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TRACE ELEMENT ABUNDANCES OF NINETY REFRACTORY INCLUSIONS IN THE ALLENDE METEORITE. S. Wakaki and T. Tanaka. Department of Earth and Environmental Sciences, Nagoya University, Nagoya 464-8602, Japan. E-mail: wakaki@gcl.eps.nagoya-u.ac.jp

Introduction: We have determined major and trace element abundances of ninety refractory inclusions and twenty-eight chondrules in the Allende (CV3) meteorite by instrumental neutron activation analysis (INAA). Inclusions investigated are 31 coarse grained inclusions and 59 fine grained inclusions. Detailed mineralogical observations are going to be made at present.

Experimental: Very small amount of the inclusion (ca. 0.1 mg) was extracted from the center of each inclusion for INAA. Samples were irradiated at a thermal neutron flux of $8.7\text{--}9.8 \times 10^{13}$ n cm⁻² sec⁻¹ for 30 hours in the JRR-3 reactor of the Japan Atomic Energy Research Institute. Gamma-ray counting was carried out on Ge semiconducting detector at Nagoya University. GSJ reference sample JB-1a was used as a standard for Na, K, Ca, Sc, Cr, Fe, Co, Zn, Hf, Ta and Th. Reagents of PGEs and REEs were also used as a standard.

Results: REE abundances. Refractory inclusions are chemically characterized by their REE fractionation patterns [1, 2]. Six coarse grained inclusions and 30 fine grained inclusions show fractionated REE patterns (group II). Two sub types of group II can be distinguished by means of Eu, Yb and Lu abundances: group IIA shows no Eu and Yb anomalies [3] and group IIB shows only a slight depletion of Lu from the LREEs (La to Sm) with no Eu and Yb anomalies. Nineteen coarse grained inclusions and 9 fine grained inclusions show almost unfractionated REE patterns (group I, III, V, VI). We have found no fine grained inclusions with group I and VI REE patterns. Six coarse grained inclusions and 20 fine grained inclusions show unfractionated REE patterns with relatively low REE abundances ($< 10 \times \text{CI}$). Based on the low abundance of the refractory elements and following observations, we have referred these inclusions as Highly Altered Inclusions (HAIs).

PGE abundances. Group I, III, V, VI inclusions show unfractionated PGE pattern at 10 to 100 times CI chondrite and depleted in Au. Group II inclusions and HAIs show overall depletion of PGEs ($< 1 \times \text{CI}$).

Alteration features. Compared to the "normal" inclusions, most of the HAIs are depleted in Ca and enriched in Fe. Ca-Fe-Na contents of the HAIs were somewhat similar to those of the chondrules, suggesting that relatively-low-temperature minerals are dominant in these inclusions. We found no clear correlation between cross section area of the inclusion and refractory element depletion which [4] has suggested.

Ce anomaly. Two coarse grained inclusions (group I and II) and 4 fine grained inclusions (group II) are found to have negative Ce anomalies in their REE patterns (CI normalized Ce/La = 0.27-0.67). Negative Ce anomaly are interpreted to reflect the volatility of Ce under an oxidized conditions [5]. Since group II inclusions are thought to be condensates, these inclusions may suggest the presence of local oxidized conditions in the CAI forming region of the solar nebula.

References: [1] Mason B. and Martin P. M. 1977. Smithsonian Contribution to Earth Sciences 19:84-95. [2] Tanaka T. and Masuda A. 1973. Icarus 19:523-530. [3] Davis A. M. and Grossman L. 1979. Geochimica et Cosmochimica Acta 43:1611-1632. [4] Hayashi M. et al. 1995. Chikyukagaku (Geochemistry) 29:37-50. [5] Boynton W V. 1978. 9th Lunar and Planetary Science Conference. pp. 120-122.

HIGHLY SIDEROPHILE ELEMENT CONSTRAINTS ON THE LATE ACCRETIONARY HISTORIES OF THE EARTH AND MOON.

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Introduction: Recent smooth-particle hydrodynamic calculations suggest that there may have been sufficient silicate-metal mixing during the Moon-forming giant impact to provide a final cleansing of the terrestrial mantle of highly siderophile elements (HSE) [1]. Subsequent late accretion of the final ~0.4% of the mass of the Earth, required to explain the relatively high HSE abundances in the terrestrial mantle, may also have been accompanied by corresponding, albeit much lower, mass additions to the Moon. Consequently, HSE abundances within and on the surface of the Moon may provide valuable insights into the timing and origin of the late accreted materials [2-4].

Discussion: Results of recent study of lunar picritic glasses [4] suggest that the lunar mantle contains much lower abundances of HSE than previously assumed. If the picritic glasses are representative of the entire lunar mantle, this could suggest: 1) late accretion occurred after formation of the lunar crust, so that most of the lunar late accretionary material was added to the lunar crust rather than mantle, or 2) the late accretionary process was highly stochastic and the Earth received proportionally far more material than suggested by dynamical calculations, or 3) HSE added to the lunar mantle either remain in the lunar mantle, sited in metal that may be present in mantle melt residues, or were removed via late lunar core formation.

To address these issues, we are examining the HSE abundances and Re-Os isotopic systematics of lunar impact-melt rocks [e.g., 3], and late-stage basalts. The impact-melt rocks provide information regarding the relative abundances of the HSE in the impactors, a potentially important fingerprint that could reflect an inner or outer solar-system origin. Results for melt rocks that were likely formed by the Serenitatis impact suggest an enstatite-chondrite-like impactor [3,5], although potential indigenous contributions to the HSE budgets of the melt rocks complicate this interpretation.

Analysis of ca. 3.0-Ga basalts may help to assess whether or not metal that is potentially present in the lunar mantle, or metal extraction of HSE to the core, led to deceptively low abundances of HSE in picritic glasses or basalts. Metal-silicate segregation leads to fractionation of Re/Os from the chondritic ratios in the silicate fraction, so early segregation of HSE into core or mantle metal would likely have led to formation of non-chondritic Re/Os in the basaltic source regions. With >1 Ga after accretion of the Moon for isotopic evolution, the mantle source of the basalts would have distinctly non-chondritic ¹⁸⁷Os/¹⁸⁸Os by the time of eruption. Also, abundances of HSE such as Pt, Ru and Pd, which are normally not as strongly compatible as Os and Ir during mantle melting, may provide insights to HSE abundances in the basalt source regions.

References: [1] Canup R.M. 2004. *Icarus* 168, 433-456. [2] Morgan J.W. et al. 2001. *Met. & Planet. Sci.* 36, 1257-1275. [3] Norman M. et al. 2002. *EPSL* 202, 217-228 [4] Walker et al. 2004. *EPSL* 224, 399-413. [5] James O.B. 1996. *LPS XXVII*, 603-604.

CRYSTALLIZATION RATES OF SHOCK MELTS IN THREE MARTIAN BASALTS: EXPERIMENTAL SIMULATION WITH IMPLICATIONS FOR METEOROID LOFTING DIMENSIONS.

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Introduction: Melt pockets, thought to be the products of localized shock-induced melting, occur as subrounded to rounded enclaves of silicate glass and crystals, distributed heterogeneously throughout the groundmass of highly shocked martian meteorites (basalts and peridotites). The origin and, in particular, the crystallization conditions for melt pockets are not well constrained. This is due, in part, to the fact that analogous features have not yet been observed in naturally shocked rocks from terrestrial impact craters, nor in controlled laboratory shock-recovery experiments.

Experimental Rationale: This study addresses the crystallization conditions after shock pressure release. It is assumed that the melt pockets cooled during their ejection from the martian surface. Since the martian atmosphere is thin (~11 km) and ejection velocities are fast (≥ 5.0 km/s), the system is modeled as a whole, where the melt is cooled in space at 2.7 K. Cooling rate estimates for the melt pockets were made using an error function solution to Fourier's law and assuming all heat transfer is via conduction. The time required for solidification of the melt is calculated for varying distances from the space/melt contact.

Experimental Methods: Dynamic crystallization experiments have been performed on synthetic glasses representative of melt pocket compositions observed in Los Angeles (stone 1), SaU 150 and DaG 476 martian basalts.

Cooling Experiments: Cooling experiments were performed on small batches of melt held on a Pt wire loop and suspended in a gas-mixing furnace. All experiments were performed at QFM-2 at a constant degree of undercooling ($-\Delta T$ 208°C) while varying the cooling rate (56°C/hr – 3120°C/hr).

Fractal analysis: Fractal analysis allows quantification of natural objects that, at first observation, may appear to be random or chaotic. In this study we have implemented the correlation function technique [1] for measuring the fractal dimension, d_f , by analyzing crystal morphology using a custom-designed Texture Correlation Calculation (TCC) program, written in Visual Basic at UNB. This enabled quantification of the mineral crystallinity in order to compare dendritic melt pocket textures between crystals formed under controlled conditions in the experiments.

Results: Bases on qualitative (texture, mineral assemblage) and quantitative (fractal analysis) results, it is deduced that melt pockets in LA cooled at a rate of 1040°C/hr – 1560°C/hr ($-\Delta T$ 208°C). SaU 150 and DaG 476 melt pockets cooled at 780°C/hr ($-\Delta T$ 208°C). Conductive cooling models for a range of meteoroid diameters (0.1 – 1.0 m) show that the original meteoroid size was small, on the order of 10 – 15 cm and that melt pockets cooled from post-shock temperature within minutes (12 – 16 min).

Our results also have a bearing on trapped martian atmospheric components because it is during the liquid stage that the gases become trapped in the melt pockets. Modeling the system for argon diffusion in a sphere, it is shown that during crystallization ~20 – 30% of trapped martian atmospheric argon may be lost from the melt pocket through diffusive transport.

References: [1] Fowler A.D. 1995. *Fractals in the Earth Sciences*. (eds. C.C. Barton & P.R. La Point) pp. 237-249.

ALKALI-FELDSPATHIC MATERIAL ENTRAINED IN Fe,S-RICH VEINS IN A MONOMICT UREILITE Paul H. Warren. Institute of Geophysics, UCLA, Los Angeles, CA 90095, USA pwarren@ucla.edu.

Ureilites are remarkably poor in feldspathic matter. Until now, only vague mention has ever been made of feldspar within a monomict ureilite; An22 [1] and An36 grains [2] were mentioned in FRO90168 and EET96001, respectively. I have scrutinized thin section EET96001,7 and found a variety of felsic grains and glasses, confined to centers of three long, winding, uncommonly fat veins of Fe,S-rich matter (now weathered into mainly Fe-oxides). In the principal instance, the felsic portion of the vein spans ~1 mm, winding at several places in a manner that suggests gentle dilation of the peridotite host. These veins were not violently impact-injected. They oozed through the host, entraining the felsic matter within them.

The feldspathic matter is for the most part remarkably alkali-rich. About 24 vol% of it is glass (5 grains large enough for analysis) with average Na₂O of ~5.2 wt% and K₂O of ~ 3.8 wt%. Of the crystalline component, 43 vol% is silica (consistently Al-poor), 23 vol% is alkali feldspar, 23 vol% is pyroxene (obviously not associated with the host ureilite based on minor element ratios such as Fe/Me and especially Fe/Cr, which is way higher than normal for ureilite pyroxene), and 9 vol% is plagioclase. The alkali feldspar is generally close to An10An50Or40 but also includes one grain (2%) of orthoclase, An9Or90. One set of three grains, all within the most Na- and K-poor glass, is relatively calcic plagioclase, An64, and there is another small An48 grain. Most of the pyroxene is fassaitic (~10 wt% Al₂O₃ and 5 wt% TiO₂).

The alkalic nature of the most of the glasses and feldspars in EET96001 tends to suggest that fractional fusion was perhaps not as prevalent during ureilite anatexis as has been inferred from recent studies of clast assemblages in polymict ureilites.

References: [1] Mason B. (1998) *Ant. Met. Newsl.* 21(1). [2] Bland P. A. (1993) *Euromet Bull.* 2(1).

MAJOR-ELEMENT ISOTOPIC DATA AND THE BULK COMPOSITION AND ORIGIN OF THE MOON

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The Moon is widely believed to have formed as a result of a giant, extremely hot impact between Earth and a roughly Mars-sized intruder. During subsequent formation of the Moon, it is conceivable that Si+Mg+Fe recondensed less efficiently than Al other refractories. Taylor [e.g., 1] advocated a high bulk-Moon Al/Mg even before giant impact was first postulated. In this work, besides acquiring new laser-fluorination O-isotopic data for a variety of achondrites [cf. 2], we assess the plausibility of a highly unEarthlike major-element composition for the impactor assuming it contributed roughly half of the mass of the Moon.

Oxygen, Mg and Fe have the advantage of being major elements. Their geochemical traits cannot be attributed to some minor component whose provenance and/or physical evolution was atypical of the bulk Moon and Earth. Precise O- and Mg-isotopic matches between the Moon and Earth's mantle [3,4] eliminate Rayleigh distillation as a potential mechanism for achieving the putative lunar Al/Mg enrichment. In principle, a giant impact scenario could still, by non-Rayleigh volatility-depletion of Mg, engender a high Al/Mg. But credibility is further strained by the popular notion [e.g. 1] of a large enrichment in the comparatively volatile FeO vs. the (silicate) Earth. Among major elements, FeO loss should have been the most extensive of all post-impact volatility-related fractionations. Assuming volatility fractionations can be neglected, mass balance (lever rule) calculations indicate that the Al- and FeO-enriched Moon hypothesis [1] implies that the composition of the impactor ("Theia" [3]) must have been grossly dissimilar to that of the protoEarth; especially in models assuming moderate-high protoEarth component in the Moon. For example, if the protoEarth component is >0.5 , a disparity in FeO of ≥ 3 is implied by levering a bulk Moon with 13 wt% FeO [1] and a literature average for the bulk-silicate Earth [5].

A low proportion of protoEarth in the Moon runs into difficulty with the O-isotopic data. Based in part on our own new data for a variety of achondrites, including mesosiderites and pallasites [2], the eight most Earthlike meteorite parent bodies (including the Moon) have average $\Delta^{17}\text{O} = -0.06 \pm (1-\sigma) 0.18\text{‰}$; a similar average but much larger σ would result from inclusion of less Earthlike meteorites such as winonaites or acapulcoite-lodranites. The σ of 0.18‰ indicates how improbable a close match between Theia and the protoEarth ($\Delta^{17}\text{O}$ inferred by [3] to be identical to within 0.03‰) would be, unless the two bodies are both products of *extensive mixing of a similar variety of initial materials*. But with an Al- and FeO-enriched bulk Moon, special pleading is required to explain why the same extensive mixing that homogenized the O isotopes did not produce similar major-element compositions for "Theia" and the protoEarth.

Besides isotopic similarity, the lunar FeO/MnO is difficult to reconcile with an FeO-enriched bulk Moon. Among primitive materials, a 3-fold disparity in FeO would suggest a comparable disparity in FeO/MnO. Recent sample and remote-sensing data favor a bulk-Moon composition that resembles Earth's mantle, except for depletions in volatile minor elements [4].

References: [1] Taylor S. R. 1999. In *Encyclopedia of the Solar System*. [2] Young E. D. & Ziegler K. 2005, this volume. [3] Wiechert U. et al. 2001. *Science* 294: 345-348. [4] Warren P. H. et al. 2005. *LPS* 36. [5] Warren P. H. 2005 *MPS*, in press.

LOSS OF HIGHLY VOLATILE ELEMENTS FROM ORDINARY CHONDRITES DURING IMPACT HEATING.

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In the ordinary chondrites the highly volatile elements show large ranges among the petrographic types. The best defined variation is for In among the L chondrites; Fig. 1 shows In data [1] plotted against type No. The range in In is a factor of 1000; the mean of the L3 chondrites is 85× higher than that in the L6 chondrites. Relatively large Bi and Tl differences among the petrographic types are also observed, though somewhat less regular than those in In [2].

The original interpretations of these variations were that they reflect outgassing associated with the heating that produced the metamorphic recrystallization [1] or that they reflect nebular accretion temperatures, i.e., that accretion occurred simultaneously with planetesimal formation [2]. The latter model requires that the planetesimals then sequentially accreted to form layered asteroids with the first condensed materials forming the lowest layers, the last accreted forming the outermost layers, and an internal heat source producing the observed metamorphism effects.

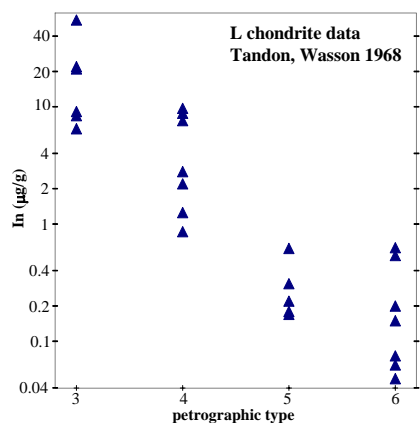


Fig. 1. Mean L3 In concentrations are 85× higher than mean L6 concentrations; the total range is a factor of 1000.

A key problem with the latter model is that asteroid growth involved random collisions that randomly mixed early-condensed and late condensed objects. A serious problem with associating the volatile loss with metamorphism is that heating only causes the elements to enter the local gas phase, but no net loss occurs if this gas remains in local voids until the asteroid cools down below the evaporation temperature. Also, the volatilities depend on the redox and other conditions in the asteroid.

There is increasing evidence that the metamorphism of chondrites was the result of impact heating [e.g., 3]. If this is correct, it raises the issue of how In and other volatiles were lost. In fact, flash vaporization of late, fine-grained nebular materials that are carriers of the highly volatile elements would lead to high loss factors for all elements within this component, but negligible loss of other materials of similar volatility but sited in components that were not vaporized. Because impacts occur on the surface of the asteroid, flash evolved gases can escape, in contrast with internally evolved gases that recondense in overlying layers.

References: [1] Tandon S. N. and Wasson J. T. (1968) *Geochimica et Cosmochimica Acta* 32, 1087. [2] Keays R. R, et al. (1971) *Geochimica et Cosmochimica Acta* 35, 337. [3] Rubin A. E. (2004) *Geochimica et Cosmochimica Acta* 68, 673.

OLIVINE IN CV CHONDRITE MATRICES: STRUCTURE, SIZE-DISTRIBUTION AND MORPHOLOGY. L. E. Watt¹, P. A. Bland¹, D. J. Prior² and S. S. Russell³. ¹IARC, Dept. Earth Science & Engineering, Imperial College, London SW7 2AZ, UK. (lauren.watt@imperial.ac.uk). ²Dept. Earth & Ocean Sciences, University of Liverpool, 4 Brownlow Street, Liverpool L69 3GP, UK. ³IARC, Dept. Min., Natural History Museum, London SW7 5BD, UK.

Introduction: The CV3 chondrites were originally divided into the oxidized (CV_{ox}) and reduced (CV_R) subgroups based principally on their modal metal/magnetite ratios and the Ni content of the metal and sulfides [1]. Later studies [e.g. 2] have shown that the oxidized CV3s can be divided into two additional subgroups, Bali-like (CV_{oxB}) and Allende-like (CV_{oxA}), each showing characteristic alteration features. These divisions are thought to be correlated to the degree and temperature of aqueous alteration experienced by these meteorites [3].

Methodology: Recent work by Watt et al. [4] has shown that olivine crystallography is related to its formation mechanism, concluding that the short a-axis crystal morphology for Allende (CV_{oxA}) matrix olivine is consistent with a formation by dehydration of phyllosilicates. In this study we have used electron backscatter diffraction (EBSD) to analyze olivine in the matrices of a variety of CV3 chondrites, in order to determine if there is a systematic variation between the different subgroups. We have determined grain size distributions, crystal structure data and olivine morphology ratios. Meteorites analyzed include: CV_R = Vigarano, Leoville & Efremovka; CV_{oxB} = Bali, Kaba & Mokoia; CV_{oxA} = Allende, Axtell & ALH84028.

Results: Analysis of our data highlights the following:

1. *Grain Size Distributions:* Cumulative grain size frequency plots reveal that the CV_{oxB} meteorites have similar distribution trends, while the CV_R meteorites appear to differ; CV_R distributions can be approximated by an appropriate power law, while CV_{ox} distributions cannot.
2. *Olivine Crystal Structure:* Where crystal structural data can be determined (i.e. in euhedral, lath shaped olivine), there is a consistent short a-axis crystal morphology for the olivine in the matrices of the CV_{ox} meteorites. This differs to the CV_R meteorites, where there is an inconsistent crystal morphology, with examples of short a, b and c axes observed.
3. *Olivine Morphology:* There is a systematic change in the ratio of euhedral laths (aspect ratio >2) to sub/anhedral grains between the 3 groups; CV_R ~ <20%, CV_{oxB} ~ 20-25%, CV_{oxA} ~ 25-35%.

Conclusions: There is a systematic variation in matrix olivine between the different CV3 subgroups, particularly between the CV_{ox} and CV_R subgroups. We propose that the variations in olivine characteristics, between the different subgroups, are related to the formation mechanisms by which the olivine has formed. The occurrence of abundant, euhedral, lath-shaped fayalitic olivine with consistent short a-axis crystal morphology and a characteristic grain size distribution in the matrix of the CV_{ox} meteorites can be attributed to a formation mechanism of dehydration of phyllosilicate [4]. It would appear that the CV_R subgroup has largely escaped these processes.

References: [1] McSween, H. Y. 1977. *GCA* 41:1777-1790. [2] Weisberg, M. K. et al. 1997. *MAPS* 32: A138-139. [3] Krot, A. N. et al. 1998. *MAPS* 33:1065-1085. [4] Watt, L. E. 2005. *LPSC XXXVI*: # 1305.

FOUNTAIN HILLS IMPACT MELTED CB CHONDRITE AND THERMAL HISTORY OF THE CB PARENT BODY.

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Introduction: CB chondrites have characteristics that sharply distinguish them from other chondrites including (1) high metal abundances (60-80 vol.% metal), (2) most chondrules are cryptocrystalline or barred, (3) moderately volatile lithophile elements are highly depleted and (4) nitrogen is enriched in the heavy isotope [1]. The unusual characteristics of the CBs, the possibility of a relatively young formation age for some CB chondrules [2] and trace element compositions of some CB metal that are consistent with condensation from a dense metal-rich gas [3], suggest that impact played a major role in the formation of CB chondrites. Fountain Hills (Arizona) is a recent find that has oxygen isotopic and mineral compositions that indicate it is a CB chondrite, but has textural characteristics that differ dramatically from other CBs and its $\delta^{15}\text{N}$ value is relatively low [4]. We studied Fountain Hills to understand the thermal history of the CB parent body.

Results: Texturally, Fountain Hills (FH) differs from other CBs. Metal is less abundant (26 vol. %) and is distributed throughout the meteorite, interstitial to the silicates. Additionally, the metal is strewn with small mineral and barred chondrule fragments. In other CBs metal occurs as discrete inclusions or fragments and is generally not associated with silicate. FH contains barred and porphyritic chondrules as well as large olivine phenocrysts up to 1 mm in size. Porphyritic chondrules are rare in other CBs and large olivine is not present. Most mineral and chondrule fragments in FH are surrounded by a mixture (melt) of fine anorthite - high-Ca-pyroxene - Si, Al-rich glass and coarse pyroxene grains. Some barred olivine fragments appear to be integrated into this material and their boundaries are obscured. Compositionally, FH is fairly homogenous. Average olivine is $\text{Fa}_{3.4}$ (s.d.=1.7). The coarse pyroxene is $\text{Wo}_{3.4}$, $\text{Fs}_{3.7}$ with 1.7 wt. % Al_2O_3 . The anorthite is pure, the fine Ca-pyroxene has up to 2 wt. % TiO_2 and 7 Al_2O_3 , the glass has 65 SiO_2 and 19.1 Al_2O_3 .

Discussion and Conclusions: FH is a partly melted CB chondrite. It experienced melting and redistribution of metal and possibly drainage of some metal resulting in its lower metal abundance relative to other CBs. Since the metal is one of the major nitrogen carriers in the CB chondrites [5], melting and separation of metal may account for the low $\delta^{15}\text{N}$ values of FH [4]. Some relict barred and porphyritic chondrules survived melting while others were completely melted or partly assimilated into the melt, which crystallized to produce olivine phenocrysts and the surrounding anorthite-pyroxene mixture. All of the CBs experienced some degree of post-accretion impact melting as evidenced by small amounts of melt at boundaries between their metal and silicate components. FH is a record of much greater degrees of impact melting than that recorded in the other CB chondrites.

References: [1] Weisberg M. K. et al. 2001. *Meteorit. & Planet. Sci.* 36, 401-418. [2] Amelin Y. and Krot A. E. 2005. *LPSC* 36, abstract # 1247. [3] Campbell et al. 2002. *Geochim. Cosmochim. Acta* 66, 647-660. [4] Lauretta et al. 2004. *LPSC* 35, abstract # 1255. [5] Sugiura N. et al. 2000. *Meteorit. and Planet. Sci.* 35, 987-996.

TERRESTRIAL AGE SURVEY OF ANTARCTIC METEORITES.

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Introduction: Terrestrial ages of Antarctic meteorites provide information on meteorite accumulation mechanisms, pairing, mean survival lifetimes and meteorite influx rates. A timely survey of terrestrial ages from various Antarctic ice fields may also provide guidance for the planning and prioritization of future ANSMET (Antarctic Search for Meteorites) field activities. We have begun a systematic survey of terrestrial ages of Antarctic meteorites. The results (prior to final publication) will be reported to MWG and will be published in the Antarctic Meteorite Newsletter.

Method. The determination of terrestrial ages using ³⁶Cl (half-life = 3.01x10⁵ yr) is a long-term on-going project [1]. Carbon-14 is also used to determine terrestrial ages but can be detected in only 30-50% of the Antarctic meteorites. The detection limit of ¹⁴C corresponds to a terrestrial age of ~35 kyr, so the longer half-life of ³⁶Cl makes it a superb analytical tool for meteorites having terrestrial ages of 35 kyr to ~3 Myr. For more than 90% of the ordinary chondrites, the measurement of ³⁶Cl suffices to ascertain terrestrial ages. The ³⁶Cl terrestrial age, T_{terr} is calculated by the following equation;

$$T_{\text{terr}} = \frac{1}{\lambda} \ln \left(\frac{A_0}{A} \right)$$

where, λ is the ³⁶Cl decay constant, A₀ is the ³⁶Cl saturation value, and A is the observed ³⁶Cl activity in the metal phase. For ordinary chondrites the saturation value is 22.1±2.8 (±2σ) dpm/kg metal [2].

Experimental: We selected ~180 ordinary chondrites from the ANSMET collections. We crush 2-3 g of each meteorite, separate the metal and purify the metal with 0.2N HCl and concentrated HF to dissolve attached troilite and silicates, respectively. After purification, the metal is dissolved along with 1-2 mg of Be, Al, Ca, and 3-5 mg of Cl carrier. After dissolution of the metal, we take small aliquots for chemical analysis by atomic absorption spectrometry. From the remaining solution we separate the Cl as AgCl and purify the AgCl for analysis of ³⁶Cl by accelerator mass spectrometry (AMS) at Purdue University. So far, we have processed ~130 meteorites. We will measure ³⁶Cl in ~100 samples in the next few months. In addition, non-magnetic fractions are available for noble gas analysis, ¹⁴C measurements, and other studies.

Metal composition: We routinely measure the concentration of Mg, Fe, Ni and Co in the metal fraction. The concentration of Mg is a measure of the amount of silicate contamination, which is generally <0.5 wt%. The concentrations of Ni and Co are functions of the chondrite type, increasing from H to L to LL chondrites [3,4]. Based on the measured Ni and Co concentrations and bulk metal contents we identified 10 chondrites that may need further petrologic examination.

References: [1] Nishiizumi K. et al. 1989. *Earth and Planetary Science Letters* 93:299-313. [2] Nishiizumi K. 1995. *LPI Technical Report Number 95-02*, pp. 53-55. [3] Rambaldi E. 1976. *Earth and Planetary Science Letters* 31:224-238. [4] Rambaldi E. 1977. *Earth and Planetary Science Letters* 36:3474-358.

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COSMOGENIC RADIONUCLIDE EVIDENCE OF A LARGE AND HETEROGENEOUS H3-6 CHONDRITE SHOWER: FRONTIER MOUNTAIN 90174. K. C. Welten¹, K. Nishiizumi¹, D. Hillegonds², M. W. Caffee³ and L. Folco⁴. ¹Space Sciences Laboratory, University of California, Berkeley, CA 94720. E-mail: kcwelten@berkeley.edu. ²CAMS, Lawrence Livermore National Laboratory, Livermore, CA 94550. ³Department of Physics, Purdue University, West Lafayette, IN 47907. ⁴Museo Nazionale dell'Antartide, Siena, Italy.

Introduction: Identifying large chondrite showers in the Antarctic meteorite collection is a challenging task driven by two objectives: it removes the bias of these showers for determining meteorite influx rates and it identifies possible candidates of complex exposure histories, which seem more frequent among large objects. As part of a study of the terrestrial ages and exposure history of H5 and H6-chondrites from Frontier Mountain (FRO), we previously identified a large shower, FRO 90174 [1]. The concentrations of cosmogenic ¹⁰Be, ²⁶Al, ³⁶Cl and ⁴¹Ca in the stone and metal fraction of nine members belonging to this shower constrained its pre-atmospheric radius to 80-100 cm [2]. We now present cosmogenic radionuclide data in 14 additional FRO H-chondrites of all petrologic types. Our results provide key evidence that the FRO 90174 shower is much more heterogeneous than previously assumed and dominates the FRO meteorite population.

Radionuclide concentrations. We separated and purified the metal fraction of 14 FRO H-chondrites. Cosmogenic ¹⁰Be, ²⁶Al, ³⁶Cl and ⁴¹Ca in the metal fractions were measured by accelerator mass spectrometry (AMS) at Lawrence Livermore National Laboratory. For 7 FRO H-chondrites, we analyzed cosmogenic radionuclides in the stone fraction at the AMS facility of Purdue University. The noble gas concentrations and detailed exposure history of this shower is discussed in [3].

Ten of the 14 FRO H-chondrites measured in this study show low concentrations of cosmogenic radionuclides in the metal phase, indicating they have the same terrestrial age, 100±20 kyr, and experienced similarly high shielding conditions as the FRO 90174 shower [1,2]. The ²⁶Al concentrations in the stone fraction of 7 H-chondrites also overlap with those previously measured for the FRO 90174 shower [2], confirming that all these specimens came from the same large object. The FRO 90174 shower now includes samples of all petrologic types (3-6) as well as fragments with a brecciated nature. The cosmogenic nuclide results thus corroborate that the specimens of the FRO 90174 shower are small samples (the largest one is merely 44 g) of a heterogeneous lithology which should be classified as an H3-6 breccia. This heterogeneous shower confirms a recent hypothesis that many brecciated ordinary chondrite showers may have gone unnoticed in the Antarctic meteorite collections [4].

Mass distribution: The cumulative mass distribution of 467 FRO H-chondrites is not smooth like that of the FRO L-chondrites, but shows a steep increase at ~30 g. This feature can be attributed to the FRO 90174 shower, which is dominated by many fragments <30 g. From the mass distribution we estimate that more than 300 of the 467 H-chondrites are part of the FRO 90174 shower. This large shower thus explains the high H/L-chondrite ratio (3.8) at FRO.

References: [1] Welten K. C. et al. 1999. *Antarctic Meteorite Research* 12:94-107. [2] Welten K. C. et al. 2001 *Meteoritics & Planetary Science* 36:301-317. [3] Leya I. et al. (this issue). [4] Welzenbach L. et al. 2005. Abstract #1425, 35th *Lunar and Planetary Science Conference*.

VOLATILE TRACE ELEMENT DISTRIBUTION IN CARBONACEOUS CHONDRITES. S. F. Wolf. Dept. of Chemistry, Indiana State University, Terre Haute, IN 47809-5901. E-mail: wolf@indstate.edu.

Introduction: Due to their high volatility during primary nebular condensation and high mobility during post-accretion heating processes, the cosmochemically volatile trace elements (VTEs) are sensitive markers of low temperature thermal processes [1]. While the VTEs are thought to occur as trace components in all mineral phases, their primary disposition with respect to mineral phase chemistry in primitive meteorites is uncertain [2]. Specific information regarding the siting of VTEs could potentially address several fundamental questions about the genesis and evolution of chondritic material. In an effort to gain a greater understanding of the siting of the VTEs we are initiating a study in which the VTE-rich carbonaceous chondrites Allende (CV3) and Murchison (CM2) are subjected to stepwise chemical dissolution to sequentially dissolve constituent mineral phases. We subsequently determine concentrations of major, minor, and trace elements in these sample leachates and evaluate element release trends to draw conclusions regarding the host phase of the individual VTEs.

Methods: We used a modified dissolution procedure based on the method of Podosek et al. [3]. In our procedure 1-g aliquots of powdered homogenized samples of each meteorite were treated with a series of increasingly aggressive reagents: H₂O, 9 M CH₃COOH, 4 M HNO₃, 6 M HCl, and concentrated HF/HCl. The resulting leachates were analyzed for major, minor, and trace meteorite elements via inductively coupled plasma mass spectrometry (ICPMS). Fractional releases of individual VTEs were calculated relative to bulk concentrations reported in Wolf et al. [4].

Preliminary Results: Here we present preliminary results for fractional releases of the VTEs Cd, Bi, Tl, and In from Allende and Murchison. The highest release fractions for Cd and In were measured in the 9 M CH₃COOH treatment. Greater than 0.8 of the total inventory of Cd and In were released from both meteorites with this treatment. Less significant but measurable fractions of Bi (0.15 and 0.20 for Allende and Murchison, respectively) and Tl (0.04 and 0.02 for Allende and Murchison, respectively) were also present in this leachate. The highest release fractions for Bi and Tl were measured in the 4 M HNO₃ treatment with 0.4 of the Bi inventory and 0.8 of the Tl inventory released from both meteorites. Our results suggest that Cd and In and to a lesser extent Tl and Bi are present in one or more readily soluble secondary phase such as a carbonate or sulfate or are present in readily exchangeable mineral surface sites. High fractional releases of Tl and Bi in the HNO₃ treatment are consistent with the hypothesis that a significant fraction of these elements are sited in HNO₃-soluble phases such as sulfides. Correlation of major, minor, and trace element releases will be used to further elucidate elemental release patterns.

References: [1] H. Palme et al. 1988. In *Meteorites and the early Solar System*. Tuscon: Univ. Arizona Press 1269 p. [2] M. E. Lipschutz and D. S. Woolum 1988. In *Meteorites and the early Solar System*. Tuscon: Univ. Arizona Press 1269 p. [3] Podosek F. A. et al. 1997. *Meteoritics & Planetary Science* 32:617-627. [4] Wolf S. F. et al. 2005 *Anal. Chem. Acta* 528:121-128.

SORTING AND CONCENTRATION OF CHONDRULES AND CAIs IN A LATE SOLAR NEBULA

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Introduction: Chondrules are found in asteroid belt objects, they are strongly concentrated, often seem to be sorted somehow, and they are found side by side to CAIs which are more than 1 million years older. We offer a unifying explanation how all these phenomena and probably more details are inevitable to occur under the single assumption that a force known as photophoresis can be applied.

The assumption: Only one assumption is needed, namely that chondrules formed when the solar nebula turned optically thin but still had a significant amount of gas. This is a very probable evolution of protoplanetary disks. The solid fraction evolves to larger bodies like planetesimals, terrestrial planets or giant planet cores. This reduces the amount of dust which is responsible for the absorption of the starlight. Eventually after less than 5 million years the disks turn optically thin [1]. However, according to the standard model of planet formation, gas still has to be present to be accreted, e.g. to form Jupiter [2]. Therefore, there probably was a time when the solar nebula was optically thin but still contained a large amount of gas. This is the only assumption we make.

The force: Once the solar nebula turned optically thin all particles were exposed to the light of the young sun. This light heats particles usually stronger on the side facing the sun than on the back side. Gas molecules accommodated on the surface leave with different temperatures (velocities) and a net force away from the sun results on the particles. This effect is called photophoresis [3]. The strength of the force depends on the gas pressure so it will be stronger in the denser inner parts and weakens further out.

The effects: This force in combination with gravity naturally leads to sorted ring like structures around the sun where particles with specific thermal properties and density are strongly concentrated [4]. Other particles are cleared out at the same time. Aggregates and larger bodies concentrate in the region of the Kuiper belt and might even trigger its formation [4]. Chondrule like particles concentrate in the region of the asteroid belt [5]. Photophoresis also prevents CAIs formed in a still optically thick disk from spiraling into the sun. Once the disk gets optically thin they are concentrated together with forming chondrules which naturally explains the age difference. In the context of chondrules and CAIs photophoresis is not only providing one more mechanism of sorting and concentration. If the one assumption is valid, concentration and sorting *inevitably* occur. Photophoresis has never been considered before for this application though the effect is almost impossible to be undone. We think that the simplicity, strength, and unifying features of the effect are quite unique.

References: [1] Haisch et al. 2001. *Astrophysical J* 553:L153-L156. [2] Pollack J. B. et al. 1996. *Icarus* 124:62-85. [3] Tong N. T. 1975. *J. of Colloid and Interface Science* 51:143-151. [4] Krauss O. and Wurm G. 2005. *Astrophysical J* (accepted). [5] Wurm G. and Krauss O. 2005. *Icarus* (submitted).

MINERALOGY AND OXYGEN ISOTOPIC COMPOSITIONS OF AN AUGITE-ORTHOPYROXENE BEARING UREILITE.

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Ureilites are the second largest group of achondrites, and are principally composed of olivine, pigeonite, and minor phases. We report mineralogy and oxygen isotopic compositions of two new ureilites, NWA2236 and NWA2234, recovered from hot deserts. We used an optical microscope, SEM, EPMA, and Raman spectroscopy for mineralogical examination.

NWA2236 is composed of medium to coarse-grained olivine (~46 vol%), orthopyroxene (~41 vol%), diopside (~6 vol%) and minor opaque phases (~6 vol%). We found graphite grains up to 0.6 mm at the grain boundaries. A few olivine crystals grow larger up to ~3 mm than average grains along one direction. This meteorite is weakly shocked, with rare mosaicism in olivine, but orthopyroxene grains show fine linear features along (100) under cross polarized light. This texture is similar to those observed for Y-791538 with the presence of minor unit-cell scale twinned clinoenstatite sequences [1]. Equilibration temperature of ~1250°C was deduced from pyroxene geothermometer [2].

NWA2234 is an ordinary ureilites, composed of coarse-grained, olivine (Fo82-92) and pigeonite (Wo9En74), with minor amount of opaque phases along grain boundaries. This ureilite is slightly shocked (S3). Olivine grains are dusty and have dark patches in cores due to the presence of fine inclusions of Fe-FeS, probably formed by later reduction. The reduction texture of pigeonite is not prominent.

The oxygen isotopic compositions of NWA2234 ($\delta^{17}\text{O} = 3.77$, $\delta^{18}\text{O} = 8.73$, $\Delta^{17}\text{O} = -0.77$) and NWA2236 ($\delta^{17}\text{O} = 0.85$, $\delta^{18}\text{O} = 5.74$, $\Delta^{17}\text{O} = -2.14$) are roughly plotted along the slope-1 trend on the oxygen 3-isotope plot, with near the highest and lowest $\Delta^{17}\text{O}$ values of ureilites [3]. These O-isotopic data are correlated with the Fo contents, a normal trend observed in other ureilites.

NWA2236 is a new member of rare augite-bearing ureilites, and is the most magnesian. This ureilite is similar to LEW85440, but diopside in NWA2236 is more abundant. The presence of graphite grains and grain boundary textures suggest that it is a residue after extraction of partial melts. The presence of primary augites both in magnesian and ferroan ureilites argue against simple magmatic differentiation in a single reservoir [1]. These facts imply that the petrogenetic origin of ureilites are complicated.

References: [1] Takeda H. 1989. Earth and Planetary Science Letters, 93, 181-194. [2] Kretz R. 1982. Geochimica et Cosmochimica Acta, 46, 411-421. [3] Clayton R.N. and Mayeda T.K. 1988. Geochimica Cosmochimica Acta, 52, 1313-1318.

METALLOGRAPHIC COOLING RATE OF THE IIIAB MAGMATIC IRON METEORITES.

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Introduction: Chemical evidence suggests that meteorites in a given magmatic iron meteorite group are representatives of the core of one parent body. It follows that the cooling rate of each magmatic iron meteorite group should be same because of the high thermal conductivity of the metal core. However, measured cooling rates in magmatic group IVA vary significantly with bulk Ni [1-3]. Although Rasmussen [4] argued that his measurements of cooling rates in group IIIAB were the same throughout the chemical group, the cooling rate variation for a given meteorite is often larger than one order of magnitude and the cooling rate range for the chemical group as a whole is almost an order of magnitude. Recent improvements in the metallographic cooling rate models has allowed us to remeasure the cooling rates in the IIIAB chemical group with much greater accuracy.

Cooling Rate Model: The metallographic cooling rate computer model developed by Yang et al. [3] was used in this study. Parameters such as the Fe-Ni and Fe-Ni (P sat.) phase diagrams, and the interdiffusion coefficients are given in this model. However, the computer model requires a knowledge of the nucleation temperature of the Widmanstätten pattern and the mechanism which controls the growth of the Widmanstätten pattern. We used the methodology given Yang and Goldstein [5]. Three mechanisms control the formation of the Widmanstätten pattern in group IIIAB irons as determined from the bulk Ni and bulk P content of the individual meteorites. We observed the mechanism, $\gamma \rightarrow \gamma + \text{Ph} \rightarrow \alpha + \gamma + \text{Ph}$ for high Ni, high P IIIAB irons, $\gamma \rightarrow \alpha_2 + \gamma \rightarrow \alpha + \gamma$ for low Ni, low P IIIAB irons and $\gamma \rightarrow (\alpha + \gamma) \rightarrow \alpha + \gamma + \text{Ph}$ at intermediate Ni and P contents.

Measurements: Ni compositions were measured across Widmanstätten bands using EPMA. The crystallographic orientations of the Widmanstätten bands were obtained using optical microscopy and electron back scattered diffraction (EBSD). The orientations were used to obtain the correct widths of the taenite regions which were measured.

Metallographic Cooling Rate in IIIAB. We investigated 14 IIIAB irons, which includes a range from low Ni to high Ni members of the chemical group. The central taenite Ni vs. taenite half-width method [6], Wood method, was used to determine the cooling rate of each meteorite. Eleven members of group IIIAB have a very similar cooling rate of 75 to 150 C/My. The three lowest Ni members of the group show a higher cooling rate (300 to 400 C/My). Our measured cooling rates suggest a metallic core in which most of the IIIAB irons cooled at a very similar cooling rate except that a few IIIAB irons which cooled at relatively higher cooling rates. The few irons with higher cooling rates could be positioned near the core-mantle boundary.

References: [1] Moren A. E. and Goldstein J. I. 1979. *Earth and Planetary Science Letter* 43:182-96. [2] Rasmussen K. L. 1995. *Geochim. Cosmochim. Acta* 59:3049-59. [3] Yang J. et al. 2005. 36th Lunar and Planetary Science Conference, #1347. [4] Rasmussen K. L. 1989. *Icarus* 80:315-325. [5] Yang J. and Goldstein J. I. 2005. *Meteoritics & Planetary Science* 40:239-254. [6] Wood J. A. 1964. *Icarus*, 3:429-59.

HYPERVELOCITY IMPACT TRACK MORPHOLOGY ON THE SPACE-EXPOSED AEROGEL ONBOARD THE EURECA SPACECRAFT ANALYZED WITH OPTICAL IMAGERY AND 3D MICRO-TOMOGRAPHY. H. Yano¹, T. Okazaki², J.A.M. McDonnell³, T. Nakano⁴, T. Noguchi⁵, K. Okudaira^{6,1}, and A. Tsuchiyama². ¹JAXA/ISAS, ²Osaka University, ³Open University, U.K., ⁴AIST/GSJ, ⁵Ibaraki University, ⁶Graduate University for Advanced Studies.

Introduction: The European Retrieval Carrier (EuReCa) was exposed in the Low Earth Orbit for 326 days in 1992-93 [1]. It carried the first space exposed silica aerogels for intact capture of micrometeoroids and space debris. It carried four 100mmx100mmx6mm aerogel blocks of 0.062 g/cc density and the results proved the feasibility of this ultra-low dense amorphous silica material as the capturing media of hypervelocity microparticles [2, 3]. Thereafter the aerogels were deployed for other space experiments (i.e., Euro-Mir95, ODC, MPAC-SEED) and interplanetary missions (i.e., Stardust).

Optical and Laser Microscope Studies: One of the four EuReCa aerogel modules was first inspected with optical microscope and laser microscope [2]. Four "carrot tracks" and other shallower crater/dent features formed by hypervelocity impacts are documented in detail. Two out of four are branched tracks and one of them "9-C" has a 95.2-micron mean entrance diameter and 229.2 and 221.7-micron branch lengths with 3.6 and 9.0 micron residues captured at their ends.

X-ray Tomography: The 9-C track was then observed at SPring-8 using a X-ray micro-computed tomography with effective spatial resolution of 0.47 micron. Details of this technique are described at elsewhere [4]. This is the first actual space-exposed aerogel track and the smallest sample ever tested with this technique. In transmittance images, the inner wall of the track exhibits high refraction contrast due to the density increase from either ablated melting or compaction during the excavation and radial expansion of the track. It is also revealed the 3-D distribution of spike cracks, fragments and the largest residues at both end tips. The track volume was estimated to 6.280×10^{-7} cm³, much accurately than image analysis.

Discussion: We also investigated whether the samples contain Fe by imaging just above and below the X-ray absorption energy thresholds of the element. As the result, the 9-C residues did not exhibit Fe so that it may well not be Fe-rich micrometeoroids but more favor of slow, mono-metallic orbital debris (e.g., Al, Ti). In this way, the XCT technique can be the first estimate of the impactor origin before Raman spectroscopy or other analyses of extracted particles. Once the impactor origin is defined, data from calibration impact experiments (e.g., [5]) will help XCT volume analyses of the tracks to determine impact condition and original size of the impactor. In conclusion, this analytical method is valid for actual space experiments like the ISS and the Stardust, in most of which expect 10-micron order impactors and sub-mm long tracks.

References: [1] Yano H., et al. 1996. *Advances in Space Research*, 17, No. 12:189-192. [2] Yano H., 1995. *Ph.D. Thesis*, Univ. of Kent at Canterbury, U.K., 286 pages. [3] Burchell M.J., et al. 1999. *Planetary & Space Science*, 47:189-204. [4] Tsuchiyama A. et al. 2005. this volume. [5] Okudaira K. et al. 2004. *Advances in Space Research*, 34:2299-2304.

THE S-PROCESS IN PRESOLAR SiC GRAINS: BARIUM THROUGH HAFNIUM.

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Introduction: We have developed an ICP-MS technique for simultaneous investigation of a large number of trace elements and isotopic compositions in “bulk” samples of presolar grains and applied it to obtain the s-process signature in the mass region from Ba through Hf.

Experimental: The sample consisted of a “diamond residue” prepared following the procedure used by [1], which is a variant of the standard procedure described by [2]. Mass spectrometric analysis was performed on a single collector magnetic sector ICP-MS (*Element II*) with the diamond residue introduced as a colloidal suspension in ammonia.

Isotopic structures: Due to numerous isobaric interferences in the REE region, isotopic ratios were determined only for a limited number of isotopic pairs. Clear s-process signatures, typically with a mixing ratio s/normal of about 2:1, were observed for Ba, Nd, Gd, Dy and Er. For Hf a (relative to normal) small s-process contribution was also seen. While not very precise, inferred s-process ratios are mostly consistent with predictions from the stellar model of [3]. However, where previous data from TIMS (cf. [4]) deviate from predictions, our data (except for Dy) support the TIMS results.

Host phase: Trace element contents of diamonds proper are small [5]. Since diamond extracts prepared following classical extraction procedures invariably contain small amounts of fine-grained SiC [6], the carrier of the observed s-process signature most likely is a small amount of SiC in our “diamond” sample. Diamonds from AGB stars as recently suggested by [7] are an alternative possibility that cannot be unambiguously ruled out.

Elemental pattern. The relative elemental abundance pattern (normalized to Nd) largely agrees with predictions [3]. Exceptions are the high Ba and the low (by more than an order of magnitude) Yb. The overabundance of Ba reflects the lower neutron exposure when compared to the solar main s-process component [8]). Yb is the last of the REE expected to condense [9], so its low abundance may reflect its relative volatility. The detailed abundance pattern may offer a possibility to determine the temperature range in which the SiC grains formed.

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References: [1] Braatz A. et al. 2000. *Meteoritics & Planetary Science* 35:75-84. [2] Amari S. et al. 1994. *Geochimica et Cosmochimica Acta* 58:459-470. [3] Arlandini C. et al. 1999. *Astrophysical Journal* 525:886-900. [4] Hoppe P. and Ott U. 1997. In: *Astrophysical Implications of the Laboratory Study of Presolar Materials*, (eds. E. Zinner and T.J. Bernatowicz):27-58. [5] Merchel S. et al. 2003. *Geochimica et Cosmochimica Acta* 67:4949-4960. [6] Daulton T. L. et al. 1996. *Geochimica et Cosmochimica Acta* 60:4853-4872. [7] Verchovsky A.B. et al. 2005. Abstract #2285. 36th Lunar & Planetary Science Conference. [8] Gallino R. et al. 1993. *Astrophysical Journal* 410: 400-411. [9] Lodders K. and Fegley B. Jr. 1993. *Earth and Planetary Science Letters* 117:125-145.

NEW HIGH-PRECISION $\Delta^{17}\text{O}$ DATA: QUERYING THE MEANING OF $\Delta^{17}\text{O}$ IN THE INNER SOLAR SYSTEM.

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Introduction: The veracity of the standard interpretation that $\Delta^{17}\text{O}$ is a unique fingerprint for individual parent bodies can be evaluated in the context of models for planetary accretion. Assigning different $\Delta^{17}\text{O}$ values to different heliocentric radii (R) in stochastic planet accretion models [1-3] shows that $\Delta^{17}\text{O}$ values for planet-sized bodies should have differed by several tenths of per mil (e.g., +0.4 ‰ to -0.2 ‰) by virtue of accreting embryos from a broad range of R . The $\Delta^{17}\text{O}$ values of the smaller lunar-sized embryos should have inherited the $\Delta^{17}\text{O}$ of their local feeding zones (small range in R) [2] and so are expected to reflect the radial and temporal distribution of $\Delta^{17}\text{O}$ in the nebula. These results show that a precision of <0.1 ‰ is required to establish unequivocally the uniqueness of $\Delta^{17}\text{O}$ values among smaller parent bodies. Infrared laser-heating fluorination (IR-LF) has an analytical precision of ~0.02 ‰ and can be used for this purpose [4-8].

Data: We obtained new IR-LF oxygen isotope data at UCLA for 11 eucrites (cumulate and basaltic), 2 howardites, 7 pallasites (MG), 5 mesosiderites, and 3 enstatite chondrites (EH3, EL3, and EL6). Our goal is to compare groups using the same procedures in a single laboratory in order to minimize systematic errors. We find that $\Delta^{17}\text{O}$ values of mesosiderites (-0.25 ± 0.04 1 σ ‰), pallasites (-0.22 ± 0.03 ‰), and HEDs (-0.23 ± 0.05 ‰), with the exception of Ibitira (-0.085 ± 0.004 ‰, cf. -0.054 ± 0.010 [4]), are indistinguishable from each other at the 0.03 ‰ level, and that enstatite chondrites (-0.01 ± 0.01 ‰) are indistinguishable from Earth at the 0.01 ‰ level.

Discussion: These data raise questions about the meaning of $\Delta^{17}\text{O}$ in the inner solar system. In the standard interpretation, they require that MG pallasites, mesosiderites, and HEDs (*sans* Ibitira) derive from the same planetary embryo or from embryos grown in adjacent feeding zones if nebular $\Delta^{17}\text{O}$ varied with R . The interpretation for the E chondrites is more complicated. If the identical $\Delta^{17}\text{O}$ values of Earth and Moon binds them together genetically [9], then one must conclude that either the E chondrites are part of the Earth-Moon system or that $\Delta^{17}\text{O}$ was the same for $R \sim 0.5$ to 2.5 AU. The latter allows for a temporal variation in $\Delta^{17}\text{O}$ in the entire inner solar nebula [10] during planet embryo growth but excludes radial variations in $\Delta^{17}\text{O}$.

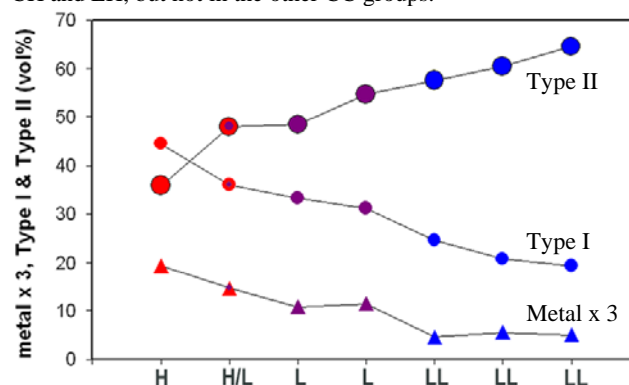
References: [1] Chambers J. (2002) *33rd Lunar and Planetary Science*: #1049. [2] Chambers J. (2001) *Icarus* 152: 205-224. [3] Wetherill G. W. (1994) *Geochimica et Cosmochimica Acta* 58: 4513-4520. [4] Wiechert U. H. et al. (2004) *Earth and Planetary Science Letters* 221: 373-382. [5] Newton J. et al. (2000) *Meteoritical & Planetary Science* 35: 689-698. [6] Franchi I. A. et al. (1999) *Meteoritical & Planetary Science* 34: 657-661. [7] Franchi I. A. and Greenwood R. C. (2004) *Oxygen in the Terrestrial Planets*: 3048. [8] Wiechert U. H. et al. (2001) *Science* 294: 345-348. [9] Pahlevan, K. and Stevenson, D. J. (2005) *35th Lunar and Planetary Science Conference*: #2382. [10] Lyons J. R. and Young E. D. (2005) *Nature* 435: 317-320.

AN ACCRETIONARY ORIGIN FOR ORDINARY CHONDRITE GROUPS. B. Zanda^{1,2}, R. H. Hewins², M. Bourrot-Denise¹, P. A. Bland^{3,4}, and F. Albarède⁵. ¹MNHN-CNRS, UMS2679, 75005 - Paris. E-mail: zanda@mnhn.fr. ²Geological Sci., Rutgers Univ., Piscataway NJ08855. ³IARC, Dept. Earth Sci. & Eng., Imperial College London. ⁴BMNH, London. ⁵ENS Lyon, 69364 - Lyon.

Introduction: OC groups are based on bulk Fe and metal abundance and might derive from separate nebular reservoirs created in part by metal gain/loss. As metal formed in type I chondrules [1], we explore the relationship between their abundances.

Method: We measured type I and type II chondrule [2] abundances in 7 primitive OC falls to compare with their bulk Fe, Ni and metal derived from wet chemistry [3]. OCs are compared with CCs [2-4], an EH3 [3,5] and CH ALH85085 [6].

Results: OC data are displayed in Fig. 1. Chondrule abundances vary little, but their nature changes significantly: Type Is (small circles) dominate in Sharps (H), but are only a third of type IIs (big circles) in Krymka (LL). Metal abundance (triangles) correlates with type Is (vol% metal = 0.035 vol % type I; $R^2 = 0.9$) and this correlation extends to the EH and the CH. This trend is also present but less distinct in the other CC groups. CI- and Mg-normalized Fe and Ni also correlate with type Is and metal in OCs, CH and EH, but not in the other CC groups.



Discussion: The groups for which type I, metal and bulk Fe and Ni correlate are those in which metal physically separated from the chondrules where it formed [1]. Bulk Fe and Ni correlation with metal shows that metal loss/gain caused siderophile fractionation and that the metal-type I correlation resulted from differential accretion: small dense metal grains have stopping times closer to those of the smaller silicate chondrules [7] and would have accreted preferentially with type Is in a turbulent regime. Rather than being derived from more or less reduced reservoirs, OC groups thus simply result from a differential accretion of larger objects (mostly type IIs) in LLs and smaller or denser objects (type Is and metal grains) in Hs.

References: [1] Campbell A. et al. 2005. *Proceedings of the Astronomical Society of the Pacific Conference Series*, in press. [2] McSween H. Y., Jr 1977. *Geochimica Cosmochimica Acta* **41**, 477-491. [3] Köblitz, J. 2005. *Metbase 7.1, meteorite retrieval software, CD-ROM*. [4] McSween H. Y., Jr 1977. *Geochimica Cosmochimica Acta* **41**, 1777-1790. [5] Weisberg M. K. and Prinz M. 1998. Abstract #1741. 29th Lunar & Planetary Science Conference. [6] Scott. E. R. D. 1988. *Earth and Planetary Science Letters* **91**: 1-18. [7] Kuebler K. E. and McSween H. Y. Jr. 1999. *Icarus* **141** 96-106.

TRANSMISSION ELECTRON MICROSCOPY OF DEUTERIUM-RICH MATRIX FROM TAGISH LAKE. T. J. Zega¹, R. M. Stroud¹, L. R. Nittler², C. M. O'D. Alexander², and A. F. Young². ¹Naval Research Laboratory, 4555 Overlook Avenue SW, Washington DC, 20375; ²Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Rd NW, Washington DC, 20015. (tzega@nrl.navy.mil).

Introduction: Extreme deuterium (D) enrichments in interplanetary dust particles (IDPs) and carbonaceous chondrites (CCs) are believed to be due to chemical fractionation in the molecular cloud that was the precursor of the solar system [1]. The largest D enrichments are carried by organic matter (OM), though D-rich water of hydration was also observed [2]. Aliphatic hydrocarbons are thought to be a major carrier of the largest D anomalies in IDPs [3], whereas the organic carriers in CCs are not well characterized. Moreover, NMR and isotope studies of purified organic matter from different CCs indicate that secondary processes can strongly affect the nature of the organics [Alexander et al. this meeting, 4]. Thus, correlated isotopic-mineralogic studies are essential to understand the nature of CC organic matter and the extent to which it is processed in the nebula and on parent bodies. Here we report results of a transmission electron microscope (TEM) study of a D-rich region of matrix material from the Tagish Lake carbonaceous chondrite.

Analytical Methods: An FEI Nova 600 dual-beam microscope (FIB) was used to create an electron-transparent section (~100-nm thick) of a fragment of Tagish Lake matrix material (carbonate-rich lithology) for which the D/H distribution was previously determined [5]. The FIB section transects two D hotspots, with δD up to ~4,000‰. It was extracted ex situ, placed onto a carbon-coated TEM grid, and analyzed with a 200 keV JEOL 2200FS TEM equipped with a high-angle annular-dark-field (HAADF) detector and energy-dispersive spectrometer.

Results: HAADF images of the FIB section reveal areas of bright and dark contrast, indicative of material with high and low atomic number. X-ray spectra show that C, O, Fe, Mg, Al, and Si occur throughout the matrix in varied amounts. However, the D hotspots are associated with areas relatively enriched in Ca and Mn. Selected-area electron-diffraction patterns indicate the presence of crystalline material in some but not all of the D-rich regions.

Discussion: The enrichment of Ca and Mn in D hotspots most likely corresponds to carbonates. Carbonates were observed in the matrix of Tagish Lake, and together with sheet silicates are taken as evidence of aqueous alteration [6]. Our results indicate that the most D-rich OM is preferentially associated with carbonates in this section, whereas OM with lower D/H typical of the bulk rock is spatially associated with sheet silicates, whose intrinsic water may also be D-rich [7]. Planned FIB-TEM studies of additional D-rich fragments should determine whether this is a general result and provide clues to the aqueous-alteration history of this meteorite and the nature of its organic matter.

References: [1] Messenger S. 2000 *Nature* 404:968-971. [2] Robert F. 2003 *Space Science Reviews* 106:87-101. [3] Keller L. P. et al. 2004 *GCA* 68: 2577-2589. [4] Cody G. D. and Alexander C. M. O'D. 2005, *GCA* 69:1085-1097. [5] Young A. F. et al. 2004 *LPSC XXXV*: 2097. [6] Nakamura T. et al. 2003 *EPSL*, 207:83-101. [7] Engrand C. et al. 2003 *LPSC XXXIV*: 1688.

A NEW TYPE OF EVOLVED LUNAR LITHOLOGY: BASALTIC-ANDESITE GLASS. R. A. Zeigler, R. L. Korotev, B. L. Jolliff, and C. Floss. Washington University, Campus Box 1169, St. Louis, MO, 63130. zeigler@levee.wustl.edu.

Introduction: We have identified a unique type of impact glass in the Apollo 16 regolith that we designate basaltic-andesite (BA) glass because the composition falls in the field of basaltic andesite according to the total alkali-silica classification [1]. Glasses with similar compositions have been previously reported at the Apollo 16 site and designated "HKFM," i.e., high-K Fra Mauro [2,3]. In detail, however, these glasses have a composition that is distinct from "Fra Mauro" glasses and other evolved lunar materials [4,5].

Methods: The 24 BA glass fragments in this study were found among the <1 mm fraction of six different Apollo 16 regolith samples. We determined major-element concentrations by electron microprobe analysis and trace-element concentrations by secondary-ion mass spectrometry on polished thick sections.

Results: The BA glasses are silica-rich (52.5 wt%), ferroan ($Mg^{\#}$: 39), moderately FeO and TiO_2 rich (13.3 and 3.6 wt% respectively), with elevated concentrations of Na_2O (1 wt%), K_2O (0.6 wt%), and incompatible trace elements (ITE; Sm: 59 ppm; Th: 17 ppm). The REE pattern and interelement ITE ratios (except for the alkalis) are similar to KREEP. Morphologically the BA glasses are angular fragments, never spherical (or even partially spherical). Some contain small blebs of meteoritic metal and minor amounts of mineral clasts.

Discussion: The BA glasses represent an evolved lithology that must have been exposed on a large enough scale to produce impact melt of this composition. In detail, it is distinct from other evolved lunar lithologies. The various "flavors" of KREEP (basalt and impact-melt breccias) are much more magnesian ($Mg^{\#}$: 50–70) and have lower FeO, TiO_2 , and ITE concentrations. Granites and felsites have different REE patterns, higher concentrations of large-ion lithophile elements (LILE), and are less mafic. Quartz monzodiorites/gabbros have less Ti, higher concentrations of ITEs, and tend to be deficient in the LILEs. Whereas it is easy to identify what the BAGs are not, it is not immediately apparent what they are, or more to the point, what they were prior to becoming glass. The presence of meteoritic metal and mineral clasts indicate that these are impact products. Given their extreme composition, they are unlikely to be a mixture in which more than one lithology is volumetrically important. Despite differences in $Mg^{\#}$ and TiO_2 concentration, BA glasses share many compositional similarities with KREEP. In fact, this composition is more like what one would expect from a magma-ocean residuum, but without having mixed with magnesian components [4,6]. Given their ITE-rich composition, the provenance of these glasses is likely to have been in the Procellarum KREEP Terrane. Their young age of (3.75 Ga [3]) and absence from the Apollo 16 ancient regolith breccias preclude their having been Imbrium ejecta. Their point of origin and the mechanism by which their abundance came to be moderately high among impact glasses at the Apollo 16 site remain obscure.

References: [1] Zeigler R.A. et al. 2004. Abstract #2082. *LPS 34*. [2] Meyer H.O.A. and Tsai H.-M. 1975. *EPSL* **28**: 234–240. [3] Zellner N.E.B. et al. 2005. Abstract #1199. *LPS 35*. [4] Jolliff B. L. 1998. *International Geology Review* **40**: 609–610. [5] Papike J. J. et al. 1998. in *Planetary Materials*, Revs. in Min., Vol. 36:5. [6] Warren P.H. 1988. *PLPSC 18*, 233–241.

MÖSSBAUER EFFECT STUDY OF IRON CONTAINING PHASES IN ORDINARY CHONDRITES.

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Introduction: Mössbauer spectroscopy is a useful tool to study ordinary chondrites for analysis of their chemical and phase composition. In this work we analyzed Mössbauer parameters of H and L chondrites including recently found new meteorite to distinguish iron containing phases.

Methods: Samples of ordinary chondrites Saratov L4, Tzarev L5, Farmington L5, Mbale L5, Kunashak L6, Zvonkovo H5, Vengerovo H5 and recently found chondrite Zubkovsky L6 in the form of powder were measured at room temperature using Mössbauer spectrometer SM-2201 with high accuracy, stability and sensitivity in transmission geometry with moving absorber.

Discussion: Mössbauer spectra of chondrites Vengerovo H5 and Zubkovsky L6 are shown in Fig. 1. Mössbauer subspectra of metal phases were very weak. Nevertheless, they were fitted using one or two sextets. The values of magnetic hyperfine field (H_{eff}) for one metal phase in chondrites were slightly different for Tsarev L5 and Saratov L4 samples and higher than those for Mbale L5, Zvonkovo H5 and Vengerovo H5 samples which values of H_{eff} were the same. Two subspectra of metal components in Mössbauer spectra of chondrites Farmington L5 and Kunashak L6 were characterized by slightly different values of H_{eff} . Mössbauer spectrum of Zubkovsky L6 sample do not contain metal phase. The values of H_{eff} for troilite phase were the same for all chondrites except Farmington L5 with lower H_{eff} and both Saratov L4 and Zubkovsky L6 with higher H_{eff} . Samples of Tsarev L5, Mbale L5, Saratov L4, Vengerovo H5 and Zubkovsky L6 contained various quantities of oxidized iron. The variation of relative areas for corresponding iron containing phases was found in different chondrites.

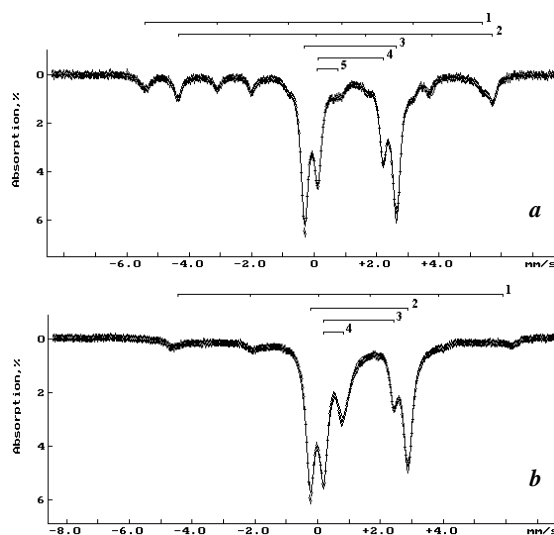


Fig. 1. Mössbauer spectra of meteorites: *a* – Vengerovo H5 (1 – FeNi, 2 – troilite, 3 – olivine, 4 – pyroxene, 5 – Fe³⁺); *b* – Zubkovsky L6 (1 – troilite, 2 – olivine, 3 – pyroxene, 4 – Fe³⁺). T=295 K.

ON THE LOCAL IRRADIATION PRODUCTION OF SHORT-LIVED ISOTOPES IN THE EARLY SOLAR SYSTEM.

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Excesses in the daughter nuclides of radioactive isotopes in various early-solar-system samples have provided evidence for the initial presence of short-lived, now extinct isotopes [e.g., 1, 2]. Two basic production scenarios have been pro-posed. One is stellar nucleosynthesis. While the abundances of some of the isotopes can result from steady-state nucleosynthesis in the Galaxy, the isotopes with shorter half lives require a single stellar source, either a supernova [3] or an Asymptotic Giant Branch star [4], immediately preceding solar-system formation. The other production mechanism for isotopes with shorter half lives is irradiation by energetic solar particles. All scenarios have some problems. We will concentrate on local irradiation.

Solar-system irradiation has received a boost by the discovery of the early-solar-system presence of ¹⁰Be [5], a nuclide that is not produced by stellar nucleosynthesis. It has found a theoretical underpinning in the X-wind model [6]. In this model not only ¹⁰Be but other short-lived isotopes such as ²⁶Al, ⁴¹Ca and ⁵³Mn in CAIs are produced by solar particles [7, 8]. A cosmic-ray production of ¹⁰Be and trapping in the pre-solar-system molecular cloud has been proposed [9], but local irradiation is needed if claims for the initial presence of ⁷Be [10], whose half life is only 53 days, can be substantiated.

However, while ¹⁰Be (and possibly ⁷Be) most likely has a local irradiation origin, various arguments can be raised against irradiation being the sole/primary source of the other short-lived isotopes:

- 1) The uniformity of an “canonical” ²⁶Al/²⁷Al ratios in CAIs is difficult to reconcile with local irradiation, which is expected to result in a much wider distribution of the ²⁶Al/²⁷Al ratio.
- 2) While the X-wind model assumes that only CAIs had the canonical ²⁶Al/²⁷Al ratio, the consistency between the Al-Mg and U-Pb clocks for CAIs and chondrules [11] and feldspars from H4 chondrites [12] indicate that ²⁶Al was wide-spread.
- 3) The irradiation production of the short-lived isotopes in the observed ratios requires very special target composition and structure and rather extreme energy and composition of the solar energetic particles [7].
- 4) There is a lack of correlation between ¹⁰Be and ²⁶Al and ⁴¹Ca in individual CAIs [13, 14].
- 5) ⁶⁰Fe, present in the early Solar System, cannot be made by spallation and requires a recent stellar source. Any such source would also provide most of the other short-lived nuclei.

References: [1] Zinner E. (2003) *Science* 300, 265-267. [2] Meyer B. S. and Zinner E. (2005) In *Meteorites and the Early Solar System II*, in press. [3] Cameron A. G. W. and Truran J. W. (1977) *Icarus* 30, 447-461. [4] Busso M. *et al.* (2003) *PASA* 20, 356-370. [5] McKeegan K. D. *et al.* (2000) *Science* 289, 1334-1337. [6] Shu F. H. *et al.* (1996) *Science* 271, 1545-1552. [7] Gounelle M. *et al.* (2001) *ApJ*. 548, 1051-1070. [8] Shu F. H. *et al.* (2001) *ApJ*. 548, 1029-1050. [9] Desch S. J. *et al.* (2004) *ApJ*. 602, 528-542. [10] Chaussidon M. *et al.* (2004) *LPS XXXV*, Abstract #1568. [11] Amelin Y. *et al.* (2002) *Science* 297, 1678-1683. [12] Zinner E. and Göpel C. (2002) *MAPS* 37, 1001-1013. [13] Marhas K. K. *et al.* (2002) *Science* 298, 2182-2185. [14] MacPherson G. J. *et al.* (2003) *GCA* 67, 3165-3179.

IDENTIFYING THE SOURCE OF THE HYDROUS CHONDRITIC INTERPLANETARY DUST PARTICLES.

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Introduction: We know that the parent asteroids of the bulk of the hydrous chondritic interplanetary dust particles (IDPs) are not represented by known meteorites. These particular IDPs are dominated by saponite, serpentine, olivine, ortho- and clinopyroxene, Ca-Mg-Fe carbonates, pyrrhotite, pentlandite, magnetite, and have observed porosities ranging up to 40% [1-4].

Kaidun Meteorite: The Kaidun meteorite contains just about everything, so appears a logical place to search for parent materials from the home of the hydrous chondritic IDPs [5]. After some searching we think that we have located some. The bulk lithology we describe in this abstract is present in most sections of Kaidun [5], where it was described as a new type of C2 chondrite. This C2 material is petrographically and mineralogically distinct from known C2 meteorites, and consists mainly of a dense assemblage of saponite, serpentine, olivine, ortho- and clinopyroxene, Ca-Mg-Fe carbonates, pyrrhotite, pentlandite, magnetite, and sundry other accessory minerals. In practically all examples this lithology is very dense, and so we never really considered a connection with IDPs. However, in sample D6 we have observed this lithology grading into exceedingly porous (up to ~50%) regions, often with rounded pores (see Figure 1). The pores must have originally contained some lost phase, which we suggest was predominantly water ice.

Discussion and Suggestions: The lithology found in Kaidun appears to be mineralogically and petrographically identical with the bulk of the hydrous chondritic IDPs. Such a link could be tested by an examination of O and N isotopes, which we intend to perform. We suggest that the pores in this material were originally filled by ices, which sublimated away (probably) on the Kaidun parent asteroid. The original home of such material would probably be on C, P or D asteroids, especially the hydrated C-class (Ch) asteroids.

References: [1] Zolensky and Barrett (1994) *Meteoritics* 29, 616-620; [2] Corrigan et al. (1997) *MAPS* 32, 509-515; [3] Bradley and Brownlee (1991) *Science* 251, 549-552; [4] Gounelle et al. (2003) *GCA* 67, 507-527; [5] Zolensky and Ivanov (2003) *Chemie de Erde* 63, 185-246.

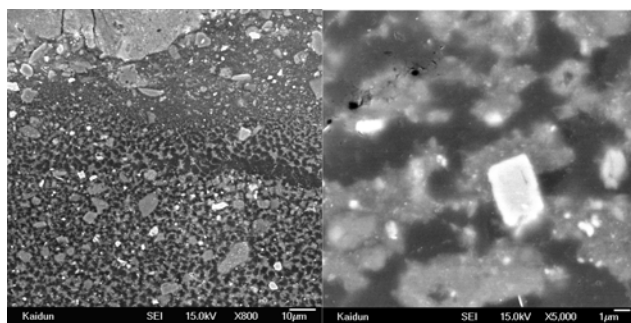


Figure 1: SEI images of the porous Kaidun C2 lithology, (left) grading into the massive lithology above, and (right) higher mag.

THERMODYNAMIC CONSTRAINTS ON FAYALITE FORMATION ON PARENT BODIES OF CHONDRITES.

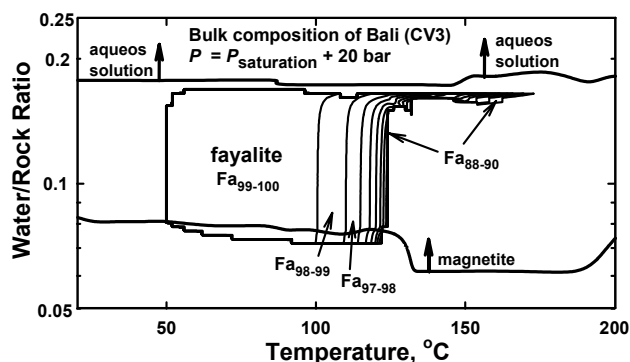
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Fayalite (Fe_2SiO_4 , Fa_{88-100}) is present in unequilibrated ordinary chondrites and in carbonaceous chondrites [e.g., 1-4]. Its coexistence with secondary minerals, young age, and O isotope data are all consistent with its formation on parent bodies [2-4]. Thermodynamic analysis performed for CV3 chondrites [2] reveals the possibility of fayalite formation on a parent body below 300°C. We model parent body alteration of chondrites through equilibrium calculations in a 17-component closed system [5] in order to evaluate effects of composition, water/rock mass ratio (WRR), temperature (T), total pressure (P), original porosity and alteration progress on the stability of fayalite. Olivine is considered as a binary regular solid solution [6].

The results show that fayalite (Fa_{88-100}) can form below $\sim 300^\circ\text{C}$, at total P above that of the water liquid-gas saturation, but only in a narrow range of $WRR = \sim 0.05-0.2$. The upper WRR boundary is close to lower values at which a solution can exist (Fig. 1). Pure fayalite (Fa_{98-100}) forms below $\sim 100^\circ\text{C}$ and Fa_{88-98} forms at higher T . Elevated P represents higher fugacity of H_2 , expands fayalite ($\text{Fa}_{>88}$) stability and increases Fa number. At 100 bars, $\text{Fa}_{>90}$ is stable below $\sim 270^\circ\text{C}$, depending on the composition of chondrite. H_2 must have been produced through oxidation by H_2O to account for elevated P . Low porosities also favor higher P and support formation of fayalite.

Fayalite coexists with magnetite, except at low WRR (Fig. 1). In models of alteration progress, consumption of solution makes magnetite less stable and creates potential for its reduction to fayalite, consistent with [2,3]. Fayalite could have formed during a low- T and high- P transition between aqueous and metamorphic stages of alteration when last portions of H_2O (liquid, gas) converted to H_2 . Low- T alteration of forsterite or kamacite is also possible [c.f., 2]. Although compositions of matrices/chondrites have only a minor effect on fayalite stability, specific T - P alteration paths led to different occurrences, amounts and compositions of fayalite.

References: [1] Hua X. and Buseck P. R. 1995. *Geochimica et Cosmochimica Acta* 59:563-578. [2] Krot A. N. et al. 1998. *Meteoritics & Planetary Science* 33:1065-1085. [3] Krot A. N. et al. 2000. *Meteoritics & Planetary Science* 35:1365-1386. [4] Hua X. et al. 2005. *Geochimica et Cosmochimica Acta* 69:1333-1348. [5] Mironenko M. V. and Zolotov M. Yu. 2005. Abstract #2207. 36th Lunar and Planetary Science Conference. [6] Chatterjee N. 1987. *Geochimica et Cosmochimica Acta* 51:2515-2525.



HYDROGEN FORMATION AND PHASE PARTITIONING DURING PARENT BODY ALTERATION OF CHONDRITES: A THERMODYNAMIC QUANTIFICATION. M. Yu. Zolotov¹, E. L. Shock^{1,2} and M. V. Mironenko³ ¹Department of Geological Sciences, ²Department of Chemistry and Biochemistry, Arizona State University, Tempe, AZ 85287; ³Vernadsky Institute, Russian Academy of Sciences, Moscow, 119991, Russia. E-mail: zolotov@asu.edu.

Ordinary and carbonaceous chondrites are oxidized compared to the redox state of the canonical solar nebula. Oxidation of chondrites mainly occurred on their parent bodies through reactions with H₂O (accreted as ice) and was likely to be accompanied by H₂ production [1-3]. H₂ is the expected product of redox reactions that led to formation of Ni-rich metal alloys, chromite, magnetite, tochilinite, pyrrhotite, pentlandite, ferrous silicates, phosphates, sulfates, carbides, carbonates and CO₂. Here we model isochemical parent body alteration through equilibrium calculations in multicomponent systems [4] in order to evaluate effects of composition, water/rock mass ratio (*WRR*), temperature (*T*, <350°C), pressure (*P*) and alteration progress on H₂ production and partitioning between liquid and gas phases. Formation of CH₄ is suppressed, consistent with observations. Calculated H₂ amounts in moles (*m*) are referenced to alteration of 1 kg of water-free ordinary or carbonaceous chondrites.

Results show that, depending on rock composition, up to 6-13 *m* H₂ can form in the presence of solution, which exists at *WRR* greater than ~0.1-0.4. At elevated *WRR*, H₂ production is limited by the mass of rock and H₂O is present at the end of reaction progress. The amount of H₂ formed increases with *T* and *WRR* and is mostly accounted for by magnetite formation. Below ~100°C and *WRR* of 0.1-1, which may characterize CI and CM chondrites, 4-6 *m* H₂ can form. The ratio H₂(aq.)/H₂(gas + aq.) varies from 10⁻¹⁰ (low *T* and *WRR*) to 1 (high *T* and *WRR*), and H₂ solubility also increases with increasing *P*.

Significantly lower H₂ amounts form in H₂O-depleted conditions without solution. However, H₂ dominates in the gas phase. At *WRR* < ~0.1, H₂ production is limited by the mass of H₂O, the instability of magnetite and the stable existence of saponite. At *WRR* < ~0.01, saponite becomes insignificant and H₂ forms mostly through oxidation of organic polymer and Cr⁰ in metal. At *WRR* = 0.001-0.01, up to 0.05-0.1 *m* H₂ forms at 0°C, 0.14-0.26 *m* forms at 100°C and 0.15-0.42 *m* forms at 350°C. The amounts of H₂ at higher temperature may characterize alteration on parent bodies of CV3 and unequilibrated ordinary chondrites.

Higher (Fe, Ni, Cr, P, S, C)/(Mg, Ca, Si, Al, Na, K) ratios, as in CI chondrites, support oxidation and H₂ formation. Lower ratios favor hydration, which limits H₂ generation through oxidation. Pressure above that of water-gas saturation permits high *P*(H₂) and may limit H₂ formation through mineral buffering.

Sequential involvement of new portions of rock during the aqueous stage of alteration increases the amount of H₂ formed, consumes solution and contributes to *P* growth. Although consumption of solution marks the conversion of H₂O-H₂ gas into H₂-rich gas, H₂ can be partially consumed through reduction of magnetite and other minerals formed in the presence of solution. At this stage, H₂ abundance can be maintained by buffering reactions that involve magnetite, ferrous silicates, silica, troilite, pyrrhotite, pentlandite and metal.

References: [1] Browning L. and Bourcier W. 1996. *Meteoritics & Planetary Science* 31:A22-A23. [2] Krot A. N. et al. 1998. *Meteoritics & Planetary Science* 33:1065-1085. [3] Rosenberg N. D. et al. 2001. *Meteoritics & Planetary Science* 36:239-244. [4] Mironenko M. V. and Zolotov M. Yu. 2005. Abstract #2207. 36th Lunar and Planetary Science Conference.