chondrite. HED assemblages and L5-like assemblages are not physically weak materials. Thus the current spectral characterizations of binary NEOs suggest that their parent bodies were weak rubble piles.

Implications: Formation of an NEO binary during a close flyby of the Earth would involve at least partial disaggregation of a rubble pile parent body. In addition to the binary object, the process would result in a cloud of meter-sized to 10’s of meters-sized meteoroids in the orbit of the binary. Since the orbital geometry requires that the orbits of the binary and its debris stream intersect the orbit of the Earth, meteorite samples from the binary object’s parent body should be over-represented among falls compared to samples derived from non-binary NEOs. This effect has been previously invoked to account for the limited age distribution of metamorphosed CI & CM chondrites [8].

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EFFECTS OF EXPERIMENTAL SHOCK AND THERMAL METAMORPHISM ON RB-SR AND U-PB ISOTOPE SYSTEMATICS IN A MARE BASALT. A. M. Gaffney¹, L. E. Borg², and Y. Asmerom³ ¹Institute of Meteoritics, Univ. of New Mexico, Albuquerque, NM, 87131. E-mail: agaffney@unm.edu. ²Dept. of Earth and Planetary Sciences, Univ. of New Mexico, Albuquerque, NM, 87131.

Introduction: Many isochrons of Martian and lunar samples show disturbances that may be the result of shock or thermal metamorphism. In order to assign age or petrogenetic significance to isochrons in these samples, it is important to independently understand and evaluate the effects of shock and thermal metamorphism on radiogenic isotope systematics. For this purpose, we have undertaken Rb-Sr and U-Pb analyses of whole rocks, mineral fractions and leachates from experimentally heated or shocked aliquots of lunar sample 10017, and we compare the results to analogous analyses of an unheated and unshocked aliquot of 10017.

Methods: One aliquot of 10017 was experimentally shocked at 55 GPa, a second aliquot was heated in a vacuum at 1000 °C for one week, and a third aliquot was left unheated and unshocked. Mineral and whole rock fractions were leached in cold ~2 N HCl for 10 minutes. Mineral fractions and leachates were purified using standard ion exchange procedures prior to TIMS isotopic analysis.

Results and Discussion: Our previous work on the unshocked and unheated ‘reference’ sample yields concordant Sm-Nd, Rb-Sr and 238U-206Pb ages (weighted average for all 3 systems = 3.612 ± 0.039 Ga). Mineral fractions from the shocked sample lie on these reference isochrons, and yield ages concordant with those for the reference sample. For both the reference and shocked samples, the leachates lie on or close to the Rb-Sr and 238U-206Pb isochrons defined by the leached mineral and whole rock fractions. Shock metamorphism alone appears to have no effect on Rb-Sr and U-Pb isotope systematics.

The whole rock (WR(R)) and whole rock leachate (WR(L)) fractions in the heated sample are disturbed relative to the reference isochrons in both Rb-Sr and U-Pb systems. In both isotope systems, the WR(R) fractions lie to the right of the isochron (consistent with loss of daughter nuclide) and the WR(L) fractions lie to the left of the isochron (consistent with gain of daughter nuclide). The recombined whole rock fractions (leached whole rock + leachate) lie on the isochrons, indicating that the re-distribution of isotopes occurs within a closed system. The plagioclase fractions lie on the reference isochron in the Rb-Sr system, but in the U-Pb system, they have gained radiogenic Pb from some other mineral component or mesostasis, and thus lie above the isochron. In general, the U-Pb system appears to be more susceptible to disturbance during heating than the Rb-Sr system.

The $^{87}$Rb/$^{86}$Sr - $^{87}$Sr/$^{86}$Sr and $^{238}$U/$^{204}$Pb - $^{206}$Pb/$^{204}$Pb compositions of the heated WR(R) and WR(L) fractions relative to the reference isochrons are consistent with increased mobilization of radiogenic components during thermal metamorphism. The radiogenic components may diffuse through crystals to the grain boundaries during heating, from where they may be preferentially incorporated into the leachates. They may diffuse faster relative to the parent or stable isotopes because, a) daughter isotopes reside in lattice sites that have been damaged by radioactive decay of the parent isotope, or b) daughter isotopes may be less compatible in lattice sites formerly occupied by parent isotopes.
**Early Impact Melting and Space Exposure History of the PAT-91501 L-Chondrite.**


**Introduction:** Early collisions among meteorite parent bodies were probably frequent, but little evidence for this exists in chondrites. The only chondritic melt attributable to early shock (known to us) is the Shaw L-chondrite (1). The 8.55 kg PAT91501 L-chondrite is a unique, unshocked, near-total impact melt. It contains vesicles and metal-troilite nodules, is depleted in siderophile and chalcophile elements, and contains only ~10% relic chondritic material (2). PAT91501 crystallized rapidly from a much more homogeneous melt than did Shaw (2), and it likely formed as an impact melt vein within an impact crater. To define the history of PAT, we measured its $^{39}$Ar-$^{40}$Ar age and concentrations of several radioactive and stable nuclides produced during its space exposure to cosmic rays.

**$^{39}$Ar-$^{40}$Ar Age:** The age spectrum shows a peak in age over ~2-20% of the $^{39}$Ar release and a sharp age decrease over the last 20% of the $^{39}$Ar release, which are produced by recoil redistribution of $^{39}$Ar during irradiation. Across 20-80% of the $^{39}$Ar release, 10 extractions define a flat age plateau with an average value of 4.463 ± 0.009 Gyr (1σ). The total Ar age is 4.442 Gyr and suggests little diffusion loss of $^{40}$Ar. This age is similar to the ~4.42 Gyr Ar-Ar age for Shaw (3) and suggests a common impact event. Whether or not the two meteorites are source-crater paired, PAT now provides the second example of a chondrite melted more than 4.4 Gyr ago.

**Cosmogenic Species:** We measured cosmogenic He, Ne, Ar, $^{10}$Be and $^{26}$Al abundances in multiple samples of PAT and found similar values among samples. Average $^{10}$Be is 20.6 dpm/kg and average $^{26}$Al is 60.7 dpm/kg. The $^{22}$Ne/$^{21}$Ne ratio is ~1.09. Comparing the cosmogenic nuclide data to data for some other chondrites and to theoretical production models, we conclude that PAT had a pre-atmospheric radius between 40 cm and 60 cm.

**CRE Age:** To calculate space exposure ages for PAT, we used the cosmogenic production rates for L-chondrites given by Eugster (4), except that the $^{38}$Ar production rate was lowered by 11%. The production rates were corrected for shielding using the measured $^{22}$Ne/$^{21}$Ne ratios. For two analyzed samples, the CRE ages in Myr are: $^{3}$He=28.7 & 28.0, $^{21}$Ne=24.6 & 27.5, $^{38}$Ar=20.6 & 23.1. The observation that the difference among ages calculated from He, Ne, and Ar for a given sample is greater than the difference in the same age between the two samples suggests that most of the apparent variation in CRE age is produced by our choice of production rates. We give greater weight to the $^{3}$He and $^{21}$Ne ages and deduce a CRE age for PAT91501 of 25-29 Myr. Exposure ages based on the $^{26}$Al-$^{21}$Ne-$^{22}$Ne and $^{10}$Be-$^{21}$Ne-$^{22}$Ne equations of Graf et al. (5) are somewhat older at ~28-34 Myr. A CRE age of 25-29 Myr would fall within a CRE age cluster for L-chondrites, whereas an older age would not. Shaw has a much younger, nominal one-stage CRE age of 0.6 My, but may have experienced a longer complex exposure (6).

REAPPRAISAL OF THE CHIBOUGAMAU TILLITE, QUÉBEC, CANADA: TOWARDS A NEW IMPACT STRUCTURE (?). S. Genest, I. Duhamel, and F. Robert. Omégalpha, 539 Route 131, Joliette (Québec), J6E 7Y8, Canada, omegalp@qcaira.com.

Because of an unusual fabric and a poorly constrained sedimentary facies interpretation [1] and of observations done in 1984 by the first author casting doubt on its glacial origin, the paleoproterozoic tillite of the Chibougamau Formation has been revisited in 2003 in order to assess a meteorite impact origin. We report the preliminary results of an ongoing research program dealing with this rock unit.

The outcrops of the Chibougamau Formation, centered at latitude 50°05’N and longitude 74°07’W, are located in the Province of Québec, Canada. The tillite unit, mainly observed within two large bands, shows a wedge shape largely controlled by steep faulting at their southernmost limits. These faults strike SW-NE, parallel to the Grenville Front. The tillite unit rests on an unaltered archean basement and is overlain by proterozoic sediments mainly composed of conglomeratic sandstone. Some clastic dykes have been observed within the basement and are oriented parallel to the faults which control the distribution of the tillite unit. They are filled with immature and poorly sorted, angular to rounded clasts thought to be related to the Chibougamau tillite [2].

The first petrographic results are: 1) no PDFs have been observed yet; 2) partly molten fragments are present; 3) presence of microbreccias surrounding clasts that are within a larger breccia; 4) flow structures; 5) amygdules; and 6) presence of reduced (burned) dolomite clasts. The dolomite clasts observed are thought to be originated from the thick dolomitic unit of the Mistassini Group.

By the present, we postulate that the Chibougamau tillite, instead of being glaciogenic, is better explained as the product of an ejecta blanket owing to an impact event, maybe the one responsible for the shatter cones observed within the stromatolitic dolomite unit of the paleoproterozoic Mistassini Basin which displays a suggestive curved geomorphic pattern.

Further works will encompass field and laboratory studies in order to better characterize the so-called tillite unit, the clastic dykes and the potential extension of the shatter cones area as well. Moreover, since the carbon-rich Chibougamau Formation shows some geological affinities with the Onaping Formation (ejecta of the Sudbury Structure), an attempt will be made to petrographically and chemically compare both units.

DUST-SIZED METEORITE ABLATION DEBRIS AMONGST MICROMETEORITES M. J. Genge and L. Preston. *Impact and Astromaterials Research Centre (IARC), Imperial College London & The Natural History Museum. Exhibition Road, London SW7 2AZ. Email: m.genge@imperial.ac.uk.

Introduction: The discovery of three oxide-bearing coarse-grained olivine particles is reported amongst Antarctic MMs collected from Cap Prudhomme that may represent meteorite ablation debris. Although classified as Type II coarse-grained MMs [1] the particles are shown to have close similarities to oxidized olivine found within the fusion crusts of chondritic meteorites. The presence of meteorite ablation debris amongst MMs is important to consider when evaluating the parent bodies of rare MM types.

Results: Three oxide-bearing olivine particles were discovered amongst a total of 518 MMs and are distinct from the majority of coarse-grained MMs (MMs dominated by pyroxene and/or pyroxene often within glass with crystal-sizes >4 µm) suggesting they might have a different origin to other particles.

Oxide-bearing olivine particles: All three oxide-bearing olivine (OBO) particles consist of an oxide-free fayalitic olivine core surrounded by a rim containing small (<6 µm) subhedral to euhedral magnetite-maghemite inclusions contained within more magnesian olivine. The oxides become larger and less abundant with distance from the core of the particle suggesting their growth by Ostwald ripening.

Two of the particles (69, 133) include aluminosilicate glass as small selvages along the outside of the particles. Aluminosilicate glass, together with iron-oxides, is also found within veins through the core of particle 133. In addition to glass, particle 69 has a thin (8 µm) rim of oxide-free olivine between the oxide-bearing olivine rim and the glass. Both particles have poorly-developed magnetite rims.

Oxide-bearing olivine in fusion crusts: Similar oxide-bearing olivine grains were noted by Genge and Grady [2] in the fusion crusts of chondritic meteorites. In the current study sufficiently coarse-grained OBO grains were found in 13 out of 47 examined chondrite fusion crusts, including oxidized CV3, CK4, LL3-6, L6 and H5 chondrites. No OBO grains were observed within reduced CV, CI, CM or Enstatite Chondrite fusion crusts.

The textures of OBO grains within fusion crusts are very similar to those found among MMs since they often have an oxide-free core surrounded by a rim of more Mg-rich olivine with iron-oxide inclusions that become coarser-grained but less abundant outwards. Within fusion crusts, however, OBOs usually are associated with an outermost oxide-free rim and many do not retain an oxide-free core. In equilibrated meteorites, oxide-free cores have compositions identical to those within the core of the meteorite.

Discussion: Oxide-bearing olivine grains are suggested here to form by oxidation of Fe$^{2+}$ within the olivine lattice and precipitation of magnetite-maghemite during entry heating. This probably varies with altitude and oxidation state of the meteorite. The reported OBO grains among MMs have compositions consistent with equilibrated L and LL chondrites.

Martian meteorites record the aqueous history of Mars. Oxygen isotopic compositions in ALH84001, with its 4.5 Gyr crystallization age and 3.9 Gyr secondary carbonates, show the planet had at least two separate oxygen reservoirs. The unique oxygen isotopic record in the silicates and secondary carbonates in ALH84001 indicates that for the first 600 Myr, the two reservoirs remained separate and suggests the lack of plate tectonics on Mars. We postulate that oxygen within the secondary phases was either added to the planet by a veneer or by cometary infall shortly after formation of Mars’ crust. As the planet evolved from having a warm-wet early history to the cold-dry planetary body, post 3.9 Gyr, significant water loss occurred, confirmed by increased D/H isotopic ratios.

Water reservoirs within 1 to 2 km of the surface resided on Mars during the Hesperian and Amazonian periods. Evidence of these water-rich environments is observed in the 1.3 Gyr Nakhliites and their secondary aqueous alteration weathering products. Nakhla has an abundance of secondary phases (i.e., hydrates, carbonates, sulfates, halites, clays etc) which demonstrate the near-surface abundance of water within the Martian crust around 600-700 Myr ago. The Shergottites show the presence of aqueous alteration processes during the past 165 Myr. Lafayette’s oxygen reservoirs within the silicates and secondary weathering phases continue to show the two distinct oxygen reservoirs.

The Martian meteorites record a unique planetary record of distinct oxygen reservoirs between the silicates and the secondary aqueous alteration phases. Despite the petrographic record of apparent low-water abundances for the SNC meteorites, ample evidence exists for aqueous processes operating near the surface of Mars. Images returned from the Mars orbiters and landers show the abundance of surface features whose origins must be associated with aqueous or fluid processes. Abundance of near-surface salts at the five Martian sites visited by landed spacecraft along with the pre-terrestrial aqueous alteration products within the SNC meteorites shows the presence of near-surface water within the planet’s outer crust. The MEX orbiter’s observations of methane within the Martian atmosphere which directly correlates with water abundances hint at the possibility of unique aqueous and/or biological processes operating on Mars today.
MINERALOGY AND FORMATION OF A POROUS, DARK XENOLITH WITHIN THE KRYMKA (L13.1) CHONDRITE.

A. L. Girich\textsuperscript{1}, V. P. Semenenko\textsuperscript{1}, A. Bischoff\textsuperscript{2}, and N. V. Kyichan\textsuperscript{1}.

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The unusual Krymka xenolith BK17 (1.1 x 0.9 mm in apparent size) is characterized by a dark appearance, fine-grained texture, the presence of magnetite, and the absence of sulfides. The xenolith is surrounded by a finer-grained, denser silicate rim. The fine-grained porous groundmass consists of micron- to submicron-sized round and anhedral grains mainly of olivine Fa\textsubscript{15.1-34.6} (mean Fa\textsubscript{21.5} \pm 6.9), \sim 5 vol.\% of magnetite, and rare metal and Ca-pyroxene. Accessory phases include phosphate (merrillite) and chromite. In most cases magnetite forms irregular clusters (up to 30 \textmu m) of anhedral grains. Coarse grains (5-20 \textmu m in size) of olivine Fa\textsubscript{5.8-17.0} (mean Fa\textsubscript{9.1} \pm 3.4) and rare Ca-pyroxene \textasciitilde{FS}\textsubscript{9.0}En\textsubscript{66.1}Wo\textsubscript{24.9} are present. Most olivine grains are zoned having Fe-enriched rims.

BK17 contains coarse-grained polymineralic constituents (up to 200 \textmu m in size) composed of subhedral and skeletal crystals of Ca-pyroxene (Fs\textsubscript{7.2-13.4}En\textsubscript{61.4-66.6}Wo\textsubscript{24.3-26.8}; up to 20 \textmu m in size) arranged predominantly on a periphery of the associations, clusters of fine grained magnetite, irregular grains of Ni-rich metal, and accessory phosphate and chromite. Metal grains have indented edges and contain lot of tiny inclusions. In addition, the xenolith contains less porous, fine-grained areas and curved bands. Some of these areas are enriched in magnetite up to 12 vol.\%. Similar enrichments of tiny magnetites were found in some groundmass areas that appear to have been molten. A probable genetic relationship between these two magnetite-rich areas is suggested.

The bulk composition of BK17, as measured by electron microprobe (defocussed beam), has a low total (84.1 wt.\%), certainly due to a high porosity and a high magnetite abundance. The SiO\textsubscript{2}/MgO ratio (1.89) is remarkably lower than that of BK17 rim (2.33) and somewhat higher than that of bulk compositions from known types of chondrites.

Conclusions: Mineralogical and chemical features allow to suggest that the xenolith BK17 is a primary rock different from the Krymka host, matrix, and other xenoliths [1-4]. Before the accretion of the Krymka parent body this xenolith was subsequently coated by finer-grained dust, that resulted in formation of a denser silicate rim. The paucity of Fe,Ni metal and the high abundance of magnetite testify the highly oxidizing conditions during the formation of BK17.

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I first heard of tektites when I took Brian Mason’s geochemistry course in 1965. Shortly thereafter, I found some glass beads, which I concluded must be microtektites related to the Australasian tektites, in five sediment cores from the Indian Ocean [1]. I then searched for and found Ivory Coast microtektites in cores from the eastern equatorial Atlantic Ocean [2]. Bill Cassidy obtained some compositional data, which helped confirm the identification of the microtektites [e.g., 3]. After this, I searched for North American (N.A.) microtektites, but before I could find them, Donnelly and Chao [4] reported finding them in an upper Eocene sediment core from the Caribbean Sea. Using biostratigraphic data from that core, we were able to find the N.A. microtektite layer in additional cores. We then discovered clinopyroxene-bearing (cpx) spherules associated with the N.A. microtektites. This layer was found to be associated with an Ir anomaly [5] and with the extinction of several radiolarian taxa. We traced the cpx spherule layer across the equatorial Pacific Ocean and into the eastern equatorial Indian Ocean. We first thought that the N.A. strewn field extended across the Pacific Ocean and into the Indian Ocean, but we later concluded that the cpx spherules belong to an older event. N.A. microtektites were then discovered in marine sediments on Barbados [6], and, so far, this is the only place where microtektites have been found on land. Because some authors referred to the upper Eocene cpx spherules and crystalline spherules at the Cretaceous-Tertiary boundary as microtektites, we realized the need for another term for impact spherules which had partly crystallized; we called such spherules microkrystites [7]. In 1987, Jean Thein reported finding an 8-cm-thick layer of N.A. tektite fragments, microtektites, and shocked mineral grains in a core from the NW Atlantic off New Jersey [8]. As a result of this discovery, we searched for and found shocked quartz, coesite, and stishovite at the other N.A. microtektite-bearing sites and in the Australasian microtektite layer. Later, we found, in the N.A. microtektite layer, shocked zircons containing a high-pressure zircon polymorph, which we named reidite [9]. Although some authors have proposed numerous upper Eocene microtektite/spherule layers, today most authors agree that there are only two: 1) the cpx spherule layer (from the Popigai impact crater); and 2) the slightly younger N.A. microtektite layer (from the Chesapeake Bay impact crater). Searches for microtektites belonging to the Central European tektite strewn field have, so far, been fruitless. As of 2005, Australasian microtektites have been found in ~50 cores. Data from these cores suggest that the source crater may be ~43 ± 9 km in diameter and may be in N. Vietnam or in the Gulf of Tonkin.

THE COOLING HISTORY OF METEORITIC METAL
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Introduction: Metal is present in all types of meteorites and
is composed of Fe, Ni and Co, sometimes with additional ele-
ments such as P, S, and C. The metal microstructure is often
quite complex and may contain kamacite, tetrataenite, a spinodal
–cloudy zone, decomposed martensite - plessite, etc. An under-
standing of the development of the microstructure of meteoritic
metal can lead to insights into the cooling history of chondrites,
pallasites, mesosiderites, irons, etc. This paper discusses how the
presence or absence of P influences the microstructure of metal,
outlines recent advances in the development of the metal-
lographic cooling rate method, and indicates new areas where
the study of metal (for example metal in CH chondrites) leads to
new insights into the cooling history of meteorites.

Metal microstructure: Experimentally it has been observed
that P is necessary for the formation of the Widmanstatten pat-
tern [1,2]. In binary Fe-Ni alloys, analogous to P free metal in
ordinary chondrites, kamacite (α) only forms on grain boundaries
during the cooling process [3]. In ordinary chondrites, taenite (γ)
grain boundaries formed during metamorphism and are the sites
for kamacite formation [4]. Zoneless plessite, for example, con-
tains no exsolved kamacite due to its formation as single crystal
taenite at high temperatures [4]. In chondrites, Fe and Ni are
mobile on metal – silicate boundaries and on taenite grain
boundaries allowing apparently isolated taenite and kamacite
grains to remain in contact. The Widmanstatten pattern on the
other hand only forms in iron meteorites due to the presence of P
and will only nucleate as the meteorite enters the α + γ + Ph
(phosphide) phase field in the Fe-Ni-P phase diagram [5]. Nu-
cleation temperatures of ~ 100°C below those given by the Fe-Ni
phase diagram are explained by the presence of P. Recent stud-
ies of the formation of plessite in meteoritic metal by electron
backscatter diffraction (EBSD) techniques [6] have shown that
taenite is retained during the cooling process as martensite nucle-
ates and then dissociates at lower temperatures.

Metallographic Cooling Rate Method: Updated diffusion
coefficients [7] and nucleation temperatures for the formation of
kamacite [5] during cooling have led to more robust and more
accurate cooling rate modeling. New cooling rates for the IVA
and IIIAB irons have been established using the Wood method
[8] showing non-constant cooling rates through these presumed
cores of asteroidal bodies.

Summary: The study of meteoritic metal continues to give
insight to the cooling history of meteorites and their parent bod-
ies.

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R. The formation of plessite in meteoritic metal (abstract) Me-
2004. Metallurgical and Materials Transactions 35A: 1681-
THE FORMATION OF PLESSITE IN METEORITIC METAL
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The formation mechanism of plessite in the metal regions of meteorites was studied using electron backscatter diffraction (EBSD) analysis. The measurement of the orientation of α bcc kamacite and γ fcc taenite, over large regions of the plessite microstructure, was obtained by EBSD for five IVB irons, the Carlton IAB-IIICD iron and zoneless plessite metal in the Kernouve H6 chondrite. The microstructure of the IVB irons is essentially all plessite except for the presence of a few kamacite plates or spindles.

There are a number of different orientations of the bcc kamacite phase in the plessite microstructure. These orientations reflect the reaction path γ (fcc) → α2 (bcc) in which the α2 phase forms on the close packed planes of the parent fcc phase according to one or more of the established orientation relationships (Kurdjumov-Sachs (K-S), Nishiyama-Wasserman (N-W) and Greninger–Troiano (G-T)) for the fcc to bcc transformation.

The orientation of γ fcc taenite-tetraenite at the interfaces of martensite α2 laths is the same across the entire plessite structure, and is the same as the original taenite single crystal of the meteorite. Therefore the γ fcc taenite, the high temperature parent single crystal metal, was retained during cooling of the parent meteorite as martensite develops according the mechanism, γ → α2+γ → α+γ [1]. This mechanism is applicable for duplex and black plessite of ~10 to ~18 wt% Ni and is generally applicable to plessite formation in iron, stony-iron and chondritic metal. The EBSD orientation data is inconsistent with the reaction mechanism, γ → α2 → α + γ, the classical formulation proposed for Type III plessite [2].

The microstructure of high P IVB ataxites is consistent with the formation mechanism proposed by Yang and Goldstein [1], γ → γ+Ph → α+γ+Ph, while the microstructure of low P IVB ataxites is consistent with the formation mechanism for low P IVB irons proposed by Yang and Goldstein [1], γ → (α+γ) → α+γ+Ph.

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LABORATORY SIMULATION OF TERRESTRIAL METEORITE WEATHERING. S. H. Gordon\textsuperscript{1}, M. R. Lee\textsuperscript{2}, C. L. Smith\textsuperscript{2}\textsuperscript{*} and M. E. Hodson\textsuperscript{1}. \textsuperscript{1}Department of Earth Science and Engineering, South Kensington Campus, Imperial College, London, U.K. \textsuperscript{2}Department of Geographical and Earth Sciences, University of Glasgow, Glasgow G12 8QQ. \textsuperscript{*}Dept. of Soil Science, The University of Reading, Whiteknights, Reading, RG6 6AB, UK. *Present address: Department of Mineralogy, The Natural History Museum, Cromwell Road, London, SW7 5BD, U.K.

**Introduction:** Terrestrial weathering of meteorite finds is a very important but a relatively poorly understood process. Thus far, studies have been limited to the investigation of rates of accumulation of weathering products or changes in bulk isotopic compositions of finds of known terrestrial age [1-5]. These studies have shown the even in arid climates, ordinary chondrites weather rapidly with production of Fe-oxyhydroxides, sulphates and carbonates. We have, for the first time, used solution chemistry experiments in combination with detailed mineralogical and petrographic investigation to study the effects of laboratory weathering on an ordinary chondrite.

**Method:** Samples of the LL6 chondrite Bensour (probable fall, Morocco/Algeria, February 2002 [6]) were used in batch dissolution experiments, employing DI water at room T for 68 days. Solute concentrations, measured by ICP-OES, were used to calculate relative dissolution rates of primary minerals. Electron probe microanalysis was used to determine the chemical compositions of primary minerals and the petrography and mineralogy of unweathered and weathered samples was studied by FEG-SEM coupled with EDS.

**Results:** Solute analyses reveal the presence of Na, Mg, Al, Si, K and Ca. The Na, K and Ca are present in greater concentrations, relative to Mg or Si, than would be expected given the olivine- and orthopyroxene-dominated mineralogy of Bensour. This suggests that Na- and Ca-rich silicates (feldspar and clinopyroxene) may dissolve more rapidly than the Mg-rich silicates (olivine and orthopyroxene), which contradicts previous work [7]. High-resolution SEM shows the presence of etch pits in clinopyroxene, and Fe-oxyhydroxide and Mg-silicate (phyllosilicate) coatings on grain surfaces, supporting results of solution modeling, which indicates that a variety of reaction products may have formed.

**Conclusion:** The composition of solutions generated experimentally are likely to be controlled by a combination of the dissolution kinetics of the primary silicate phases and the precipitation of reaction products. These results have important implications as they show that appreciable weathering occurs even over a short time period (tens of days). The formation of reaction products, such as phyllosilicates, is particularly significant given the importance of these minerals as an indicator of parent body aqueous alteration e.g. carbonaceous chondrites and Nakhlites.

PRODUCTION OF SHORT-LIVED NUCLIDES BY SOLAR ENERGETIC PARTICLES: THE KEY PARAMETERS. J. N. Goswami, Physical Research Laboratory, Ahmedabad 380054, India. E-mail: goswami@prl.ernet.in

The short-lived nuclides with half-life less than a couple of million years (\(^{41}\)Ca, \(^{36}\)Cl, \(^{26}\)Al, \(^{10}\)Be and \(^{60}\)Fe), whose presence in the early solar system has been inferred from meteorite data, must had been produced either shortly before or during the very early evolution of the solar system. A local production of these nuclides due to interactions of solar energetic particles (SEP) with nebular material has been proposed. This proposal has been strengthened by the presence of the short-lived nuclide \(^{10}\)Be in the early solar system. Beryllium-10 is a product of energetic particle interactions. The other short-lived nuclides, with the exception of \(^{60}\)Fe, can also be products of energetic particle interactions.

In the local production scenario, Sun is considered as the source of the energetic particles. The key parameters in this scenario are: (i) irradiation setting and duration, (ii) composition and intensity of solar energetic particles (SEP), (iii) composition and the nature of the targets and (iv) cross-sections of nuclear reactions of interest.

Two broad irradiation settings have been proposed. In the conventional scenario, the SEP irradiation is considered to have taken place within the inner solar system and parameters such as the SEP flux, irradiation durations, nebular shielding are considered as free parameters. On the other hand, in the X-wind irradiation scenario, the SEP irradiation took place very close to the Sun and the irradiation duration is constrained by the model parameters. Further, the SEP are considered to be dominated by impulsive flares with extremely high \(^{3}\)He abundance in this model. The target composition generally considered in both the scenarios are either solar (CI) or refractory (CAI) in nature, although the details differ. The reaction cross sections are fairly well known for most of the pertinent nuclear reactions, with the sole exception of \(^{3}\)He induced reactions, a crucial parameter for production calculations in the X-wind irradiation model.

An overview of our present understanding of these key parameters will be presented along with their impact on the various model predictions.
IRRADIATION PROCESSES IN EARLY SOLAR SYSTEM: A REVIEW. M. Gounelle1,2. 1CSNSM-Université Paris XI, Bâtiment 104, 91 405 Orsay Campus, France. 2Department of Mineralogy, The Natural History Museum, London SW7 5BD, UK (gounelle@csnsm.in2p3.fr).

It has long been recognized that irradiation by energetic particles could have played an important role in the Solar System formation and evolution [1]. Early Solar System irradiation processes can have synthetized light stable isotopes (D, Li, Be, B) [1], short-lived radioactivities such as 10Be ($T_{1/2} = 1.5$ Ma) or 26Al ($T_{1/2} = 0.74$ Ma) [2], but can also account for 21Ne excesses in carbonaceous chondrites olivine grains [3] or for large oxygen isotopic anomalies found recently in the Murchison carbonaceous chondrites [4]. The interest for irradiation processes in early Solar System has recently been boosted by two important findings.

First, X-ray observations of protostars has revealed an ubiquitous, variable, flare-like, enhanced X-ray activity relative to the present Sun ($x 10^4$) [5]. Translated in terms of energetic proton fluences, it represents an enhancement factor of $10^4$ relative to the present Sun [6, 7]. This enhancement is large enough to produce short-lived radioactivities abundances comparable to what is observed in the early Solar System [8, 9]. X-ray observations of protostars will be discussed in a talk by E. Feigelson [7].

Second, it has recently been shown that 10Be [10] and possibly 7Be ($T_{1/2} = 53$ days) [11] were alive when Calcium-Aluminium-rich Inclusions of carbonaceous chondrites formed. Because beryllium radioactive isotopes cannot be made in stars, these findings have been interpreted as an unambiguous evidence for early Solar System irradiation [10, 12, 13]. This view has however recently been challenged for 10Be that could have originated from Galactic Cosmic Ray trapping in the progenitor molecular cloud core [14].

In this paper, we will present all the implications of a possible early Solar System irradiation, focusing on the important problem of the origin of short-lived radionuclides. We will discuss the key issue of the initial abundance of short-lived radionuclides such as 26Al [15] and 41Ca ($T_{1/2} = 0.1$ Ma) [16]. In light of these new data, we will critically present the models exploring the irradiation origin of some short-lived radionuclides [12, 13, 17, 18].

AQUEOUS ALTERATION OF NAKHLITES: IMPLICATIONS FOR WATER ON MARS. Monica M. Grady1, M. Anand2, J. C. Bridges1, V. K. Pearson1, I. A. Franchi1 and I. P. Wright1. 1Planetary and Space Sciences Research Institute, The Open University, Walton Hall, Milton Keynes MK7 6AA, UK; 2Dept. Mineralogy, The Natural History Museum, Cromwell Road, London SW7 5BD, UK. E-Mail: m.m.grady@open.ac.uk.

Introduction: The nakhlites are all clinopyroxenites that vary mainly in grain size rather than composition. They are almost unshocked rocks that formed at or near the Martian surface in a slowly-cooled, thick cumulate pile, with the various members of the group thought to be derived from different depths within the intrusion [1]. The rocks bear traces of low temperature aqueous processes that can be used to infer conditions on the Martian surface. The meteorites have been altered by weathering, leading to the production of secondary minerals associated with which are low concentrations of Martian organic material [2, 3]. There are at least two populations of martian weathering products within nakhlites: (1) ‘clay minerals’ formed in situ within olivines, by the alteration and hydration of silicates and (2) precipitation of carbonates and sulphates within cracks.

Several parameters have been employed to infer a differential alteration sequence amongst the nakhlites. Bridges and Grady [2] modelled an evaporation sequence on the basis of mineral assemblages. Mikouchi et al. [4] used olivine core and rim compositions to deduce a depth of crystallisation within the nakhlite magma pile. We have taken these two models, and applied them to the seven currently known nakhlites, in order to determine whereabouts in the cumulate sequence the meteorites fit. Specifically, we are looking at the modal abundance of clay minerals (determined by phase mapping using SEM) and the abundance and isotopic composition of carbonates (determined by acid dissolution and mass spectrometry). We are testing the hypothesis that the clay minerals and carbonates formed from two separate fluid reservoirs. Carbonates were produced by surface waters in contact with the atmosphere percolating down through the magma pile, and clay minerals were produced by melted ground water circulating at depth. If the hypothesis is correct, then there might be opposing gradients in alteration product abundance, with carbonate abundance decreasing down the pile, and clay mineral abundance increasing.

Our first result concerns MIL 03346, which has the least equilibrated of all nakhlite olivines [5]. If equilibration is a marker for depth within the cumulate pile [1, 4], then MIL 03346 must derive from the outermost edge of the intrusion, perhaps even a chilled margin. MIL 03346 seems to contain only sparse carbonates (< 5 ppm), although its olivine grains are broken by clay veinlets. It is possible that the outer edge that MIL 03346 represents is of the bottom of the intrusion, and not the top.

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CHLORINE-RICH APATITES IN SNC’S: EVIDENCE FOR MAGMA-BRINE INTERACTIONS ON MARS? J. P. Greenwood, Earth & Environmental Sciences Dept., Wesleyan University, Middletown, CT 06459 USA jgreenwood@wesleyan.edu

Chlorine-rich apatites are ubiquitous in Martian meteorites. Chlorapatite is rare on Earth, as fluorapatite is the dominant phosphate phase in terrestrial igneous rocks. Recent work suggests that the chlorapatite of the Stillwater and Bushveld Intrusions results from the interactions of magma and briny fluids [1]. Due to the partitioning of F/Cl in magmatic systems, there is not a simple mechanism for forming chlorapatites without the addition of a Cl-rich component. I propose that all SNC’s that contain chlorapatite formed from interactions of SNC parent magmas with subsurface brines on Mars. If true, one must question our basic assumptions regarding Martian geochemistry, as derived from the study of SNC meteorites. For example, high D/H in chlorapatites [e.g. 2] may not be magmatic values, but a signature of the briny fluid. Theories on the chemical composition of the Martian mantle, as derived from the chemical composition of SNC’s [e.g. 3], need to be re-evaluated in light of the interactions of SNC parent magmas with brines. Partitioning studies of trace elements between Fe-rich SNC-type magmas and saline fluids are needed to properly evaluate the role of brines in Martian magmatic systems.


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Introduction: The solar wind (SW) is the major source of information to study the solar composition of volatile elements. It provides insights about the Sun’s present state, its evolution and the composition of the proto-solar nebula. SW noble gases can be used to study processes causing fractionation between the Sun and the SW. Moreover, they are useful to determine compositional variations for distinct SW energy regimes including the high energy SEP component apparently abundant in lunar samples [1]. We will present noble gas data collected on Genesis [2] with a bulk metallic glass target (BMG) [3].

Experiment: The BMG plate was exposed during the entire SW collecting period of 884 days. So far, extensive X-ray photoelectron spectroscopy (XPS) analyses were carried out on the BMG to determine the thickness and composition of surface contamination ubiquitous on Genesis targets. For qualitative information XPS energy scans (0–1200 eV) were measured on 90 spots (ø = 100 µm). On areas revealing most intense contamination signals tilt angle measurements were done to determine the thickness.

Noble gases will be released by pyrolysis of the BMG at about 1300 °C and by closed system stepwise etching (CSSE) [4]. This depth resolving technique allows us to distinguish noble gases related to the SW from ions implanted at higher energies (SEP) and thus implanted to larger depth.

Results: The XPS data show that contamination is omnipresent on the BMG surface. The major contaminant is a polymerized organic layer mainly consisting of Si, C, O, N and minor F. Its signals are highest close to the holes used for screws to mount the BMG. This supports the idea that the organic layer is related to glue the screws of the BMG were fixed with. However, since the BMG element Zr is always visible in the XPS spectra, contamination at the measured spots is very unlikely to be thicker than 10 nm (max. depth resolution of XPS used for this study). If the organic layer has been deposited homogeneously on the surface, which we expect after extensive XPS survey, then this layer would not have influenced the noble gas trapping noticeably. Minor elements as Mg stem from soil particles of the Utah desert.

Overall, XPS analyses and microscopic studies indicate that the BMG is suitable for precise noble gas analysis. Noble gas results will be discussed at the conference.

WHAT ARE THE PETROLOGIC TYPES OF THERMALLY METAMORPHOSED CM CHONDRITES?

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Introduction: Unequilibrated ordinary and CO chondrites can be placed in a metamorphic sequence, ranging from type 3.0 to 3.9. At the low end of this scale, chromite exsolved from ferroan olivine (Fa₂₅) grains due to light heating. The progress of this reaction is a good indicator of metamorphic changes between type 3.0 and 3.2 [1]. The same effect has been observed in lightly metamorphosed CV [1] and enstatite [2] chondrites.

A small number of CM- and CI-like chondrites show effects of thermal metamorphism [3-4]. These have experienced textural integration, loss of volatile and mobile trace elements, and dehydration reactions consistent with peak metamorphic temperatures of up to 500-600°C, similar to temperatures inferred for ordinary chondrites of petrologic type 3.4-3.6. Here, we examine the mineral chemistry of ferroan olivine in metamorphosed CM-like meteorites in order to compare them to the relatively well-studied ordinary and CO chondrites.

Method: CM chondrites showing a wide range of aqueous alteration as well as metamorphic effects were analyzed: A-881655, B-7904, WIS 91600, PCA 91008, and Y-793321 (metamorphosed); Mighei, Murchison, Murray, QUE 93005, 97990, and 99355 (unmetamorphosed, variably altered). Fifty randomly selected ferroan olivines were analyzed by electron microprobe in each (only 6 were found in QUE 93005).

Results and discussion: Ferroan olivine in unmetamorphosed CMs is uniformly rich in Cr, with mean compositions in individual chondrites ranging from 0.28±0.10 to 0.38±0.10 wt% Cr₂O₃, independent of degree of aqueous alteration. Compositions are similar to those in CO3.0 chondrites, and lower than those in type 3.0 ordinary chondrites. Using the scales defined for the other chondrite groups, these CMs would all be designated type 3.0. Two metamorphosed CMs have lower Cr in olivine than unmetamorphosed group members: B-7904 and Y-793321 have means of 0.19±0.08 and 0.23±0.10 wt% Cr₂O₃, respectively, whereas WIS 91600 and PCA 91008 are indistinguishable from normal CMs. Using a similar scale to that for ordinary chondrites, B-7904 and Y-793321 would be classified as type 3.1, while the other two would be type 3.0. A-881655 has anomalously Mn-rich olivine compositions, probably formed during dehydration of phyllosilicates.

Petrologic types inferred from olivine in metamorphosed CMs do not agree with the high metamorphic temperatures inferred from chemistry and other mineralogical properties. Either the temperature-time history was very different than in similarly heated ordinary and CO chondrites, the chemistry of olivine (e.g., Cr site occupancy or oxidation state) was different, the high abundances of C and H₂O affected the rate of exsolution of chromite from olivine, or these did not have CM chondrite protoliths.

OXYGEN ISOTOPES AND ORIGIN OF OPAQUE ASSEMBLAGES IN CARBONACEOUS CHONDRITES.
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Introduction: Opaque assemblages (OAs), also called Fremdlinges, are complex objects that normally contain Fe-Ni metals, magnetite, sulfides, phosphates, silicates, PGE-metal nuggets and their oxides. OAs occur in Ca-Al-rich inclusions (CAIs), chondrules, and matrix of carbonaceous chondrites [1-9]. The unique and complex mineral components of OAs indicate that they formed at a wide temperature range and under highly variable redox conditions [1]. O isotopes of OAs, unavailable until now, can help constrain the origin of these objects and provide insight into early solar system processes.

The morphology, texture, and mineralogy of OAs (~100 to ~350 µm in size) from the Ningqiang carbonaceous chondrite were previously described in [9]. In situ O isotopic compositions were obtained for 12 magnetite and 1 whitlockite grains from 5 Ningqiang OAs. Eight olivine grains adjacent to the OAs were also analyzed. O isotopic compositions of magnetite show variations both among OAs (~16‰ in δ¹⁸O) and within one OA (~9‰ in δ¹⁸O) located inside of a compound olivine chondrule. All the OA magnetite data fall along a regression line with a slope of 0.52 and Δ¹⁷O = -2.9‰, which is intriguingly identical to the Allende Mass Fractionation (AFM) line [10]. The whitlockite grain, as well as the magnetite from FeNi-sulfide-magnetite inclusions in Ningqiang chondrules [11], falls on the OA magnetite regression line as well. O isotopic heterogeneity exists in olivine grains within and among chondrules. The olivine data plot below the magnetite regression line but above the carbonaceous chondrite anhydrous mineral (CCAM) line. Magnetite has higher Δ¹⁷O values than its adjacent olivine. In the OA of a compound olivine chondrule, the average Δ¹⁷O of magnetite is (-2.7±0.5)‰, much higher than that of adjacent olivine (-6.1±0.5)‰.

It has been proposed that OAs could have formed by: 1) direct nebular condensation [2-4], 2) crystallization from immiscible metallic-sulfide-oxide liquids during CAI and chondrule formation [6, 7], and 3) low temperature oxidation of preexisting metal alloys [7, 8]. The O isotopic compositions of OAs in chondrules and matrix from Ningqiang present conclusive evidence that OAs formed by aqueous alteration of metal alloy precursors on parent bodies. Therefore, OAs do not represent the oldest solids in the solar nebula, instead, they provide constraints on secondary processes on asteroidal bodies.

ACCRETION OF DIFFERENTIATED ASTEROIDS — BEFORE, DURING OR AFTER CHONDRULE FORMATION?  H. Haack1, J. A. Baker2, and M. Bizzarro1,3

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Introduction: Mg-26 anomalies in CAIs, HEDs, mesosiderites, and angrites suggest that achondrites are fragments of asteroids that differentiated approximately 3 My after CAI formation[1,2]. Since chondrules probably formed until about 2 My after CAI formation there is only a time span of 1 My to accrete, heat and differentiate unless the achondrite parent bodies accreted before the chondrite parent bodies. Using reasonable assumptions regarding the initial abundance of 26Al and 60Fe we have modeled the early thermal evolution of differentiated asteroids in order to constrain their accretion times and sizes.

Heat sources: Assuming homogenous distribution of 26Al, asteroids accreting early enough may have been heated to the point of differentiation solely by 26Al decay. The δ26Mg in mantle and crustal samples not only constrain the timing of differentiation but also constrains the amount of 26Al decay since CAI formation and thus the maximum amount of heating possible due to 26Al. Furthermore, 60Ni anomalies in troilite suggest that 60Fe was also present at the time of accretion [3].

Differentiation of achondrites: Differentiation concentrates Al in the crust and therefore results in a positive δ26Mg for the crust and a negative δ26Mg for the mantle relative to average Solar system - if 26Al was present at the time of melting. Mg-26 excesses in eucrites, angrites, and basaltic clasts in mesosiderites suggest differentiation between 2.6 and 3.3 My after CAIs[2].

Results: We find that an asteroid differentiating between 2.6 and 3.3 My after CAI formation must have accreted between 0.75 and 1.3 My after CAI formation for an initial 60Fe/56Fe ratio of 0.0 and 4.0e-6 respectively. A later accretion time would require faster heating, which could be accomplished with a higher initial 60Fe/56Fe ratio or an additional heat source. We consider this highly unlike as the highest 60Fe/56Fe ratio we used of 4e-6 is already 4 times higher than the measured ratio [3] and no other viable heat source is known to exist. We therefore conclude that the achondrite parent bodies accreted while chondrules, now found in chondrites, were still forming and therefore that the accretion of achondrite parent bodies predate accretion of chondrite parent bodies.

The early accretion not only explains why the differentiated asteroids melted whereas the chondrite parent bodies escaped melting it also suggest that the differentiated asteroids formed from solids forming earlier than most of the solids represented in chondrites. We find that asteroids with a minimum radius of 10 km in radius can be heated sufficiently to differentiate. It is possible that smaller asteroids could heat sufficiently if their initial porosity was higher thus resulting in a lower thermal conductivity. This would, however, not change the heating time prior to formation of the crust.

THORIUM ABUNDANCES AT LUNAR RED SPOTS: IMPLICATIONS FOR GEOCHEMICALLY EVOLVED, NON-MARE VOLCANISM ON THE MOON. J. J. Hagerty¹, D. J. Lawrence¹, B. R. Hawke², D. T. Vaniman¹, R. C. Elphic¹, and W. C. Feldman¹. ¹Los Alamos National Laboratory, MS D466, Los Alamos, NM 87545. E-mail: jhagerty@lanl.gov. ²Hawaii Institute of Geophysics and Planetology, Honolulu, HI 96822.

Introduction: Lunar red spots are features on the nearside of the Moon characterized by high albedo and strong absorption in the ultraviolet [1]. These red spots include the Gruithuisen domes, the Mairan domes, Hansteen Alpha, the southern portion of Montes Riphaeus, Darney Chi and Tau, Helmet, and an area near Lassell crater [2]. Several workers have used morphologic evidence to suggest that many of the red spots are extrusive, non-mare volcanic features that could be composed of Th-rich lithologies [2, 3]. However, the initial results from the Lunar Prospector Gamma Ray Spectrometer showed that the apparent Th abundances for the red spots were not consistent with Th-rich rock, which led Hawke et al. [3] to conclude that the red spots are composed an unknown rock type. Subsequent studies by Lawrence et al. [4, 5] used improved knowledge of the Th spatial distribution for small features on the lunar surface to revisit the interpretation of Th abundances for features considerably smaller than the instrument footprint. Lawrence et al. [4, 5] and Hagerty et al. [6, 7] used the improved Th dataset, in conjunction with forward modeling techniques, to show that the Th abundances of several lunar red spots are much higher than previously proposed (i.e., > 25 ppm Th). These high Th values are consistent with evolved lunar lithologies such as granites and felsites [e.g., 8, 9].

Forward Modeling: Forward modeling of planetary gamma-ray data is a process whereby surface abundances are estimated using data from measured abundance distributions, geologic maps, and high-resolution data from Clementine [10]. The expected gamma-ray flux from the estimated abundances is propagated through the entire instrument response to get simulated data. The simulated data are then compared to the measured data and, if needed, the modeled abundance distribution is iteratively modified until a match is achieved.

Conclusions: Our forward modeling technique provides a way to more accurately estimate the true Th abundances of small area features on the lunar surface. The validity of the forward modeling technique has been bolstered by three successful applications of the model (e.g., Hansteen Alpha [5], the Gruithuisen Domes [6], and Lassell [7]). The combination of high Th values and existing morphologic data for lunar red spots provides evidence for the existence of evolved lunar lithologies.

A SOURCE REGION FOR MARTIAN METEORITE ALH 84001: EOS CHASMA, MARS. V. E. Hamilton. Hawai'i Institute of Geophysics and Planetology, Univ. of Hawai'i, Honolulu, HI 96822. E-mail: hamilton@higp.hawaii.edu.

Introduction: A global search of infrared data collected by the Mars Global Surveyor Thermal Emission Spectrometer (MGS TES) revealed only one spatially significant exposure, in Eos Chasma (Valles Marineris), of orthopyroxene-rich materials matching the spectral signature of ALH 84001 [1]. Here I evaluate spectral, thermophysical, and geomorphic evidence for this location as the ejection site of ALH 84001.

Spectral Observations: Up to ~45% of the ALH 84001-like surface materials in Eos Chasma consist of ortho-pyroxene (OPX), with the remainder consisting of basaltic minerals [2]. Using a range of compositions between Mg$_{70-90}$ [2] verified the results of [1] and modeled the composition of the OPX as Mg$_{70-77}$, consistent with ALH 84001.

Thermophysical Observations: TES thermal inertias of the OPX-rich material are in the range of ~230 – 720 J m$^{-2}$ K$^{-1}$ s$^{-1/2}$, consistent with a wide range of particle sizes from coarse particulates (~375 µm) to rocky material and/or bedrock [1].

Geomorphological Observations: The OPX-rich materials are a lobate deposit that superposes Eos Chasma floor materials. There are several lobes, with an inferred direction of flow onto the central chasm floor radial to the southern wall. The edges and upper surfaces of the deposit do not resemble those of typical mass wasting deposits observed elsewhere in the Valles Marineris. Lobate ejecta deposits provide a better morphologic analogue to the Eos Chasma deposits [2]. The remnants of a probable impact crater, ~20 km diameter & now partially collapsed, appear to be located on the southern rim.

Eos Chasma: ALH 84001 Ejection Site? Based on the combined compositional, thermophysical, and geomorphic observations, I propose that the OPX-rich deposits observed in Eos Chasma are a lobate ejecta deposit related to the ejection of the ALH 84001 meteorite. Martian meteorites may have been ejected from craters as small as ~1.5 – 3 km in diameter [3, 4]. Examination of the OPX-rich materials using THEMIS and MOC visible images reveals no craters this large. Thus, it is unlikely that the lobate materials were spread across the floor and subsequently impacted to eject ALH 84001. Another possibility is that an impact event producing the lobate deposit simultaneously ejected ALH 84001. In either case, the OPX-rich materials likely were located within the wall rock prior to their dispersal across the valley floor. Such a location is consistent with the formation of an ancient orthopyroxenite like ALH 84001. All Martian meteorites are estimated to have been ejected from Mars in the last 20 My, the low number of sizable craters on the Eos Chasma deposit is consistent with its relatively recent emplacement as an ejecta blanket. The complex shock history of ALH 84001 has been invoked to suggest that it must have been moved from its location of origin to a shallower depth prior to ejection; earlier impact events in this region may have disturbed the local stratigraphy such that the recent impact proposed here was able to eject ALH 84001 and disperse all or part of the source deposit and local basaltic rocks across the valley floor, physically mixing and exposing them.

THE SIGNIFICANCE OF HYDROUS GLASSES IN ARGENTINE IMPACT MELT BRECCIAS. R. S. Harris and P. H. Schultz. Department of Geological Sciences, Brown University, Providence, Rhode Island, 02912-1846, USA (scott_harris@brown.edu).

**Introduction:** Vesicular melt breccias collected from the vicinity of Centinela del Mar, Argentina have been interpreted to have formed during a hypervelocity impact into pampean sediments approximately 445 (±21) ka [1]. The breccias contain lechatelierite and baddeleyite indicative of temperatures exceeding ~1770°C [2]. Some entrained plagioclase grains contain planar deformation features (PDFs). Al kali feldspars exhibit low refractive indices and contain probable PDFs, deformation twins, and zones of diaplectic glass. Lamellarly twinned sanidine grains display “alternate twin melting”, a phenomenon reported only from impact craters and ejecta deposits [3-6]. The degree of feldspar deformation indicates a range of shock pressures from ≤ 10 to ~35 GPa [7]. Within these impact melt breccias, we have identified abundant hydrous glasses similar to those described by [8] in clasts from Ries suevites.

**Hydrous Impact Glass:** The hydrous glasses typically are bright yellow and occur as ubiquitous clasts, patches, and flow-like structures encapsulated within a clear to brown “host” glass containing 1 to 3 wt% H$_2$O. Water concentrations in the hydrous glasses range from 16 to 24 wt% and do not appear to have resulted from any post-impact alteration or secondary hydration. In fact, cooling fabrics and textural relationships demonstrate that the hydrous glasses must have been physically separate, low-viscosity, volatile-rich melts prior to quenching of the host glass.

The hydrous glasses tend to be associated with a particular assemblage of mineral and glass clasts and most commonly are wrapped around densely fractured quartz sand grains. We suggest that the hydrous glasses represent excavation and melting of lithologically distinct, water-rich strata (perhaps a buried sand or quartzite aquifer).

The hydrous glasses sometimes contains sub-micron exsolution bubbles which, according to [9], is evidence of prograde H$_2$O solubility in silicate melts. Data from static high-pressure experiments [9] show that the transition from retrograde to prograde solubility occurs above 0.5 GPa. Water concentrations approaching those observed here and in the Ries examples [8] should be expected around 1 GPa at very high temperatures.

**Implications:** Hydrous impact glasses can provide information about the lithology and hydrology of the target. They also may provide a unique signature of high-pressure formation useful for diagnosing ejecta formed during impacts into porous sedimentary strata and regoliths.


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Gamma-ray astronomy of radioactivities in the Galaxy can complement the study of these isotopes in the early solar system. For example, measurements by the COMPTEL gamma-ray telescope confirmed that the interstellar medium in the Galaxy contains about 2-3 solar masses of $^{26}$Al [1]. From this one may infer a mean interstellar $^{26}$Al/$^{27}$Al ratio of $\sim 3 \times 10^{-6}$, which is below the canonical early solar system value of $5 \times 10^{-5}$. The COMPTEL observations also led to the inference that infall in the Galaxy’s past history was important in diluting the concentration of interstellar $^{27}$Al [2] and that Galaxy’s recent star formation rate has been roughly 5 solar masses per year [3].

New observations from balloon and satellite platforms are providing further constraints. Increasingly refined maps of the $^{26}$Al distribution in the Galaxy provide key information on its stellar sources [4]. The width of the 1807.7 keV gamma-ray line from the decay of $^{26}$Al provides information on the velocity of this isotope in the interstellar medium, which, in turn provides clues about the chemical state in which it might reside (e.g., [5]). Recent gamma-ray observations of $^{56}$Fe with the INTEGRAL satellite may provide similar constraints on this isotope as well as the relative production of $^{26}$Al and $^{56}$Fe in core-collapse supernovae [6].

SYRTIS MAJOR AS THE SOURCE OF THE NAKHLITE/CHASSIGNITE MARTIAN METEORITES. R. P. Harvey1 and V. E. Hamilton2 1Department of Geological Sciences, Case Western Reserve University, Cleveland OH 44106-7216 (rph@case.edu). 2Hawai‘i Institute of Geophysics and Planetology, University of Hawai‘i, Honolulu, HI 96822 (hamilton@higp.hawaii.edu).

Absolute timescales were established for Earth and the Moon using samples recovered with full geological context. Although the mechanism of Martian meteorite delivery destroys their original context, it is theoretically possible to regain this context by matching unique physical, geochemical and spectral properties with potential parent volcanic units on Mars.

We have identified the Syrtis Major (SM) volcanic complex as a site that offers such a unique match to the known properties of the nakhlite/chassignite group of martian meteorites. SM is the largest of several relatively ancient shield volcanoes superimposed on the Southern Highlands of Mars [e.g. 1]. Although often described as “basaltic”, SM differs significantly from a typical basaltic shield. Very low slopes and long thin flows require a very low viscosity magma, and large regions of the surface lie significantly below the inferred regional surface, suggesting widespread thermal erosion [1, 2]. SM’s deep calderas with their significant positive gravity anomaly suggest a high-density magma chamber rich in accumulated olivine and/or pyroxene [3]. SM is therefore much more consistent with a differentiated ultramafic volcanic complex such as the Bushveldt than with a basaltic shield.

Spectroscopy supports this view. Recent global views show SM is enriched in CaO and MgO relative to the surrounding southern highlands [4]. OMEGA data suggests a two pyroxenes lithology dominated by high-Ca pyroxene, with localized olivine [5,6]. TES and THEMIS data have identified Mg-rich Chassigny-like olivine in the adjacent Nili Fossae region, while the flanks of SM in the same region show the signature of Fe-rich olivine [e.g. 7-8].

The nakhlite/chassignite meteorites share common crystallization and ejection ages suggesting they originated within a single differentiated series of flows and were ejected during a single impact event. High-Ca pyroxene and high-Fe olivine are unique to the nakhlites and persuasively similar to the mineralogy of eastern Syrtis Major. Likewise, Chassigny’s Mg-rich olivine-dominated mineralogy is compellingly similar to that seen in adjacent Nili Fossae, where early olivine-rich, hot and very fluid lavas from Syrtis may have invasively penetrated that terrain. This unique match of mineralogical signatures compellingly suggests nakhlite/chassignite meteorites were derived from the northeast region of Syrtis Major volcanics. Several craters of sufficient size (>5km dia) exist in the region; one particular elliptical crater cluster has very favorable characteristics.

Towards an Atlas of Chondrule Textures. 
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Introduction: Chondrites of all kinds are a major class of meteorites whose detailed provenance is poorly understood and complex. They are classified and named based in part upon their structure, mineralogy and texture, and in part upon their bulk chemistry and mineral chemistry. Understanding their origin is critically dependent on understanding the origin of their chondrules and other constituents, how these have become associated, and what processes are documented by their lithology and petrology. Few studies examine the internal textures of chondrules with a view to interpreting their origin and that of the chondrites that contain them, or to compare chondrules from different groups and petrologic grades. The textures of Earth rocks and minerals, along with their chemistry, are studied to determine their origins; meteorite studies favor chemistry almost exclusively to derive the origins and classification of extraterrestrial rocks.

Current Situation: Recent books [1,2,3] and articles [4,5] have published photomicrographs or back-scattered electron (BSE) images of chondrules, or of thin sections of chondrites [6]. In research papers [cf .5] the illustrations support detailed mineral or isotope chemistry, and conclusions from those analyses, even though variations in chondrule texture along with chemistry are observable. Elsewhere the images support conclusions about classification without definitive textural details being compiled. Others are detailed pictures with no accompanying interpretation.

Data Needed: Textural interpretation down to the scale of the mineral and chondrule matrix analyses (a few microns), or comparative textural documentation of different chondrules from the same meteorite, is usually missing. Chemical and isotopic data need to be interpreted in the context of the textural and mineralogical characteristics of the analyzed objects within the meteorites, not independent of those characteristics. This requires a more rigorous textural documentation and classification of chondrites and chondrules than is currently common practice. In particular it requires imaging and interpretation of chondrite structures and chondrule textures at all appropriate scales where information about their origin may be gleaned, and it requires reference materials. An atlas of chondrule textures is required.

Advances: The proposal to focus a community effort among researchers interested in systematic textural studies of chondrules and chondrites, through a dedicated web site and list [7], is moving towards implementation later this year. A host for the web site and other resources have been obtained. We have many of our own images and interpretations to start the compilation. Potential contributors and collaborators are invited to contact us.

EARLY METAL RECORDS; METAL INCLUSIONS IN ACAPULCOITE-LODRANITE SILICATES. J. S. Herrin, D. W. Mittlefehldt, and J. H. Jones. NASA Johnson Space Center (KR), Houston, Texas 77058. E-mail: ja-son.s.herrin1@jsc.nasa.gov

Introduction: Acapulcoites and Lodranites are primitive achondrites widely considered to be the metamorphic products of a chondritic protolith. As such, a detailed history of their formation provides a glimpse into the earliest stages of formation of differentiated asteroidal bodies. Silicate mineral grains in these meteorites have experienced metamorphic growth from a presumably chondritic primary texture. Inclusions in these grains thus potentially preserve a record of the thermal and chemical history of their parent body.

Results: Metal inclusions analyzed by EPMA in several Antarctic Acapulcoite-Lodranites are thought to have been entrapped by growing silicates, rather than formed in situ through reduction of silicate hosts, a notion supported by (1) petrographic textures sometimes preserving metal decoration of pre-existing grain boundaries and (2) significant concentrations of elements that are present only at very low concentrations in silicate hosts, such as Co (0.4-0.8 wt%). Within each sample, there is no discernable difference in Co concentration between metal inclusions and metals grains in the matrix of the sample. Matrix metals are predominantly Fe-rich (5.5-7.5 wt% Ni), but exhibit a continuum of Fe/Ni compositions up to 53 wt% Ni, with the maximum Ni concentration observed varying between samples. Metal inclusions are almost exclusively Fe-rich (4-7.5 wt% Ni) with Ni contents similar to, but often lower than, the most Ni-poor matrix metal within a given sample. Of the meteorites examined, compositional differences between metal inclusions and matrix metals are most apparent in EET84302, MAC88177, GRA95209, ALHA81261, and MET01195. Cr is frequently present at considerably higher concentrations in metal inclusions (up to 0.13 wt% Cr) than matrix metals (typically <0.01% Cr). The opposite relationship is seen for P, with inclusions being depleted (typically <0.02 wt% P) relative to matrix metals (up to 0.3 wt% P).

Discussion: No simple process can simultaneously account for the discrepancies observed for major and minor elements between inclusion and matrix metals. Cr enrichment in metal inclusions is likely a primary feature, with lower Cr contents in matrix metals being the result of oxidation, considering that (1) chromite is a rare inclusion phase yet is comparatively abundant as a matrix phase, (2) Cr enrichment is observed in both metal and sulfide inclusions, (3) similarly high Cr concentrations characterize metals in chondrites, the presumed protolith, and (4) matrix metals are enriched in Ni relative to inclusions, the possible result of oxidation of metallic Fe. P and Co distributions, however, seem to contradict this oxidation scenario. Although P depletion of metal inclusions could result from local production of Ca-phosphates within silicate grains, petrographic evidence for this is often lacking. Alternately, temperature-dependent reduction of phosphates may have slightly enriched matrix metals during peak metamorphism. Similar Co content of inclusions and matrix metals indicate little production or oxidation of metal either in the matrix or within the inclusion, thereby contrasting with the behavior of Ni (see 4 above). Trace element studies could shed light on each of these processes, as well as the possible production of eutectic melts in the Fe,Ni metal-sulfide system.
MODELING 3-DIMENSIONAL OBJECTS FROM 2-DIMENSIONAL THIN SECTIONS. D. C. Hezel. Institute of Geology and Mineralogy, University of Cologne (Köln), Zülpicherstraße 49b, 50674 Köln, Germany d.hezel@uni-koeln.de.

Introduction: The bulk compositions of chondrules are poorly known, but are essential for any theory of chondrule formation. A cause for this lack of data is the problem of obtaining these. One fast approach is calculating the 2-d “bulk composition” of an object and taking this as the 3-d composition. This method implicitly assumes that the 2-d slice is more or less representative of the 3-d object. As this assumption is more a question of faith, such bulk estimates are inevitably criticised at conferences or by reviewers. I am currently programming a model to study whether this method can be reliably used.

Technique: At the present stage the program runs in a 2-d version, which means that the bulk composition of a 2-d object is recalculated from a 1-d section (= a line). The 3-d version will be the next step.

Results: A first result of these calculations is shown in the figure below. A 2-d “chondrule” contains 15 “crystals” (rectangles). The diagram shows the mesostasis/crystal(m/c)-ratios calculated from 200 vertical lines cutting the chondrule. The true m/c-ratio is plotted as dashed line in the diagram. As can be seen the m/c-ratio calculated along the vertical line can deviate from the true ratio by about ±0.15.

More detailed results will be presented at the conference, including statistical treatment of factors like amount of crystals, crystal size, effect of heterogeneous crystal distribution, etc.
BARNIUM ISO.IOPIC COMPOSITIONS OF CHEMICAL SEPARATES IN CARBONACEOUS CHONDRTES. H. Hidaka1 and S. Yoneda2. 1Department of Earth and Planetary Systems Science, Hiroshima University, Higashi-Hiroshima 739-8526, Japan. E-mail: hidaka@hiroshima-u.ac.jp 2Department of Science and Engineering, National Science Museum, Tokyo 169-0073, Japan.

Introduction: Barium has seven stable isotopes with the mass numbers 130, 132, 134, 135, 136, 137 and 138. 130Ba and 132Ba are p-process isotopes, 134Ba and 136Ba are s-only process isotopes, and 135Ba, 137Ba and 138Ba are s- and r-process isotopes. In addition, 135Ba isotopic abundance may be affected by decay from presently extinct 135Cs isotope (t1/2=2.3 Ma), which can be used for Cs-Ba geochronological application [1-3]. Isotopic studies of carbonaceous chondrites have provided useful information to understand the cosmochemical evolution in the early solar system. Previous isotopic studies of barium in carbonaceous chondrites show the presence of independent s- and r-processes components [4,5]. Here we report further isotopic results of barium in carbonaceous chondrites for a detailed discussion of nucleosynthetic components in the early solar system.

Experiments: Six carbonaceous chondrites were used in this study: Orgueil (CI), Murray (CM2), Mighei (CM2), Efremovka (CV3), Kainsaz (CO3), and Karoonda (CK4). 0.2-0.3 g of each powdered sample was leached by 0.1 M acetic acid-ammonium acetate, 0.1 M HCl, and 2 M HCl, successively, and the residue was finally decomposed by HF-HClO4 with heat. A barium fraction was chemically separated using a conventional cation exchange method [2,5]. Isotopic measurements of the individual fractions were performed by a VG54-30 thermal ionization mass spectrometer equipped with seven Faraday cups.

Results and Discussion: We expected the isotopic excess of only 135Ba derived from 135Cs decay in order to develop Cs-Ba chronometry. However, the barium isotopic data in most of leachates show variable 135Ba excesses correlated with 137Ba excesses, suggesting the presence of nucleosynthetic components for s- and r-processes in the solar system. In particular, the acid residues from two CM2, Murray and Mighei, show significant evidence for enrichments of s-process isotopes, which suggest the contribution of presolar SiC grains. These data are consistent with previous results from other CM2, Murchison and Sayama [5].

The leachate from acetic acid in Orgueil reveals larger 135Ba excess than those of other samples, although it is also accompanied by a small 137Ba isotopic excess probably due to an addition of r-process component. Judging from the high Cs/Ba elemental ratio in the leachate, the 135Ba isotopic excess of Orgueil may include the contribution of 135Cs decay.

With commitment to return to the Moon, there is new impetus in research to find solutions to the many challenges the lunar environment presents. Return to the Moon and subsequent exploration of Space will only be successful if answers to problems such as material handling, dust control and oxygen production are found. Investigation of processes that will result in solutions to these issues requires the availability of suitable amounts of lunar soil for engineering and scientific study. Lunar soil, however, is a scarce commodity on Earth and hence, suitable lunar soil simulants, such as JSC-1 and MLS-1, are required.

Lunar simulant JSC-1 was produced to facilitate engineering studies in preparation for human activities on the Moon. These studies include material handling, construction, excavation, dust control, space suit durability, oxygen production, sintering to produce building blocks and for dust mitigation on the Moon. JSC-1 is a glass-rich basaltic ash, which approximates the bulk chemical composition, mineralogy, particle size distribution and engineering properties of low-Ti lunar mare soil 14163 [1]. In its chemistry, 14163 is actually atypical of the majority of the lunar soil. Therefore, JSC-1 complements, but does not replace, lunar simulant MLS-1, which approximates the bulk chemical composition of a high-Ti, Apollo 11 soil, 10084. MLS-1 is derived from a high-Ti hornfels. Lunar soils generally contain varying amounts of glass and agglutinates due to micrometeorite impact. To further approximate MLS-1 to lunar soils, MLS-1 was processed in an in-flight sustained shockwave plasma reactor. In this way, 10 to 30 wt. % glass was produced [2].

Processes under consideration for the In Situ Resource Utilisation (ISRU) of lunar resources are dependent on the engineering characteristics of the lunar regolith, its bulk chemistry and, in some instances, its mineralogy. Whilst the bulk chemical compositions and engineering characteristics of JSC-1 and MLS-1 are known, a more detailed knowledge of their mineral compositions is required. Detailed knowledge of their engineering characteristics, chemistry and mineralogy will assist in the development of suitable solutions to the problems presented by a return to the Moon. It will also allow for direct comparison of the results obtained by the various groups working on these problems and in a better understanding of how the different processes devised on Earth will eventually be applied on the Moon.

Microwave radiation is ideally suited to engineering processes on the Moon. At 50–60% efficiency levels, it far surpasses laser and conventional heating for energy efficiency, it is an available technology and it is relatively inexpensive. Furthermore, the chemical and physical properties of lunar soil make it ideal for coupling to microwave radiation [1]. This property of lunar soil opens opportunities for the application of microwave radiation to problems as diverse as dust mitigation and production of liquid lunar oxygen. Implementation, however, requires a full investigation of the reaction so as to make best utilization of the technology. Since lunar soil is a rare commodity on Earth, it is not feasible to undertake studies that require large quantities of it. Simulants must be used as an alternative material. We have undertaken experiments, using lunar simulants JSC-1 and MLS-1, to establish their validity as substitutes of lunar soil in these investigations.

Microwave heating experiments of lunar soil (e.g., [2]) attributed the successful coupling of microwave radiation to the presence of solar wind radiation defects on the surface of grains and to the presence of abundant ilmenite in some of the Mare soils [3]. When applying microwave radiation directly to simulants (e.g., [4]), however, it was found that despite the Ti-magnetite content of JSC-1 and high ilmenite content of MLS-1, neither coupled successfully. Taylor and Meek [1] attributed the unusual behavior of lunar soil in a microwave field to the presence of abundant nano-phase Fe$^0$ (np-Fe$^0$) in the agglutinitic glass that surrounds each soil grain. Each np-Fe$^0$ particle acts as a conductor, separated from the other np-Fe$^0$ particles by the dielectric glass; thus creating energy sinks and the subsequent generation of heat.

In our experiments we have subjected JSC-1 and MLS-1 directly to a microwave field using a conventional 2.45GHz microwave oven. Results prove Ti-magnetite and ilmenite aid in the coupling of these simulants but a high enough temperature to result in melting or sintering is not achieved. The addition of small proportions of 1-3µm Fe$^0$ particles, to simulate the presence of np-Fe$^0$, has resulted in JSC-1 and MLS-1 coupling with microwave radiation and reaching temperatures as high as 1200°C (the melting point of MLS-1 [5]) at heating rates of 1000°C/min.

INFLUENCE OF THE EXPLOSION MECHANISM ON THE EJECTA OF CORE COLLAPSE SUPERNOVAE.

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Core collapse supernovae are responsible for at least half of the galactic inventory of Fe-group elements and probably for the majority of the Fe-group nuclei seen in metal-poor stars. Recent supernova simulations manifest a proton-rich ($Y_e > 0.5$) region in the innermost ejecta as a result of neutrino interactions [1-3]. A consequence of this proton-rich ejecta is enhanced abundances of $^{45}$Sc, $^{49}$Ti, and $^{64}$Zn, which are consistent with chemical evolution studies and observations of low metallicity stars [4,5]. Inclusion of neutrino and anti-neutrino capture reactions in the reaction network can also result in significant production of light p-process nuclei [4,6], making the innermost ejecta of core collapse supernovae a possible source for these rare isotopes.


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CORRELATED POSITIVE ANOMALIES IN CE AND YB FOUND IN REFRACTIVE INCLUSIONS FROM THE NINGQIANG METEORITE: FRACTIONATION OF RARE EARTH ELEMENTS UNDER VARIABLE CONDITIONS.

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**Introduction:** As a part of the systematic study of refractory inclusions in the Ningqiang meteorite [1], we conducted ion microprobe analyses of rare earth elements (REEs) in various types of refractory inclusions in this meteorite. Some preliminary results have been presented in [2,3].

**Results:** We analyzed one hibonite-bearing fluffy type A, one hibonite-bearing compact type A, eight fluffy type A, one compact type A, two type B, two spinel-pyroxene, one anorthite-spinel-rich, and two amoeboid olivine inclusions (AOIs). Their bulk chemical compositions lie along the expected condensation trajectory on the anorthite-gehlenite-forsterite plane [1].

The following four REE patterns are recognized: (1) almost flat (unfractionated) REE pattern with or without Eu (and sometimes Yb) anomalies, (2) Group II (Group IIA) pattern [4,5] showing depletions in the heavy REEs (HREEs) except Tm (and Yb), (3) almost flat REE pattern with positive anomalies in Ce, (\(\pm\)Eu) and Yb (modified Group I), and (4) a pattern similar to Group II but with positive anomalies in Ce (\(\pm\)Eu) and Yb (modified Group II). There seems to be no correlation between the observed REE patterns and bulk chemical compositions or inclusion type. This suggests that most of the REE patterns have been established prior to condensation of major elements like Si and Mg.

It is interesting to note that 9 out of 18 inclusions show positive anomalies in Ce (\(\pm\)Eu) and Yb (modified Group I and modified Group II patterns). These are new types of REE patterns which have not been well documented. We performed some condensation calculations to understand the origin of these REE patterns. We suggest that these patterns are produced by a process similar to that produced the Group II pattern but at slightly lower temperatures, where not only ultra-refractory HREEs but also light REEs (LREEs) become partly condensed and removed from the system. The remaining gas will show large depletion in HREE and some fractionation in LREE as well, resulting in positive Ce anomaly (modified Group II). Modified Group I pattern may be interpreted as a mixing of a modified Group II pattern and an unfractionated pattern; this may happen when gas-dust separation is incomplete. The present results show REE fractionation occurred under variable conditions.

ANOMALOUS NIR AND MöSSBAUER SPECTRA IN ANGRA DOS REIS AND OTHER HIGH-Ca PYROXENE SPECIMENS.  E. J. Hoffman.  1Physics Department, Morgan State University, Baltimore, MD 21251, USA (ehoffman@morgan.edu)

In an attempt to match asteroidal near-infrared (NIR) reflectance patterns Burbine et al. [1] presented laboratory spectra for three angrites, meteorites containing pyroxenes with large abundances of Ca, Ti, and Al. Of the three, Angra dos Reis gives an anomalous (“Type B”) NIR spectrum [2], similar to those patterns that turn up almost at random in spectra of terrestrial high-Ca pyroxenes (clinopyroxenes) [3, 4].

Fe ions are responsible for the pertinent absorption bands, and Mössbauer spectroscopy, an additional Fe-sensitive method, showed a similar dichotomy [5, 6], reminiscent of those for a well-studied synthetic Fs10Wo50 sample [7]. For both NIR and Mössbauer the spectra for Angra dos Reis suggest that Fe$^{2+}$ ion is located in the M2 (larger) octahedral site, where crystal structure refinement shows only Ca$^{2+}$ [8].

Trying to resolve the mystery, a comparative spectral study of some 40 terrestrial high-Ca pyroxenes has instead turned up yet another anomalous result: in Mössbauer spectra for most NIR Type B samples an anomalously-intense ferric ion signature appears [presented in part in Refs. 9–12].

One group of samples [3, 10, 11] consists of sets matched for approximately identical composition. For one set of two, PYX020 (NIR Type B), scanning electron microscopy (SEM) revealed in sample PYX018 (NIR Type B) andradite as a minor phase that might account for the anomaly; the other member of the set, PYX020 (Type A) showed essentially pure diopside (R. M. Housley, personal communication). Further work will include spectroscopic and SEM examination of experimentally mixed samples and of other matched sets.

No comparable new finding resulted from SEM examination (R. M. Housley, personal communication) of the Angra dos Reis sample which with this quest began. Thus at least two mechanisms seem to be at play in the spectroscopic anomalies of high-Ca pyroxenes, one in Angra dos Reis, potentially of significance in understanding angrite evolution, and a new one in many other samples, perhaps involving exsolution phases [11].

CHARACTERIZATION OF A SMALL CRATER-LIKE STRUCTURE IN SE BAVARIA, GERMANY

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Introduction: In SE Bavaria, many small scale (5 m to ca. 100 m diameter), circular, bowl shaped structures have been previously interpreted as archaeological objects or geologic structures with ambiguous description of their origin. In and around many of these structures, fractured rocks are frequent, some possess a well developed crater rim, and in a few structures melt rocks can be found. This paper focuses on the macroscopic, microscopic, and geophysical characterization of a 11 m diameter, bowl shaped, crater-like structure in Holocene till beds, showing extreme thermal effects in a 20 m diameter area.

Analytical methods: Optical microscopy, SEM/EDX, and XRD were used to characterize material from thermally altered bed rocks and from particles extracted from surrounding soil. The area of the crater-like structure was mapped using a magnetic susceptibility meter, a fluxgate magnetometer, and a ground penetrating radar (GPR) system.

Results: The investigated structure is a bowl-shaped, circular depression of 11 m rim-to-rim diameter in Holocene, glacial till beds. It has a pronounced rim wall of ca. 0.5 m height and a bottom ca. 0.5 m deeper than the surrounding. The crater wall consists of thermo-plastically deformed bed rocks indicating temperatures exceeding 1500°C throughout the whole crater wall of ca. 20 m diameter. XRD spectra indicate high temperature phases of quartz but no indication for shock metamorphism could be confirmed by microscopic observation. The GPR survey shows that the morphology of the crater walls continues into depths of several meters with strong reflections from the crater floor. Both magnetic surveys show strong magnetic anomalies associated with the thermally altered crater wall material. The magnetic susceptibility of the wall material is significantly higher than that of the surrounding. Magnetic mapping shows a strong magnetic anomaly, consisting of a large number of individual small-scale dipole-structures, probably representing strongly re-magnetized boulders from the glacial till beds. In the surrounding soil and in melt crusts of thermally altered bed rocks, spherules and inclusions of iron silicon [3] and carbon [4] materials could be found.

Interpretation: In contrast to previous interpretations, we have to conclude that the thermal effects and depth structure of the investigated object cannot be explained by glacial geology, by archaeology, by bombing, or by primitive industrial processes. The occurrence of FeSi materials indicates a high-energy, reducing environment [5]. Despite a positive proof at present, an impact-related origin of the investigated structure should be considered.

TANEZROUFT 057, MARALINGA AND EET 99430 — THREE DIFFERENT CK CHONDRITE ALTERATION PROCESSES OR ALL THE SAME? H. Huber1, A.E. Rubin1 and J.T. Wasson.1 Institute of Geophysics and Planetary Physics, UCLA. E-mail: hhuber@ucla.edu

Introduction: In our study [1] on common siderophile element anomalies in carbonaceous chondrites of the Karoonda group (CK) different mechanisms leading to Ni and Co depletions in these highly oxidized meteorites were discussed. The key parameters are the contents of Ni and Co (as well as Au and Se) and the Ni/Co ratio. Refractory siderophiles are not depleted and lithophile elements are not recognizably different compared to Karoonda (CK fall).

Methods: We performed INAA, optical microscopy, SEM and EMPA analysis to determine the bulk chemical composition, and to assess compositions and distributions of opaque minerals.

Results and Discussion: The following three CK chondrites illustrate the different patterns of alteration and loss (variations are relative to mean CK): Maralinga – depleted in Ni, Co, Au and Se; Tanezrouft 057 – depleted only in Ni and Co; EET 99430 – enriched in Ni, Co, Au and Se. The depletions and enrichments are in the range of a factor of 2-3 of mean CK contents. Maralinga is a member of a set of hot and cold desert samples (e.g., Dar al Gani 431, NWA 060, NWA 1563, NWA 1558, LEW 86258) with depleted abundances in Ni, Co, Au and Se [1]; Tanezrouft 057 and QUE 93007 also share similar distributions; no other CK chondrite was found with the enrichments observed in EET 99430.

The above-mentioned CKs are petrographic type 4-5; and although they have high weathering indices of 3-4, it appears that weathering has produced only minor effects. Magnetite is the most abundant opaque phase. Sulphide loss (mainly pentlandite) appears to be responsible for the depletions in Ni and Co and the reduced Ni/Co ratio in Maralinga and Tanezrouft 057. Variable conditions of impact-induced transport on the parent-body are inferred to be responsible for variations in the Au and Se depletions.

For EET 99430 the scenario is strikingly different. The bulk-compositional anomalies in EET 99430 cannot be explained by high abundances of opaque phases - sulfides are rare (0.1-0.2 vol.%) and mainly tiny (<2-µm-size) pentlandite grains. This reflects the reduced S-content of 1/10 of Karoonda [2]. The apparent S and Se decoupling during impact processes on the parent body is accompanied by enrichments in Ni in the remaining pentlandite (as also seen in Maralinga) a process that was experimentally shown to be the first step of pentlandite alteration towards violarite and magnetite [3]. Further aqueous alteration may have produced water-soluble Ni-rich sulfates and leaching of these.

Thus, the three processes seem to be consistent with a highly complex history with different local conditions. EET 99430 seems to have undergone a high enrichment in the siderophiles with subsequent loss of the sulphides. Maralinga lost Ni and Co by loss of sulphides but additionally were depleted by impact-processed depletions in the siderophiles, whereas Tanezrouft 057 lost its sulphides but “started” with a siderophile composition comparable to mean CK chondrites.

GEOCHEMICAL, TEXTURAL AND MINERALOGICAL ANALYSIS OF TWO FGMMs FROM ANTARCTIC AEOLIAN TRAPS. K. A. Huwig¹ and R. P. Harvey¹. ¹Dept. of Geological Sciences, Case Western Reserve University. E-mail: huwig@case.edu.

Introduction: Micrometeorites exhibit a broad range of compositions, textures and mineralogy. The selection effects due to collection methods further compound this wide variation. Micrometeorites and cosmic spherules are collected from a variety of sources such as glacial ice in Antarctica and Greenland [1,2,3], deep sea sediments [4], and aeolian traps in Antarctica [5,6].

We have begun a study of the mineralogical, textual and geochemical distinctions between micrometeorites from various terrestrial sources; our particular emphasis is on differences between those collected through "wet" methods, such as melting glacial ice, and those collected "dry" from aeolian traps. It has been noted that samples collected from the ocean and melted glacial ice show clear depletions in Ni, S and Ca [1]. Preliminary analyses of samples collected from the aeolian traps do not seem to show a similar depletion, suggesting that extensive or moderate contact with liquid water may alter the original mineralogy and geochemistry of these particles in significant ways.

Methods: The aeolian micrometeorites used in this study were sorted magnetically and optically from moraine sediments at “Station D”, at the downwind edge of the Lewis Cliff Ice Tongue [5]. Potential unmelted micrometeorites (no spheres) were then mounted and sectioned, and backscattered electron images and EDS spectra were used to confirm features indicative of extraterrestrial origin, such as the presence of a glassy, vesicular and/or magnetite-rich rim, the presence of Ni in metal or sulfides, or an overall “chondritic” composition. More than 150 micrometeorites from 63-400µm in diameter have been examined so far, and have provided an intriguing glimpse of the variety of materials accreting to Earth in this size range. The major micrometeorite types (soriaceous, coarse grained, fine grained and composite [7,8]) are all represented. Some of these micrometeorites, particularly several of the coarse grained ones, exhibit interesting textures and mineralogy consistent with that of chondrules.

From this collection we have selected two fine-grained micrometeorites for detailed geochemical and mineralogical comparison to similar samples from “wet-based” collections and IDPs. Both fit the "fgMM" classification [8]; one with a compacted matrix exhibiting chemical and mineralogical heterogeneity (C2 type) and one highly porous fgMM (C3 type). Elemental maps of these samples will be used as a guide for focused ion beam removal of several TEM sections of representative regions of each particle that can be used to analyze their mineralogy and texture at the nanometer scale. Following TEM analysis we will remove the remaining particle mass from their mounts for fine scale x-ray tomographic imaging that can reveal the broader scale texture and mineralogy of the sample.

A 3-D TOMOGRAPHIC SURVEY OF COMPOUND CHONDRULES IN CR CHONDRITES ACFER139. S.N. Hylton1,2, D.S. Ebel2, and M.K. Weisberg2,3 1Dept. of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge MA 02139. (nyoshiv@mit.edu). 2Dept. of Earth and Planetary Sciences, American Museum of Natural History, Central Park West at 79th St., New York NY 10024. (debel@amnh.org). 3Dept. Physical Sciences, Kingsborough College, CUNY, Brooklyn, NY 11235 (mweisberg@kbcc.cuny.edu)

Introduction: Compound chondrules are two or more chondrules joined together while plastic or brittle [1,2]. Studies of compound chondrules have been conducted in order to understand the chondrule formation process, including the dynamic setting and precursor materials. Chondrule formation is poorly understood and it is not entirely clear what features of chondrules are nebular and which result from processes on parent body surfaces. Our evidence suggests that both primary and secondary processes are responsible for compound chondrules. Primary processes include collisions among semi-molten individual chondrules free-floating in space [1], and secondary processes include parent-body impacts that cause jostling, fracturing and compaction [2]. By understanding chondrule collisions and impacts we can better constrain what was happening during early solar system formation, including mean interparticle distances, relative velocities, and cooling rates [3,4].

Method: We used synchrotron x-ray computed micron tomography (XR-CMT) as a new method of measuring and surveying compound chondrules in 3 dimensions (3-D), and explored its advantages and limitations. It is well-suited to CR chondrites with high-contrast metal rimming FeO-poor chondrules [5]. We studied ~2 cm$^3$ of ACFer139 and Renazzo (both CR2) by 3D tomographic analysis, followed by 2-D surfaces analysis of serial slices. We measured chondrule abundance, diameter, and textural relationships in 3-D. Previous (2-D) studies of ‘enveloping’ compound chondrules [1,2] were reexamined and two new compound categories, touching and aggregate compounds, are introduced.

Results and Conclusion: Our examination suggests a 9.6% frequency of compound chondrules (excluding the new categories), twice the value in ordinary chondrites of 4% reported by [1] and almost four times the value of 2.4% reported by [2] in OC. We observe little or no metal between enveloping pairs that are each rimmed by metal grains. Based on 3-D tomography, with follow-up 2-D sample analysis we conclude: (1) Compound chondrules occur more frequently in CR chondrites than in ordinary chondrites. (2) Compound chondrule study, including textural, thin section, and chemical analysis, should be expanded to include touching and aggregate compound chondrules. (3) Enveloping compound chondrules [2] constitute more than 9.6% of all CR chondrules, and, with the addition of the new categories, compounds comprise more than 75% of all chondrules in CR chondrites. (4) The high frequency of touching and aggregate compound chondrules bears upon the accretion and impact history parent body or bodies of CR chondrites.

PETROLOGICAL AND GEOCHEMICAL CLASSIFICATION OF THE SOPOT CHONDRITE


The Sopot meteorite fell in April 27, 1927, 12:00 – 13:00 hrs. in Oltenia (Dolj District). After detonations, a shower of stones fell, of which only eight small ones were found, totalling 958.287 g, the largest weighing 294 g [1, 2]. The fragments recovered are kept in 2 museums from Romania (Craiova and Cluj-Napoca) and in one collection from Austria. The meteorite was not classified so far.

Two polished thin sections representing the Sopot chondrite were studied with optical and electron microscopy. Quantitative chemical analyses of the constituent minerals were obtained on the carbon-coated, polished thin sections by using a JEOL JSM-6400 scanning electron microscope at the University of Salzburg, Austria.

The microscopic study in thin sections revealed the presence of the following types of chondrules in the Sopot chondrite: well defined or readily distinguished PO – porphyritic olivine, POP – porphyritic olivine-pyroxene, RP – radial pyroxene and BO – barred olivine (sometimes polysomatic) chondrules, ranging in size from 200 µm up to 600 µm.

Based on the bulk chemical composition [3], the ratio Fe (in metallic form)/Fe (in oxide and sulfide form) is 0.56/0.36 which is consistent with the H-group. The value of reduced Fe (Fe˚ and FeS)/Si (mole ratio) = 0.67, plotted against the value of oxidized Fe (FeO)/Si (mole ratio) = 0.25 on a Urey – Craig diagram indicate H-group as well.

The matrix is recrystallized, the feldspar (An_{12}Or_{5}Ab_{83}) occurs in grains smaller than 50 µm and the igneous glass is absent. Pyroxenes are mainly orthopyroxenes but less than 20% of the grains are clinopyroxenes. Other minerals identified in polished thin sections are kamacite, troilite, taenite, plessite, cromite and magnetite. Based on petrographic data, the Sopot chondrite is classified as petrologic type 5.

Analysis of 11 olivine grains from two thin sections shows a variation in composition from Fa_{17} to Fa_{19} mole% fayalite (avg. Fa_{18}; PMD 1.7%). Eight orthopyroxene grains from thin sections show a range in composition from Fs_{16} to Fs_{17} mole % ferrosilite (avg. Fs_{17}; PMD 1.3%).

According to the classification of meteorites, Sopot may be considered as an ordinary chondrite – Hs, belonging to the primitive meteorites class.

The shock degree of this chondrite may be estimated as S-3, weakly shocked [4] based on the shock effects in metallic phases and silicates: olivine with planar fractures, undulatory extinction and irregular fractures, plagioclase with undulatory extinction, irregularly shaped troilite grains within metallic Fe-Ni, rapidly solidified metal-sulfide intergrowths, plessite and opaque shock veins.

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COMPARATIVE PETROLOGY OF YAMATO AND MIL 03346 NAKHLITES
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Introduction: Two different nakhlites were recently recovered from Antarctica. We have reported the petrographies and petrologies of Yamato nakhlites (Y000593, Y000749 and Y000802) [1,2] and MIL 03346 nakhlite [3]. In this paper, we present the comparative petrology of Yamato and MIL 03346 nakhlites.

Differences in mode and chemistry: Whole rock compositions are slightly different between Yamato and MIL 03346 nakhlites [1,4]. The MIL 03346 nakhlite is richer in Al₂O₃ (3.59 wt%), Na₂O (1.01 wt%) and K₂O (0.29 wt%) than the Yamato nakhlites (1.96, 0.66 and 0.17 wt%, respectively), and it is poorer in MgO (9.33 wt%) and FeO+Fe₂O₃ (19.23 wt%) than Yamato nakhlites (11.09 and 21.55 wt%, respectively). SiO₂ (49.20 wt%) and CaO (15.00 wt%) of MIL 03346 are nearly identical to those of Yamato nakhlites (48.35 and 14.90 wt%, respectively).

Modal abundance of magnesian olivine grains in MIL 03346 (~1 vol%) is much less than that in Yamato nakhlites (~10 vol%). Modal abundance of mesostasis in MIL 03346 (31.5 vol%) is more than that in Yamato nakhlites (10.5 vol%). The whole rock compositional difference is ascribed to the modal abundance difference of mesostasis, although the composition of mesostasis is slightly different from each other: the mesostasis of MIL 03346 is olivine-saturated, and that of Yamato nakhlites is silica-saturated.

Inclusions in phenocrysts: Magmatic inclusions occur in augite and olivine phenocrysts in Yamato nakhlites. Those in MIL 03346 occur only in augite phenocrysts. Magmatic inclusions in augite phenocrysts in MIL 03346 are larger than those in Yamato nakhlites. Mineral assemblages of magmatic inclusions are similar to each other in the two nakhlites.

Textural differences: Lamellae and symplectites consisting of magnetites and augites occur in olivine phenocrysts in Yamato nakhlites, but they are lacking in olivine grains in MIL 03346. Mesostasis in MIL 03346 is glassy and that in Yamato nakhlites mostly consists of fine-grained plagioclase.

Comparison of calculated intercumulus melts: Taking into account the modal abundances of cumulus phases, we estimated intercumulus melt compositions based on the mass balance calculation [2,3]. The intercumulus melt composition for MIL 03346 is similar to that for Yamato nakhlites except Ca-contents (CaO = 9.81 and 12.42 wt%, respectively).

Different crystallization paths: We show the different crystallization paths for the two from the intercumulus melts toward mesostasis. The difference may be due to the different cooling rate, the intercumulus melt of MIL 03346 cooled more rapidly than Yamato nakhlites.


Large variations in calcium and titanium compositions are well known in hibonites from CM2 chondrites [e.g. 1]. The anomalies are predominantly in the heavy isotopes with percent level variations quite common. In some cases extremely large positive anomalies are found with the most extreme being a 27% excess in $^{50}$Ti. The magnitude of this anomaly rivals that in presolar SiC grains albeit with a different isotopic signature. Hibonites have dominant effects in the heavy isotopes consistent with a quasi-equilibrium process, whereas the SiC grains have V-shaped Ti isotopic patterns more consistent with slow addition of neutrons (s-process). While the preservation of large variations in circumstellar condensates is not surprising, the magnitude of the Ti isotopic variations in meteoritic hibonites far exceeds that in any other solar nebula products, including CAI from CV3 chondrites.

These inclusions therefore offer an intriguing view of the incorporation of Fe-group isotopic anomalies. There are very few anomalous grains with large excesses of $^{50}$Ti. Two grains from Murray both have 10% $^{50}$Ti excesses [2], and there appear to be two crystals with near 27% excesses of $^{50}$Ti [1,3]. Some of the crystals may be fragments of larger inclusions and that there may be only two extreme compositions.

We have reinitiated a search for hibonite crystals with large Ti and Ca isotopic anomalies. This requires analysis of many grains because of their low abundance even within the hibonite population. We have developed a protocol for rapid characterization (approx 10 minutes) to a level of around ± 5 ‰ in Ca and Ti isotopes. Using this approach we now have three hibonite inclusions with $^{50}$Ti abundances 20% or more above terrestrial. Characterization of these grains for other systems will be carried out but thus far there is little to indicate exceptional behaviour in REE, O isotopes, or Mg isotope systematics. Oxygen isotopes probably underwent exchange with an ambient nebular gas. REE abundance patterns suggest a nebular source and little input from presolar sources. Mg isotopes are near terrestrial consistent with the low $^{26}$Al/$^{27}$Al environment for these grains. This probably reflects the presence of nonradiogenic $^{27}$Al in the precursors [4]. Individual crystals appear to represent discrete entities with their own characteristics. The precursors were probably originally refractory dust; the hibonite crystals reflecting homogenization and crystallization in the early solar nebula. The outstanding issue with these grains is where they fit within the chronology of the solar system.

METACHONDrites: Recrystallized And/or Residual Mantle Rocks From Multiple, Large Chondritic Parent Bodies. A. J. Irving, T. E. Bunch, D. Rumble, III and T. E. Larson, 1 Earth & Space Sciences, University of Washington, Seattle, WA 98195 irving@ess.washington.edu; 2 Dept. of Geology, Northern Arizona University, Flagstaff, AZ 86011; 3 Geophysical Laboratory, Washington, DC 20015; 4 Los Alamos National Laboratory, NM 87545.

Although the concept that multiple, relatively large, and differentiated planetary bodies existed in the early asteroid belt is not new [1], only recently has evidence from meteorite samples has been marshalled to support this idea [2]. The recovery of new specimens from Northwest Africa has made it possible to forensically reconstruct such planetary bodies from fragments representing core, mantle, crust and regolithic rocks. This relies on the assumption that such fragments will share common oxygen isotopic signatures. Some specimens are highly recrystallized rocks devoid of chondrules which possibly represent mantle samples. The term primitive achondrite has been applied to such rocks; yet, if they are texturally evolved rocks from chondritic precursors, we suggest that metachondrite is a better term.

Metachondrite Groups: At least five different groups of metachondrites can be recognized, and each can be affiliated with a specific chondrite class utilizing oxygen isotopes:

CV NWA 3133, NWA 1839 [2]
CR NWA 3100, Tafassasset, LEW 88763 [2]
CH Lodranites, acapulcoites [3]
NWA 1463, NWA 1058 Winonaites (+ IAB irons)
H NWA 2353, NWA 2635, NWA 3145 (+ IIE irons)

Unique chondrites NWA 1463 [4] and NWA 1058 [5] may represent the regolith of the winonaite parent body [3]. Since these specimens contain obvious chondrules, they should not be termed achondrites (despite a likely genetic relationship).

Metachondrites From the H Chondrite Parent Body: NWA 2353 (paired with NWA 3145) and NWA 2635 have polygonal-granular textures, no chondrules and, respectively: mean grainsize (0.2; 0.5 mm), olivine (F978;8;18,7, FeO/MnO = 34.38; F289, FeO/MnO = 35), orthopyroxene (Fs15.8Wo1.1 to Fs16.8Wo1.2, FeO/MnO = 19.26; Fs16.8Wo2.6, FeO/MnO = 20), plagioclase (An12;Or3 to An27;Or2.5, An12(Or2.5), with accessory metal, chromite, merrillite and troilite. Clinopyroxene (Fs17.2Wo3.4 to Fs4.2Wo10.4, FeO/MnO = 16-22) occurs only in NWA 2353/3145. Their oxygen isotopic compositions (δ18O = 5.1, 5.10; δ17O = 3.31, 3.16; Δ17O = +0.440, +0.510 per mil for NWA 2353; δ18O = 3.23, 2.98; δ17O = 5.03, 4.37; Δ17O = +0.575, +0.676 per mil for NWA 2635) overlap those of H chondrites [6] and IIE irons [7].

Brachinites are rare clinopyroxene-bearing, dunitic achondrites with very ancient formation ages [1, 2]. A 1500 gram fairly fresh, dark brown stone with thin translucent fusion crust acquired in Morocco by Greg Hupé (provisional number NWA 3151) is the seventh known member of this group. Re-examination and oxygen isotopic analysis of NWA 595 indicate that it may be an ungrouped ultramafic achondrite unrelated to the brachinite parent body.

Petrology of NWA 3151: This dunitic rock is relatively coarse grained (0.7-1.6 mm) with a polygonal-granular texture. It is composed predominantly of olivine (~95 vol.%, Fa$_{35.7}$, FeO/MnO ~ 81) with minor clinopyroxene (Fs$_{10.5-10.6}$Wo$_{44.7-45.2}$, FeO/MnO ~ 44, Cr$_2$O$_3$ = 0.65 wt.%, Al$_2$O$_3$ = 0.95 wt.%), altered metal (with some relict taenite), troilite, chromite (Cr/(Cr+Al) = 0.729), and very rare K-poor, sodic plagioclase (An$_{36.2-39.9}$Or$_{0.2}$) and orthopyroxene. This rock has many similarities to brachinites EET99402/EET99407 [1].

Petrology of NWA 595: We have confirmed the previous description and mineral compositions for NWA 595 [3] (except that we judge the weathering grade to be only W2-3); yet some features are not consistent with its original classification as a brachinite. In comparison with Brachina, Eagles Nest, Reid 013, Hughes 026, ALH84025 and EET99402/7, NWA 595 has less ferroan olivine (Fa$_{28.30}$), more orthopyroxene, no plagioclase, and significantly lower FeO/MnO ratios for both olivine (~50) and clinopyroxene (~30), causing it to plot outside the main brachinite field defined by [4].

Oxygen Isotopic Compositions: Replicate analyses of acid-washed whole rock samples by laser fluorination gave $\delta^{18}$O = +4.86 ± 0.03, $\delta^{17}$O = +2.42 ± 0.02, $\Delta^{17}$O = -0.15 ± 0.02 per mil for NWA 3151, and $\delta^{18}$O = +5.30 ± 0.05, $\delta^{17}$O = +2.66 ± 0.04, $\Delta^{17}$O = -0.09 ± 0.01 per mil for NWA 595. The values for NWA 3151 are very similar to those for other brachinites [5] (and for ultramafic achondrite QUE 93148 [4, 6]), whereas the values for NWA 595 plot closer to the TFL.

Brachinite Parent Body Brachinites may represent residual mantle rocks, or possibly recrystallized igneous cumulates [1], from a disaggregated, differentiated planetary body in the very early asteroid belt. Although similar in oxygen isotopic composition to HED group meteorites, mesosiderites and angrites [5], the brachinites have different FeO/MnO systematics (and have more ancient formation ages than the first two types), implying that they derive from a separate body.

THERMOLUMINESCENCE STUDY OF SHOCKED SANDSTONE.
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Introduction: A semi-circular topographical feature (approximately 900 meters in diameter) is located in the eastern side of Mt. Oikeyama on Shirabiso Highland, which lies in the southern part of the Akaishi Mountains, Nagano Prefecture in Japan. Planar microdeformations of the quartz were found in sandstone from this area [1]. These planar microdeformations might be so-called planar deformation features (PDFs) that were formed by the impact more than 10GPa, suggesting that this structure also has formed by hypervelocity impact event [1-4]. In the present study, thermoluminescence (TL) of following three samples was measured to confirm the evidence of impact shock metamorphism. (1) Sandstone collected from outside of the crater, (2) Sandstone experimentally shocked by railgun experiments at 10GPa (abbreviated to railgun sandstone), (3) Metamorphic sandstone collected from inside of the crater at Mt. Oikeyama.

Thermoluminescence: Induced TL was measured after a dose of 250Gy ⁶⁰Co gamma ray irradiation. A new, relatively large, peak appeared at 350 °C in the TL glow curve of the railgun sandstone, comparing with that of the sandstone collected from the outside of the impact crater, in addition to common TL peak at 150°C. There is a slight bulge TL peak at 350 °C even in the metamorphic sandstone.

2D TL and compositional analysis: Firstly, 2 dimensional TL was measured with a 2D TL readout system to determine the positions responsible for the TL at 350 °C. Next, to specify the minerals emitting the TL we analyzed compositions of these positions in the sandstone samples by an EDS. Result shows that the mineral responsible for the peak at 350 °C is sodium-rich plagioclase, whereas potassium-rich feldspar is responsible for the TL at 150°C.

TL spectra analysis: The TL spectral measurements were carried out for three types of sandstone by a monochromator-attached 2D TL readout system. The new TL peak at 350 °C appeared at 380 nm for the railgun sandstone and the metamorphic sandstone, different from 420 nm emission at low temperature.

Conclusion: Experimental shock at 10GPa produced a new TL peak at 350 °C in sandstone. Sodium-rich plagioclase in sandstone is responsible for this new peak, of which wavelength is 380 nm. Sodium-rich plagioclase in the metamorphic sandstone shows also a slight bulge TL peak at 350 °C. These facts imply that sodium-rich plagioclase is a mineral to record shock metamorphism, and the semi-circular topographical feature at Mt. Oikeyama was formed by hypervelocity impact event.

ISHEYEVO: A NEW CB CHONDRITE. M.A. Ivanova¹, M.A. Nazarov¹, N.N. Kononkova¹, and F. Brandstaetter². ¹Vernadsky Institute of Geochemistry and Analytical Chemistry, Kosygin St. 19, Moscow 119991, Russia (venus2@online.ru). ²Naturhistorisches Museum, A-1010, Vienna, Austria.

Introduction: CB chondrites are rare metal-rich carbonaceous chondrites and are divided into two subgroups [1]: the CBₐ subgroup (Bencubbin, Weatherford and Gujba), and the CB₉ subgroup (HH237 and QUE94411). CBₐ chondrites are coarse-grained (up to 1 cm) and contain 40-60 vol% of FeNi metal. CB₉ chondrites are fine-grained and richer in FeNi metal (>70 vol%). CB₉’s also have CAIs, zoned metal grains and matrix lumps. In comparison with CHs, all CB’s lack POP chondrules. We report on petrography and mineral chemistry of Isheyevo, a new metal-rich carbonaceous chondrite found in Bashkortostan, Russia in October, 2003. Isheyevo is a CB chondrite with unusual features.

Results: The Isheyevo meteorite has a well-developed dark brown fusion crust and consists of FeNi metal grains, abundant CC, POP, PO, BO chondrules, rare zoned olivine-pyroxene chondrules, chondrule fragments, CAIs, and hydrated matrix lumps. Chondrules and metal grains are 0.02-1 mm in size. Isheyevo has petrological type 3, shock stage S1 and weathering grade W1.

FeNi metal content varies from 30 to 70 vol% in different sections. The mean is 52 vol%. FeNi metal grains are mostly homogeneous but some are zoned. Typical metal grains contain 4.2-8.4 wt% Ni, 0.2-0.5 wt% Co, and 0.03-0.6 wt% Cr, but there are rare FeNi grains containing 26 wt% Ni and 0.6 wt% Co. Nickel and Co are positively correlated; Cr is negatively correlated. The Co/Ni ratio of the Isheyevo metal is solar. In zoned metal grains, Ni content decreases and Cr increases smoothly towards the edges. Troilite blebs are enriched in Cr (2.5-13 wt%). Olivine and low Ca pyroxene are Mg-rich, Fa₂.₅ and Fs₂.₁Wo₁.₇ respectively and occur in Mg-rich POP and PO chondrules of Type I. Fe-rich olivine (Fa₁₀.₃₈) and pyroxene (Fs₆.₁₂Wo₀.₈₁) occur in Type II POP, PO, and BO chondrules containing a glassy mesostasis. Unusual zoned olivine-pyroxene chondrules are similar to those from the NWA 470 [2] and Acfer 182 [3] CH chondrites. Grossite-rich CAIs are abundant. INAA data for a 20 mg chip of Isheyevo are: 2.74 wt.% Ni; 717 ppm Co; 2608 ppm Cr, 8.2 ppm Sc, and 1.59 ppm Ir.

Discussion: Based on the FeNi metal content (30-70 vol%), Isheyevo definitely belongs to the CB chondrites. However, chondrule and metal grain sizes (0.02-1 mm) are similar to CH and CB₉ chondrites. Unlike all CB chondrites, chemical compositions of Isheyevo olivine and pyroxene are very variable. With both type I and II POP chondrules, Isheyevo is similar to CH chondrites, but not to any CB chondrites. Unusual zoned olivine-pyroxene chondrules are also typical for CHs. Similar to CB₉’s, Isheyevo contains CAIs, but grossite-rich CAIs are more abundant in CHs. Like CB₉’s and CH’s, Isheyevo has chemically zoned metal grains and heavily hydrated matrix lumps. CAIs, zoned FeNi metal grains, and Mg-rich chondrules have definite features of nebular condensation. In mineral chemistry, the presence of grossite-rich CAIs, POP and zoned chondrules, in chondrule and metal grain sizes, Isheyevo is closer to CHs and supports the genetic unity of the CR-CH-CB clan.