Experimental Study on Kinetic Condensation of Metallic Iron Under Controlled Supersaturation
S. Tachibana, Y. Ikeda, H. Nagahara, K. Ozawa, and M. Yamada .......................................................... 5294

A New Fireball in Early April: A Possible Association with the Příbram Radiant
G. Tancredi ............................................................................................................................................. 5269

Cosmic Ray Flux Variation During Mid-19th Century Revealed by Low $^{44}$Ti Activity
in Allegan Meteorite
C. Taricco, N. Bhandari, P. Colombetti, N. Verma, and G. Vivaldo ...................................................... 5205

Iron Spherules with Silicate Cores and a Chondritic Aggregate Sphere from Deep-Sea Sediments
Y. Tazawa and T. Fukuoka ....................................................................................................................... 5183

Chemical Compositions of Antarctic Micrometeorites and Their Types
Y. Tazawa, T. Fukuoka, N. Hoshi, Y. Fukushi, Y. Saito, T. Noguchi, and T. Yada ..................................... 5186

Records of Impact Events in the Elga (IIE) Iron
S. N. Teplyakova ......................................................................................................................................... 5025

Ion Microprobe U-Pb Dating of Phosphates in Very-low-Ti Basaltic Breccia
K. Terada, Y. Sasaki, and Y. Sano ........................................................................................................ 5129

Lu-Hf Systematics of the Angrite SAH99555
K. Thrane, J. N. Connelly, M. Bizzarro, L. Borg, and D. Ulfbeck ........................................................... 5340

Timing of Differentiation of Pallasite Parent Bodies: Evidence from Al-Mg System
T. Tomiyama, M. Bizzarro, A. N. Krot, G. R. Huss, and T. E. Bunch ..................................................... 5086

Hf-W Constraints on the Formation and Thermal Metamorphism of Acapulcoites
M. Touboul, T. Kleine, B. Bourdon, J. Zipfel, and A. J. Irving ............................................................... 5313

Early Solar System Chronology in the Astrophysical Context
M. Trieloff and H. Palme ........................................................................................................................... 5084

Aluminium-rich Chondrules and Type C CAIs: An Experimental Comparison of Formation Conditions
E. J. Tronche, R. H. Hewins, and G. J. MacPherson ............................................................................... 5381

Chromium Isotopic Study of Ureilite
T. Ueda, K. Yamashita, and N. Kita ....................................................................................................... 5178

Microscopic Magnetic Field Distributions of Unequilibrated Ordinary Chondrites
M. Uehara and N. Nakamura .................................................................................................................. 5232

A Possible Origin for the Depletion of Siderophile Elements in Chondrules
M. Uesugi and M. Sekiya ......................................................................................................................... 5172

The Type Ia Supernova and Origin of the Solar System
G. K. Ustinova ........................................................................................................................................... 5045

The Surface Elemental Composition of 4 Vesta Based on HED Meteorites: Prospective Study for Interpretation of Gamma-Ray and Neutron Spectra for the Dawn Mission
T. Usui and H. Y. McSween Jr. .................................................................................................................. 5160
The Structure and Origin of Metal in Isheyevo CB/CH Meteorite

K. A. Uymina and V. I. Grokhovsky................................................................. 5230

Weathering of Ordinary Chondrites from the Atacama Desert, Chile: First Results from Mössbauer Spectroscopy

E. M. Valenzuela, Y. Abdu, R. B. Scorzelli, J. B. de Campos, M. Duttine, P. A. Bland, and D. Morata................................................................. 5203

Magnetic Anisotropy of Carbonaceous Chondrites and Achondrites

M. van Ginneken, J. Gattacceca, and M. Gounelle ........................................ 5253

An Universal Meteorite Formation Process

M. E. Varela and G. Kurat ............................................................................. 5050

Aqueous Corrosion Textures on Weathered Chain Silicate Surfaces as Possible Terrestrial Analogs of Pyroxene Alteration in Mars Meteorites

M. A. Velbel and S. J. Wentworth.................................................................. 5219

Whole-Rock Oxygen Isotope Compositions are Unrelated to Degree of Aqueous Alteration in CM2 Chondrites

M. A. Velbel, E. K. Tonui, and M. E. Zolensky.............................................. 5325

Isotope Analyses of the Coarsest Grain-Size Fractions of Orgueil Nanodiamonds

A. B. Verchovsky, A. V. Fisenko, L. F. Semenova, and I. P. Wright............... 5245

Asteroid Colors: A Novel Tool for Magnetic Field Detection? The Case of Vesta

P. Vernazza, R. Brunetto, G. Strazzulla, M. Fulchignoni, P. Rochette, N. Meyer-Vernet, and I. Zouganelis ............................................................. 5075

A Source of the Popigai Impact Fluidizites: Data on Trace Elements

S. A. Vishnevsky and S. G. Simakin............................................................... 5016

A Target Source of the Popigai Impact Fluidizites: Data on REE

S. A. Vishnevsky and S. G. Simakin ................................................................ 5017

Re-Evaluation of High Resolution ⁴⁰Ar/³⁹Ar Ages of Plagioclase Separates from IAB Silicate Inclusions and Implications for the Thermal History of the IAB Parent Body

N. Vogel and P. R. Renne .............................................................................. 5211

Characterization of Presolar Silicate Grains by Combined NanoSIMS/TEM Studies

C. Vollmer, P. Hoppe, F. E. Brenker, R. M. Stroud, and C. Holzapfel .............. 5194
EXPERIMENTAL STUDY ON KINETIC CONDENSATION OF METALLIC IRON UNDER CONTROLLED SUPERSATURATION.
S. Tachibana¹, Y. Ikeda¹, H. Nagahara¹, K. Ozawa¹, and M. Yamada¹. ¹Department of Earth and Planetary Science, University of Tokyo.  E-mail: tachi@eps.s.u-tokyo.ac.jp

Introduction: Condensation is a fundamental process to form solids under low-pressure conditions as in the primitive solar nebula. The condensation rate from vapor is proportional to \( \left( \alpha_c p - \alpha_e \right) \), where \( p \) is a vapor pressure near the substance, \( p^{eq} \) is the equilibrium vapor pressure, and \( \alpha_c \) and \( \alpha_e \) are called the condensation and evaporation coefficients that express kinetic hindrances for evaporation and condensation (0<\( \alpha_c, \alpha_e \leq 1 \)), respectively. It is important to determine \( \alpha_c \) and \( \alpha_e \) as a function of temperature and \( p \) in order to understand timescales and physical conditions for condensation of solid objects in the early solar system. A previous study on evaporation of metallic iron, a major Fe-bearing phase in the early solar system, under controlled \( p \) showed that \( \alpha_c \) and \( \alpha_e \) are dependent on both temperature and \( p \) in the undersaturated conditions [1]. In this study, we have performed condensation experiments of metallic iron on a substrate under controlled \( p \) and condensation temperature in order to examine growth kinetics of metallic iron and its dependence on physical conditions for condensation such as \( p \) and temperature.

Experiments: A metallic iron pellet, put in the end of an alumina tube, was evaporated at ~1270°C for 6-48 hours, and the evaporated iron gas was condensed onto a molybdenum or metallic iron substrate, of which temperature was ~960°C. The alumina tube was used to collimate the evaporated iron gas escaping from the tube and to increase the incoming flux onto the substrate. The weight changes of the evaporation source and the substrate were measured by an electric microbalance, and condensates were examined by FE-SEM equipped with EDS.

Results and Discussion: Metallic iron was condensed on the substrate under the supersaturation ratio (S) of <10, which was estimated from the weight change of the evaporation source and the kinetic theory of gases escaping from the alumina tube. No other iron-bearing phase such as iron oxides was condensed. Condensation steps with the interval of <100 nm were observed at the surface of metallic iron, indicating that lateral growth of metallic iron occurred under relatively low supersaturation conditions and that kinetics of surface atomistic processes should thus be taken into account to understand the growth kinetics. Our preliminary results showed that the actual condensation flux, obtained from the weight change of the substrate, was not significantly smaller than the ideal net condensation flux at 960°C and S of <10. Although further detailed experimental work is needed, this implies that the kinetic hindrance of condensation of metallic iron under relatively low supersaturation conditions may not be significantly large.

A NEW FIREBALL IN EARLY APRIL: A POSSIBLE ASSOCIATION WITH THE PŘÍBRAM RADIANT.
Gonzalo Tancredi. Depto. Astronomía – Fac. Ciencias. Uruguay gonzalo@fisica.edu.uy

Introduction: On 6:50 TU April 4, 2004 a very bright fireball was observed in the southern part of Uruguay (South America). After interviewing more than 30 witnesses we were able to reconstruct the trajectory of the bolide. In order to compute the trajectory in the atmosphere, we have developed a variant of the method of intersection of planes [1]. For each witness we obtain a plane in the space where he viewed the bolide, different weights could be assigned to each witness. The common intersection of the planes is computed by solving two overdetermined system of linear equations with the Single Value Decomposition method.

Conclusions: We reach the following conclusions:
• The peak absolute magnitude was M ~ -18, corresponding to a meteoroid with a mass over 1 Ton.
• We obtain a set of solutions depending on the distributions of weights assigned to the observations. Assuming a velocity at infinity of 18 km/s, we obtain the following geocentric radiants are:
  ▪ For equal weights: RA = 184°; Dec = 8°
  ▪ For weights proportional to the maximum height respect to the horizon observed by the witness: RA = 190°; Dec = 21°

The large difference between the two solutions expresses the bad quality of the visual data. Nevertheless, it is interest to point out that the second solution is quite close to the radiants of the Příbram meteorite [2], the first meteorite recovered by the European Fireball Network in April 7, 1959 (Czech Republic), which it is proposed to be associated with the Neuschwanstein meteorite [3] also recovered by the EFN in April 6, 2002 (Austria).

We also investigate other fireballs observed in early April and the distribution of incoming material from the Near Earth Asteroid population for those days.

COSMIC RAY FLUX VARIATION DURING MID-19th CENTURY REVEALED BY LOW $^{44}$Ti ACTIVITY IN ALLEGAN METEORITE.

C. Taricco¹, N. Bhandari², P. Colombetti¹, N. Verma¹, G. Vivaldo¹, ¹Dipartimento di Fisica Generale, Università di Torino, Via P. Giuria 1, 10125 Torino, and Istituto di Fisica dello Spazio Interplanetario (IFSI), INAF, Corso Fiume 4, 10133, Torino, Italy, ²Basic Sciences Research Institute, Navrangpura, Ahmedabad, India.

Introduction: We have shown that the activity of cosmogenic radioisotope $^{44}$Ti ($T_{1/2} = 59.2$ yrs) is a good index of centennial scale modulation of Galactic Cosmic Ray (GCR) flux by heliospheric magnetic field [1,2] and, compared to the conventional studies based on atmospheric $^{14}$C and $^{10}$Be in terrestrial archives, has the basic advantage that terrestrial influences, due to climatic changes in deposition rate variations, etc. are completely avoided. The measurements in 19 chondrites show that the GCR flux decreased by about 43% over the past 235 years [1] and, superimposed on this declining trend, the $^{44}$Ti activity also shows a ~87 year oscillations, in phase with the Gleissberg cycle of solar activity. Since $^{44}$Ti activity in meteorites integrates the production over a few decades before the fall, our calculations indicate a phase difference of a few decades between the cosmic ray intensity variations and time of fall of the meteorites. Thus the centennial solar cycle predicts GCR flux minima during the middle of 19th and 20th centuries, reflected in the observed $^{44}$Ti activity minima around 1900 and 2000. In order to confirm these minima with better accuracy, we have now set up an improved gamma-ray spectrometer and measured the $^{44}$Ti activity of a ~ 250 g fragment of H5 chondrite Allegan, which fell on 10 July 1899 in Michigan (USA).

Experimental system: The new set-up is a highly specific and selective spectrometer located at the underground (70 m.w.e.) Research Station of Monte dei Cappuccini in Torino (Italy). The main detector is a high purity large Ge diode (about 3 kg) with high resolution (2 keV at 1332 keV) and relative efficiency (150%), surrounded by an active shield of NaI(Tl) of about 90 kg. The passive shield consists of 20 cm thick high purity lead and 5 cm oxygen free high conductivity copper. The electronic chain has been tailored for the measurement of 1157 keV γ-ray from $^{44}$Ti($^{44}$Sc) in coincidence with annihilation photons from β⁺ decay.

Results: Using this detector, we have measured $^{44}$Ti activity of the Allegan meteorite for about 3 months, obtaining a net counting rate of (0.0008±0.0001) cpm. This value is significantly above the background of the system. This value, corrected for the target elemental (Fe+Ni) abundances and shielding effects based on cosmic ray tracks, gives a $^{44}$Ti activity of (4.84±0.61) dpm/kg (Fe+Ni). This activity is lower than the values measured in Alfanello (date of fall: 1883) and Bath (1892), which fell before Allegan, and Olivenza (1924) which fell afterwards, but similar to the values obtained in Lancon (1897) and Holbrook (1912) which fell within a few years of Allegan. These results confirm the centennial modulation of the GCR flux and its minimum during mid-19th century.

IRON SPHERULES WITH SILICATE CORES AND A CHONDTRIC AGGREGATE SPHERE FROM DEEP SEA SEDIMENTS.

Y. Tazawa1 and T. Fukuoka2. 1Department of Physics, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan. (e-mail:tazawa@cr.ephys.kyoto-u.ac.jp.). 2Department of Environmental Systems, Faculty of Geo-Environmental Sciences, Rissho University, Kumagaya 360-0194, Japan.

Introduction: Spherules from deep-sea sediments (DSSs) usually have metallic cores consist of Fe, Ni, Co, and/or platinoid elements [e.g., 1, 2]. The cores are thought to be formed from ablation droplets by heating and quenching during the Atmospheric entry of meteoroids.

Here, we report six deep sea spherules proved of their extra-terrestrial origin by their high abundances of siderophile elements (SPE: e.g., Ni, Co, Ir, Os, Au, etc.) and chondritic compositions of lithophile elements (LPE: e.g., Mg, Al, Sc, V, Cr, Mn, Fe), especially two iron spherules have silicate (glassy?) cores so far unknown in anywhere. They have been studied on their chemical and petrological features by INAA, EPMA, SEM/EDX and XDP.

Samples: Spherules analyzed here are three iron spherules (IS) and three stony spherules (SS) extracted from sediments dredged from 4700 m deep floor at the Central Pacific Ocean (9°30’N, 174°18’W ~ 9°31’N, 174°17’W)[3], which were provided by late Prof. K. Yamakoshi, and K. Nogami.

Results: (a) One of IS, whose bulk composition assayed by INAA is: Fe 67.6%; Ni 4.50%; Co 0.18%; and Ir 2.34ppm, and also by XDP is: spotty patterns of magnetite (d=8.43Å) and wüstite (d=4.28Å), has a mantle of Ni, Co rich Fe oxide (i.e., Fe 69.60%; Ni 4.06%; Co 0.35%; O 25.30%) and an eccentric spherical core of Ni, Fe rich silicate (i.e., SiO2 35.2%; NiO 31.8%; FeO 19.1%; Al2O3 6.6%; MnO 3.2%). (b) Another IS, whose bulk composition is: Fe 67.0%; Ni 1.59%; Co 0.24%; and Ir 0.41ppm and also magnetite (a=8.43Å), wüstite (a=4.30Å), has also a mantle of Ni, Co rich Fe oxide (i.e., Fe 71.09%; Ni 1.46%; Co 0.40%; O 25.62%) and an “amoeboidal (or a walnut-shape)” silicate (glassy?) core consists of Si, Fe, Al, Mg, and K (i.e., SiO2 64.9%; FeO 17.4%; Al2O3 10.9%; MgO 3.7%; K2O 2.1%). These kinds of silicate or glassy cores have never been observed in IS. (c) The rest IS, whose bulk composition is: Fe 66.0%; Ni 5.16%; Co 0.18%; and Ir 3.97ppm and also magnetite (a=8.34Å), wüstite (a=4.28Å), is a homogeneous brick work of μm-sized grains of magnetite and wüstite (i.e., Fe 66.4%; Ni 5.1%; Si 1.2%; Co 0.3%; Cr 0.2%; O 26.6%) except voids or glassy grains in the central region. (d) A SS is an fragile and porous aggregate of μm-sized grains of mafic silicates, oxides, and sulphides, and shows an XDP pattern of faint and broaden lines of magnetite (a=8.51Å), wüstite (a=4.25Å), and olivine (d100= 2.75Å, a=4.86Å, b=10.01Å, c=6.02Å). These features harmonize well with the bulk composition (i.e., Mg 20.3%, Fe 20.1%, Ni 1.27%, Al 0.46%, Cr 0.20%, Mn 0.10%, Co 484ppm, V 89ppm, Sc 4.91ppm, Os 1.9ppm, Ir 0.51ppm, and Au 0.42ppm) quite similar to C1 (except for higher Os, Au, and Mg and lower Al and Mn contents).

CHEMICAL COMPOSITIONS OF ANTARCTIC MICRO-METEORITES AND THEIR TYPES.

Y. Tazawa¹, T. Fukuoka¹, N. Hoshi², Y. Fukushi²,³, Y. Saito³, T. Noguchi⁴ and T. Yada⁵. ¹Department of Physics and Astrophysics, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan, (tazawa@cr.scphys.kyoto-u.ac.jp), ²Department of Environmental Systems, Faculty of Geo-Environmental Science, Rissho University, Kumagaya 360-0914, Japan, ³Radio Isotope Laboratory, College of Science and Engineering, Aoyama Gakuin University, Sagamihara 229-8551, Japan, ⁴Department of Materials and Biological Science, Ibaraki University, Mito 310-8512, Japan, ⁵Department of Earth and Planetary Science, University of Tokyo, Tokyo 113-0033, Japan, ⁶(Present Address) Department of Earth and Planetary Science, Tokyo Institute of Technology, Tokyo 152-8551, Japan.

Microparticles of extraterrestrial origin survived from heating during the Atmospheric entry and weathering after the settling on the Earth have been collected in large quantities from Antarctica [e.g., 1-4]. They called “Antarctic micrometeorites (AMMs)” have been investigated widely in recent years, because in which primitive and/or unknown grains have been expected to be found [e.g., 5-8]. Instrumental neutron activation analysis (INAA) is the most advantageous mean to measure abundances of many elements of individual microscopic samples (≥ sub-μg in weight) in quantitative, simultaneous, and nondestructive ways. So far, we have investigated chemical features of individual AMMs by means of INAA [9-11]. We report here recent results of AMMs.

41 individual AMMs collected from Dome Fuji Station (77°19’S, 39°42’E; water tank deposit) [2], Point K-5 near Kuwagata Nunatak (72°06’S, 35°15’E; bare ice) and Point MY-3 near Minami-Yamato Nunataks (72°26’S, 35°20’E; bare ice) around Yamato Mountains [3], and Point N-7 near Tottuki Point (68°55’S, 39°51’E; bare ice) on the Soya Coast [4] have been confirmed as those well preserved chondritic compositions, though one third of them were fully melted in appearance: (1) Abundance patterns normalized to CI and Mg (LPEs and REEs), and CI and Fe (SPEs) are classified into 6 types. 7 MMs show the patterns parallel to CI within 0.2~5 times of CI (type I), 14 MMs show the patterns similar to the type I except Ir or Co lowered to 0.1 (type II), 7 MMs show the patterns with Na (0.002~0.1), Ir (0.1~0.6), and Au (≤ 0.5) depletions (type III), 7 MMs show Cr (0.1~0.3), Na (≤ 0.7), Ir (0.8~0.5), Co (≤ 0.7) and Au (≤ 0.4) depletions and Mn (2~6) enrichments (type IV). Rest 5 of 6 MMs show LPE patterns similar to achondrite or scatter ones and absent of REEs (type V). The last one is an iron type MM.

RECORDS OF IMPACT EVENTS IN THE ELGA (IIE) IRON.
S. N. Teplyakova. Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences. E-mail: svun2002@mail.ru

Introduction. Previous investigations of silicate inclusions (SI) in IIE irons suggested that SI probably were formed by the partial melting of H-chondrite precursors, or by condensation of minerals and metals from the solar nebula [1-5]. Here we report results on mineralogy, petrology and mineral chemistry of eleven SI and the host metal of the Elga (IIE) meteorite. It was shown that chemically SI are similar to those of the Miles (IIE) and that some of SI after their formation were melted as a result of local heating during impact metamorphism.

Results: The silicate inclusions consist of euhedral pyroxene crystals (Wo37-44En44-50; Cr2O3 1.5 wt%; Fe/Mn=15-31) enclosed in a SiO2-rich feldspatic glass (Ab26-28Or7-26 to Ab39-40Or51). Mineral modes are (vol%): pyroxene 22-34; glass 66-78. Minor phases include bronzite, chromite, schreibersite, phosphate, troilite, kamacite and taenite. Locally, some glass contains FeNi metal as well metal-sulfide and silicate globules. Fe-Ni-P inclusions are in both the Elga metal and in SI. Objects within metal are rounded, but objects in SI are irregular shape. All Fe-Ni-P inclusions have an unusual dendritic-like texture. The bulk composition of SI silicate portion is (wt%): SiO2 65.8; TiO2 0.27; Al2O3 12.71; Na2O 6.24; K2O 1.71; CaO 5.28; MgO 4.69; MnO 0.1; FeO 2.81; Cr2O3 0.36. Elga host metal shows plastic deformation, while the SI show brittle deformation.

Discussion: The mineral assemblage of the Elga SI is similar to other IIE irons [6]. Fe/Mn ratios and Cr2O3 content of pyroxenes from the Elga SI are similar to those of other IIE inclusions, primitive achondrites and ureilites. The Elga SI are enriched in K, Na, and Al compared to SI IIE iron and H-chondrites indicating of the high abundance of feldspar component. Chemically, SI resemble the cryptocrystalline inclusions of the Miles (IIE) [1]. Ca-phosphate surrounds the SI, indicating reduction reactions between metal and silicate due to thermal metamorphism, after impact event. Some SI are similar to the melt pockets observed in shocked chondrites. Such structures may have formed due to impact melting and mixing of silicate and metal melts, followed by rapid cooling. In iron meteorites, dendritic Fe-Ni-P objects have not previously been found coexisting with silicate melts. We believe that the dendritic structure of these objects is the result of rapid cooling. Deformed Widmanstatten pattern throughout the sample, SI which are similar to the melt pockets, and coexisting lamellar and the dendritic schreibersite objects suggests local heating and may reflect varying temperatures across the shock wave front. Brittle deformation of some SI also supports the impact hypothesis for the origin of the melts after the metal and silicate material had already been combined in a body.

ION MICROPROBE U-Pb DATING OF PHOSPHATES IN VERY-LOW-TI BASALTIC BRECCIA.

K. Terada1, Y. Sasaki1 and Y. Sano1. 1Department of Earth and Planetary Systems Science, Hiroshima University, Higashi-Hiroshima 739-8526, JAPAN (terada@sci.hiroshima-u.ac.jp), 2Center for Advanced Marine Research, Ocean Research Institute, The University of Tokyo, Nakano-ku 164-8639, JAPAN.

Abstract: The lunar meteorites have valuable informations for understanding the evolution of the Moon’s crust, because each meteorite may potentially provide a new insight into the thermal history of unexplored regions of the Moon. In spite of their scientific interests, chronological studies of Very-Low-Ti (VLT) basaltic meteorites have not be well understood, since the most VLT basalt meteorites are brecciated and consist of mixtures of materials with different origins. In this paper, we summarize our recent studies of in-situ U-Pb dating of VLT meteorites.

An ion microprobe analyses of mare-origin’s phosphates in Yamato-981031 resulted in a total Pb/U isochron age of 3535 ± 170 Ma in the 238U/206Pb - 207Pb/206Pb - 204Pb/206Pb 3-D space (95% confidence limit), while those of QUE 94281 resulted in a total Pb/U isochron age of 3401 ± 170 Ma and 65 ± 300 Ma (95% confidence limit). These formation ages of phosphates are consistent with each other and also agree with previous studies of 3569 ± 100 Ma for EET 96008 [1] and 3521 ± 138 Ma for EET 87521 [2], whose basaltic components are also classified into VLT mare basalt. This result indicates that there is no chronological impediment to the hypothesis that these meteorites have originated from the same place on the Moon and were launched by a single impact, which has been proposed based on the similarity of launching ages, mineralogical and geochemical signatures [3-5].

Recent global and high-resolution mappings of chemical composition and mineralogical composition on the Moon observed by Clementine and Lunar Prospector enable us to discuss on the ejection sites of some lunar meteorites [6-8]. Assuming the scenario for Yamato-981031 [8], our data suggest that the formation age of northern parts of mares of near-side of Moon (possibly, Mare Frigoris or Lacus Somniorum or Lacus Mortis) might be about 3.5 Ga. Thus, our in-situ dating techniques of lunar brecciated meteorites coupled with the higher-resolution remote-sensing data may provide a radiometric (not based on the crater density) chronological assessment of unexplored regions on the Moon.

LU-HF SYSTEMATICS OF THE ANGRITE SAH99555.
K. Thrane1, J.N. Connelly1,2, M. Bizzarro1, L. Borg3 and D. Ulfbeck1. 1Geological Institute, University of Copenhagen. E-mail: kthrane@geol.ku.dk. 2Dept. Geological Sciences, University of Texas, at Austin. 3Institute of Meteoritics, University of New Mexico.

Introduction: Estimates of the $^{176}$Lu decay constant derived from terrestrial and meteoritic (chondrites and eucrites) samples have differed significantly and correspond to $1.87 \times 10^{-11}$yr$^{-1}$ [1,2] and $1.93-1.98 \times 10^{-11}$yr$^{-1}$ [3-6], respectively. More recently, Amelin’s [7] internal isochron from a 4557 Ma meteorite using phosphate minerals yielded an estimate of the $^{176}$Lu decay constant compatible with the terrestrial value.

Objectives: We use the 4566.18 Ma [8] angrite SAH99555 to derive an internal isochron using silicate phases to further evaluate both the $^{176}$Lu decay constant and the initial $^{176}$Hf/$^{177}$Hf ratio of the solar system.

Method: We dissolved carefully-picked olivine, pyroxene and plagioclase mineral fractions (2 each) from SAH99555 as well as two whole-rock samples. HFSEs and REEs were first separated from the bulk matrix using cation resin after which Hf and Lu/Yb were further purified using TODGA and RE-spec resins, respectively [9]. Lu and Hf were analysed on the Axiom MC-ICP-MS in Copenhagen. Sm and Nd from the LMREE cuts from the RE-spec step were further purified using methylactic columns and were analysed on the VG Sector 54 TIMS at the University of New Mexico.

Results: In the Lu-Hf system, the two pyroxene, two olivine and two whole-rock fractions define a line with slope and intercept of $0.09516 \pm 0.00100$ and $0.27968 \pm 0.000030$. The slope corresponds to ages of $4874 \pm 48$ Ma and $4584 \pm 45$ Ma using the meteoric- [6] and terrestrial-derived decay constants, respectively. Two plagioclase fractions plot slightly above the line. In the Sm-Nd system, the two pyroxene and two whole-rock fractions define a line corresponding to an age of $4591 \pm 49$ Ma. The olivine and plagioclase fractions plot above the WR-pyroxene line.

Discussion: Concordance between the WR-pyroxene Pb-Pb age [8] and our WR-pyroxene Sm-Nd age demonstrate both isotopic systems were undisturbed in these components. The line defined in Lu-Hf space by replicate WR-pyroxene-olivine fractions indicates that Lu-Hf in these components also behaved as a closed system. The slope of this internal isochron infers that $^{176}$Lu decayed at a rate or in a manner comparable to that determined for chondrites [6]. The derivation of this internal isochron for a differentiated basalt precludes accelerated $^{176}$Lu decay via formation of the short-lived isomer $^{176m}$Lu ($t_{1/2} = 3.7$ h) by $\gamma$-ray irradiation [10] prior to accretion of the angrite parent body. Instead, any formation of the isomer $^{176m}$Lu caused by $\gamma$-ray irradiation requires this energy to have been derived internally after angrite crystallization, which implies short-lived nuclides served as a possible energy source.

TIMING OF DIFFERENTIATION OF PALLASITE PARENT BODIES: EVIDENCE FROM Al-Mg SYSTEM.

T. Tomiyama1*, M. Bizzarro2, A. N. Krot3, G. R. Huss4, and T. E. Bunch1. 1HIGP/SOEST, University of Hawai‘i at Manoa, Honolulu, HI 96822, USA. 2Geological Institute, University of Copenhagen, DK-1350, Denmark. 3ARC Desert Research Field Station, Prescott, AZ 86301, USA. *tomi@higp.hawaii.edu.

**Introduction:** Pallasites probably sample the core-mantle boundaries of parent bodies that experienced extensive melting and differentiation due to decay of $^{26}$Al ($\tau_{1/2} \approx 0.73$ Myr). Both the Al-Mg and metal-silicate fractionation recorded by pallasites can be potentially dated using short-lived isotope systematics. Precise bulk Pb-Pb and Al-Mg isotope analyses suggest that the accretion and differentiation of planetesimals occurred within ~1 Myr of formation of CAIs [1,2]. Based on differences in chemistry, mineralogy and O-isotopic compositions, several pallasite groups may exist [3]. We have initiated a high-precision Al-Mg isotopic study of several groups of pallasites to understand the time scale for their differentiation.

**Experiments:** Micro-drilled powders and chipped fragments of pallasite olivine and pyroxene were dissolved with HF-HNO$_3$ and Mg was purified by cation exchange chemistry. Magnesium isotope ratios were measured by MC-ICPMS, and $\delta^{26}$Mg* values are reported relative to the mean mass-bias-corrected $^{26}$Mg/$^{24}$Mg obtained on bracketing terrestrial standards (DSM-3 or mantle olivine). Samples are analyzed at least 8 times.

**Results:** Analysis of the J-11 mantle olivine yielded of –0.004 ± 0.008 ‰, i.e. identical to the terrestrial standard, while silicates from four pallasites representative of different (sub)groups exhibit resolvable $^{26}$Mg* deficits (average of –0.022 ± 0.008 ‰; Table 1), in agreement with previous reports [4].

<table>
<thead>
<tr>
<th>Sample</th>
<th>Group</th>
<th>Mineral</th>
<th>$\delta^{26}$Mg* (‰)</th>
<th>Error (2σ)</th>
</tr>
</thead>
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<td>Omolon</td>
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<td>-0.025</td>
<td>0.009</td>
</tr>
<tr>
<td>Huckitta</td>
<td>M.G. anom met. [5]</td>
<td>ol</td>
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<td>0.006</td>
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<tr>
<td>Springwater</td>
<td>M.G. anom sil. [5]</td>
<td>ol</td>
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<td>0.012</td>
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<tr>
<td>Zinder</td>
<td>Pyroxene Pal</td>
<td>opx</td>
<td>-0.017</td>
<td>0.008</td>
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</tbody>
</table>

**Discussion:** In a model where $^{26}$Al was homogeneous in the early solar system, the present solar $^{26}$Mg/$^{24}$Mg ratio represents addition of $^{26}$Mg* to an initial $^{26}$Mg/$^{24}$Mg ratio. If Al-Mg fractionation decreased the Al/Mg ratio relative to solar while $^{26}$Al was alive, deficits of $\delta^{26}$Mg* will result. All pallasites we measured have $\delta^{26}$Mg* deficits, indicating formation within the life span of $^{26}$Al. Assuming an initial $^{26}$Al/$^{27}$Al ratio of ~5.85 × 10$^{-5}$, based on bulk CAIs [6,7], and a solar $^{17}$Al/$^{16}$Mg ratio of ~0.1, we calculate an initial $\delta^{26}$Mg* of ~ –0.042. If a pallasite parent body had a solar bulk Al/Mg ratio, the time necessary to raise the initial $\delta^{26}$Mg* to ~ –0.022, when the pallasites differentiated, would be ~0.8 Myr. This result is highly model-dependent reflecting choices of Al/Mg, initial $\delta^{26}$Mg*, and details of differentiation.

Introduction: Acapulcoites are primitive achondrites that have modal mineral abundances similar to ordinary chondrites and exhibit broadly chondritic bulk compositions. Their formation probably involved thermal metamorphism and melting at the Fe,Ni-FeS cotectic. Their textures reflect extensive solid-state recrystallization [1]. However, there is evidence from metal inclusions in pyroxene and in few olivine cores that partial melting of silicates occurred [2]. $^{182}$Hf–$^{182}$W chronometry is well suited to constrain the timescales of thermal metamorphism (and melting) in the acapulcoite parent body and here we present the first Hf-W data for acapulcoites.

Results: Metals separated from the acapulcoites Dhofar 125 and NWA 2627 are enriched in W (~800-900 ppb) and have $W$ values of ~ -3 ($W$ is the deviation of $^{182}$W/$^{184}$W from the terrestrial standard value in parts per 10,000). Whole-rock analyses for NWA 2627 (~600 mg) and Dhofar 125 (~150 mg) yield Hf/W ratios of ~0.6 and ~1.6 and $W$ values of ~-2 and ~-1.5, respectively.

Discussion: The Hf-W systematics of the NWA 2627 and Dhofar 125 whole-rocks are consistent with a chondritic bulk composition for the acapulcoites. Differences in Hf/W and $W$ between NWA 2627 and Dhofar 125 might reflect sample heterogeneities but may also be due to differences in the chemical composition of acapulcoites. The chondritic Hf-W systematics of NWA 2627 and Dhofar 125 indicate that, if partial melting occurred, these melts were not extracted. The enrichment of W in the acapulcoite metal is similar to that observed for metals in equilibrated ordinary chondrites, indicating transfer of W from silicates into metal during thermal metamorphism. Tungsten model ages for the NWA 2627 and Dhofar 125 metals are 5±2 Myr after formation of Allende CAIs (using $W = -1.9+0$ for carbonaceous chondrites [3] and initial $W = -3.47+0.20$ [4]). These ages are similar to Hf-W ages obtained for equilibrated ordinary chondrites, indicating similar timescales of metamorphism on the acapulcoite and ordinary chondrite parent bodies. The W model ages for the NWA 2627 and Dhofar 125 metals are older than a Pb-Pb age for phosphates [5] and a Mn-Cr age for oxides and silicates from Acapulco [6]. If the latter are representative for all acapulcoites, then these age differences could reflect different closure temperatures for Hf-W and Pb-Pb/Mn-Cr. Alternatively, Hf-W ages might date the onset of metamorphic heating whereas Pb-Pb and Mn-Cr ages might reflect cooling from peak metamorphic temperatures (as suggested by [7] for ordinary chondrites).

EARLY SOLAR SYSTEM CHRONOLOGY IN THE ASTROPHYSICAL CONTEXT

M. Trieloff 1, H. Palme 2. 1University of Heidelberg, Institute of Mineralogy, D-69120 Heidelberg. E-mail: trieloff@min.uni-heidelberg.de. 2University of Cologne, Institute for Mineralogy and Geochemistry, Zülpicherstrasse 49b, 50674 Köln, Germany.

Radioisotope chronologies from both long-lived nuclides ([238,235]U-[206,207]Pb, [40K-40Ar] [1,2]) and short-lived radionuclides ([129]Xe from [129]I; T_{1/2}=16 Myr [3], excess [26Mg] from [26]Al; T_{1/2}=0.73 Myr [4], [53]Cr from [53]Mn; T_{1/2}=3.7 Myr [5], [182]Hf from [182]W; T_{1/2}=9 Myr [6,7]) provide a framework for the formation of solids in the early solar system. We present an early solar system chronology based on the calibration of short-lived isotope chronometries to several tie points (CAIs, H chondrites, Acapulco), and planetesimal heating in the early solar system [2,8]. Conditions of formation of the first solids in the solar nebula varied - most probably due to p,T differences imposed by the early sun - with radial distance and/or time, and caused the compositional variety of planetesimals concerning refractory and volatile elements, metals, and Mg-rich silicates [8,9].

Radiometric dating and chemical composition suggest that individual planetesimals grew rapidly in the asteroid belt (within < 1 Myr), but different planetesimals formed over a time interval of 4 million years [2,7,8], well within the lifetime of protoplanetary dust disks in extrasolar systems [10,11]. Early planetesimals were heated to varying degrees by decay heat of short-lived nuclides (primarily [26]Al) [2]. This caused melting and differentiation in early (within < 2 Ma after CAIs) formed planetesimals and led to the formation of iron cores and basaltic rocks, while chondritic planetesimals that accreted later remained undifferentiated [2,7,8]. As most chondrules were immediately consumed in accreting planetesimals, they were only preserved in unmelted chondritic parent bodies and their age distribution is biased to the formation time interval of chondrites 2-3 Ma after CAIs [8]. The formation of solids in the early solar system (CAIs, chondrules, planetesimals and terrestrial planets) are still insufficiently linked to astrophysically constrained processes like early protostellar activity, disk dissipation, formation and migration of gas planets interacting with young disks [10,11]. Models of Earth and Mars formation based on [182]Hf-[182]W core formation ages estimate the presence of planetary embryos of 60% the size of Mars after 2-4 Ma. This requires the early presence of Jupiter to effectively prevent the formation of a proto-planet in the asteroid belt. Planetesimal formation in the asteroid belt and the terrestrial planet formation zone at <3 Ma after CAIs was likely accompanied by inner disk clearing permitting solar wind irradiation (and possibly volatile element depletion) of terrestrial – and partly asteroidal - precursor planetesimals [12].

ALUMINUM-RICH CHONDRULES AND TYPE C CAIs: AN EXPERIMENTAL COMPARISON OF FORMATION CONDITIONS.
E. J. Tronche¹, R. H. Hewins¹,² and G. J. MacPherson ³¹ Laboratoire d’Etudes de la Matière Extraterrestre , MNHN & CNRS-UMS2679 61 rue Buffon, 75005 Paris, France, ²Dept. of Geological Sciences, Rutgers University, 610 Taylor Road, Piscataway NJ 08854, USA, ³Department of Mineral Sciences, MRC NHB-119, National Museum of Natural History, Smithsonian Institution, Washington, D.C. 20560 USA.

Introduction: Aluminum-rich chondrules are a compositional link between ferromagnesian chondrules and plagioclase-rich (Type C) CAIs [1]. However, whereas Al-rich chondrules are compositionally and texturally very diverse, Type C CAIs are a much more restricted group of objects. We previously [2] reported dynamic crystallization experimental results that demonstrate the relationship between bulk composition, mineralogy, texture, maximum melting temperature (T$_{\text{max}}$), and cooling rate for 4 different Al-rich chondrule bulk compositions. Here we more thoroughly contrast those results (for the 2 most plagioclase-normative compositions only: PL-1 and PL-2; see [2]) with experiments on a Type C CAI synthetic bulk composition in order to constrain whether or not the two groups of objects formed under similar conditions (thermal histories). The experimental techniques and starting compositions were reported in [1].

Results: As expected, first order differences exist because of differing bulk compositions. The Type C CAI melt yields liquidus spinel, followed successively by anorthite, aluminous diopside, and melilite. The two Al-rich chondrule compositions are less spinel-normative and have forsterite as a late crystallizing phase. Type C CAIs can be formed at subliquidus temperatures (1400-1450°C), a little bit higher than for type B chondrules [3], but similar to Al-rich chondrules of PL1 and PL2 compositions. Cooling rates for this type of composition and those temperatures do not change textures much and no estimation can be made. We cannot say that the Type C CAI and the two Al-rich chondrule compositions have different thermal histories.

Discussion: Natural type C CAIs usually have ophitic textures, but the anorthite lath sizes can vary enormously from one type C CAI to another. Also they seem to have a wide range of oxygen isotopic compositions [4] and $^{26}$Mg excesses [4-5], that could lead to the idea of different formation processes for this group of objects. Hence, a quantitative study of textures, mineral zonation and melilite abundance in primitive and remelted C-CAI might prove instructive. Peak temperatures probably increased from type B CAIs to ferromagnesian chondrules, but C-CAI may include objects with CAI-like and chondrule-like heating-cooling conditions.

The Mn-Cr chronometer is an ideal tool to unravel the age of igneous activities in the early solar system. However, recent discovery of isotope anomaly on $^{54}$Cr in differentiated meteorites (e.g. [1, 2]) makes the isotopic investigation of $^{54}$Cr/$^{52}$Cr also very important. In this study, we have measured the Cr isotopic signature of three monomict ureilites, ALHA77257, Y-791538 and META78008. All measurements were made using Finnigan MAT262 mass spectrometer in a single collector peak-jumping mode [2]. In order to minimize the effect of residual mass fractionation, a relatively large number of repeated measurements were made for each sample (>40 sets of 300 ratios).

The results of the three samples show that their $\varepsilon^{53}$Cr vary from +0.04 to +0.29, and $\varepsilon^{54}$Cr from -0.73 to -1.16. These values are correlated on a $\varepsilon^{53}$Cr versus $\varepsilon^{54}$Cr diagram (Fig. 1), and the slope of the linear trend is similar to that of the terrestrial standards. Such correlation may indicate that the effect of residual mass fractionation has not been fully eliminated for these samples. However, it is also difficult to reject the possibility at this point that the three samples are from isotopically different reservoir.

If we assume that they are from a single reservoir, we can calculate the $\varepsilon^{54}$Cr value of the ureilite parent body (UPB) by taking the average of all the $\varepsilon^{54}$Cr values determined so far. Our current best estimate calculated using this procedure is $\varepsilon^{54}$Cr = -0.93 +/- 0.23. This value is in good agreement with our earlier work [2], as well as the value recently reported by Shukolyukov and Lugmair [3]. While the number of data is still limited, the currently available data clearly indicate that the Cr isotopic signature of the UPB is different from those of carbonaceous chondrites ($\varepsilon^{54}$Cr>0) and Earth ($\varepsilon^{54}$Cr = 0).

Fig. 1 Results of the Cr isotopic analysis.

MICROSCOPIC MAGNETIC FIELD DISTRIBUTIONS OF UNEQUILIBRATED ORDINARY CHONDrites.
M. Uehara and N. Nakamura. 1Division of Geoenvironmental Science, Tohoku University, Sendai 980-8578, Japan. E-mail: syok@dges.tohoku.ac.jp.

Introduction: Unequilibrated ordinary chondrites preserve metallic phases formed during solar nebular processes [1-3]. The metallic phase of Fe-Ni grains appear to simultaneously preserve a magnetic environment of the early solar nebula as a Natural Remanent Magnetizations (NRMs). An experimental study suggested that abundant submicron-sized kamacite grains in a reduced “dusty” olivine acquire magnetically stable pre-accretional NRMs when the chondrules were formed [4]. Lauretta et al. [2] suggested that silicon-bearing Fe-Ni grains in the matrix of Bishunpur (LL3.1) were formed in the reducing environment of chondrule melts. It implies that such Fe-Ni grains in the matrix also acquired pre-accretional NRMs. Furthermore, if these metal grains were magnetized before incorporation into chondrules, their NRMs should be randomly oriented. Hence, the correlation between magnetic grains and their NRMs is interesting, because it provide constraints on the thermal, chemical and magnetic environment of the solar nebula, and the acquisition process of NRMs in the nebula. However, there is no study focused on NRM of these Fe-Ni grains in the unequilibrated ordinary chondrites. Here, we report spatial distributions of NRMs in unequilibrated ordinary chondrites using a custom-made scanning MI (magneto-impedance) magnetic microscope.

Method: We examine a 3 mm thick slice of NWA1756 (LL3.0/3.2). Images of the out-of-the-page component of the magnetic field 300 μm above the sample were obtained by a scanning MI magnetic microscope that has a resolution and sensitivity of 500 μm, 360 nT, respectively. The measurements were made in a three-layered mu-metal magnetic shield.

Results and discussion: Magnetic images of the NWA1756 sample reveal a spatially heterogeneous pattern of magnetization showing eight distinct magnetized points, suggesting pre-accretional NRMs. A comparison with the magnetic minerals shows that magnetized points are associated with kamacite in the matrix, which is often surrounded by FeS, and also shows that large (~ 300 μm) kamacite grains were strongly magnetized. Although a chondrule contains dusty olivine grains, we detect only a slight magnetic signature from this chondrule. These preliminary results suggest that the scanning MI magnetic microscopy is able to decide the NRM carriers in the unequilibrated ordinary chondrites.

**A POSSIBLE ORIGIN FOR THE DEPLETION OF SIDEROPHILE ELEMENTS IN CHONDRULES.**

M. Uesugi and M. Sekiya, 1 Japan Synchrotron Radiation Research Institute (JASRI) 1-1-1 Kouto, Sayo-cho, Sayo-gun, Hyogo 679-5198, Japan, 2 Department of Earth and Planetary Sciences, Faculty of Sciences, 33 Kyushu University, Hakozaki, Fukuoka, 812-8581, Japan

**Introduction:** Chondrules have a distinctive feature that they are depleted in siderophile elements relative to the solar elemental abundance [1]. Several processes, such as ejection of iron component by high-speed rotation of chondrules during their formation and fractionation in the condensation of chondrule precursor materials from hot nebular gas, are considered to be possible reasons of the iron-chondrule separation [2]. Separation due to physical fission of chondrule and metallic iron part is one of the most probable reasons for the depletion. The fission could occur at the time of chondrule formation, so, if the physical fission is responsible to the depletion of siderophile elements in chondrules, we can obtain important information of chondrule formation processes by investigating the feature. We propose a new viewpoint for the study of this process, based on the theoretical calculation of the separation of melted chondrule and iron sphere at the time of the chondrule formation.

**Basics:** We calculated total surface energy of a melted chondrule, a melted iron sphere and their interface for the cases those an iron sphere is on the surface (hereafter, we call this condition as ON), inside (IN) and outside (OUT) of a melted chondrule. At first, we estimate the interfacial energy between the melted iron and chondrule by calculating the equilibrium shape for ON state and comparing it with the natural chondrules. In the calculations, we use 1830 erg cm\(^{-2}\) for the interfacial energy, which is the average of the result from three chondrules, and 400 and 1700 erg cm\(^{-2}\) for the surface energies of melted chondrule and Fe, respectively.

**Results and discussion:** Our calculation shows that the total surface energy for OUT condition is lower than that for IN condition. This means that once a melted iron sphere which initially inside of a melted chondrule reaches the surface during the chondrule formation process, the iron sphere is immediately ejected to the outside of the melted chondrule. And also, it is difficult that a melted iron sphere which initially outside of a melted chondrule penetrates into the melted chondrule, because strong surface tension prevents the penetration. On the other hand, the total surface energy for ON condition is lower than any other conditions. This means that if a melted iron sphere initially on the surface of a melted chondrule, the iron sphere is strongly bound on the surface by the surface tension. Thus, our calculations show that iron spheres being inside of melted chondrules are easily ejected to the outside of the chondrules, if they reach the surface of melted chondrules during the chondrule formation. If a melted chondrule has some amount of angular momentum, iron spheres are transported to the surface of melted chondrules, and immediately leave from the surface of chondrules. Thus, the ejection of iron sphere due to surface tension would play important role for the origin of the contents of siderophile elements in chondrules.

**References:**
THE TYPE Ia SUPERNOVA AND ORIGIN OF THE SOLAR SYSTEM.
G. K. Ustinova. Institute of Geochemistry and Analytical Chemistry, RAS, Moscow. E-mail: ustinova@dubna.net.ru

Introduction: Because of the absence of the r-process products among the extinct radionuclides with the short intervals of generation, the last supernova before the formation of the Solar system was the Type Ia Supernova (the so-called carbon-detonation supernova), which could not survive the carbon explosive burning and was fully disrupted [1]. The injection of its specific matter (especially, large amounts (0.4-0.6 M$_\odot$) of iron [2]) into the protosolar nebula created the initial large-scale chemical heterogeneity of the accreting matter, which led to the initial (before condensation!) metal-silicate separation of the matter in the conditions of the supersonic turbulence in the collapsing nebula [3]. Both the factors ranged the consequence of events in the formation of the Solar system bodies, which is recently derived from the Hf-W chronometry [4, 5].

Drafts of Scenarios: The large quantity of synthesized and shock wave accelerated iron nuclei were among the first ones that penetrated into the collapsing protosolar nebula and, being captured by supersonic turbulence, they created some iron-rich regions of various scale, so that the further condensation and accumulation in those regions formed the iron planetesimals and iron parent bodies. In some cases of especially huge vortices the captured iron laid the metallic core embryos of some planets, which were built up further due to magmatic differentiation. This fact promoted the rapid formation of the planets, which follows from the $^{182}$Hf-$^{182}$W data [4, 5]. The intermediate and light nuclei of the Type Ia Supernova also reached the accreting system and rather later were captured gradually by the especially huge vortices, which still were not dissipated. They had played the key role in formation of the earth group planets under the reducing conditions being typical for the corresponding heliocentric distances. When practically all the injected iron was caught by the turbulence, the new developed vortices captured the intermediate-mass explosion products. Depending on the distance from the protosun, and, therefore, from the different PT-conditions of condensation, the different types of stony bodies of various scale were created, whose accumulation led later to the formation of stony planetesimals and the parent bodies of stony meteorites of different types. Certainly, all the possible cases of the blended matter could occur. The most part of the unburned C and O of the Type Ia Supernova was accreted at the conclusive stage of accretion in the various conditions of low temperatures and free gravitation that provided the formation of carbonaceous chondrites of different types. The giant planets were apparently formed by the giant vortices in the main matter of the protosolar molecular nebula at the distances which had not been reached by the exploded matter of the Type Ia Supernova.

Summary: The thorough development of the above frame models will substitute the chondrite models of the Solar system.

THE SURFACE ELEMENTAL COMPOSITION OF 4 VESTA BASED ON HED METEORITES: PROSPECTIVE STUDY FOR INTERPRETATION OF GAMMA-RAY AND NEUTRON SPECTRA FOR THE DAWN MISSION.

T. Usui and H. Y. McSween Jr. 1 1 Planetary Geosciences Institute, Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996, USA. E-mail: tusui@utk.edu

Asteroid 4 Vesta, believed to be the parent body of the voluminous howardite, eucrite, and diogenite (HED) achondrites [1-3], will be investigated by the Dawn orbiting spacecraft [4]. Dawn carries a gamma-ray and neutron detector (GRaND) that will measure and map some major and trace element abundances [5]. Drawing on HED geochemistry, we propose a quantitative mixing model that uses element ratios (determined more precisely than absolute elemental abundances) appropriate for the interpretation of GRaND data.

Because the spatial resolution of GRaND is relatively coarse, analyzed chemical compositions on the surface of Vesta will likely reflect mixing of three end-member components: diogenite, cumulate eucrite, and basaltic eucrite. Reliability of the mixing model is statistically investigated based on published whole-rock data for HED meteorites (N = 48). We demonstrate that the mixing model can accurately estimate the abundances of all the GRaND-analyzed major elements, as well as minor elements (Na, Cr, and Mn) not analyzed by this instrument. We also show how a similar mixing model can determine the modal abundance of olivine, and we compare estimated and normative olivine data for olivine-bearing diogenites.

This study provides a way to leverage the large geochemical and mineralogical database on HED meteorites as a tool for interpreting chemical analyses by GRaND of mapped units on the surface of Vesta. Therefore, this study should help constrain the geologic context for HED meteorites and provide new insights into the structure and igneous evolution of Vesta.

THE STRUCTURE AND ORIGIN OF METAL IN ISHEYEVO CB/CH METEORITE.
E-mail: ksenia_uimina@mail.ru, grokh47@mail.ru.

Introduction: The unique mineralogical, chemical and textural data of the CR chondrite clan meteorites is poorly understood and widely discussed [1-4]. Recently discovered metal-rich Isheyevo meteorite contains several lithologies with different contents (7-70 vol%) of Fe-Ni metal and genetically links CH and CB of carbonaceous chondrites [5]. Zoned metal grains with striking components distribution are the most interesting. Both nebular and asteroidal models have been proposed to explain this distribution [6]. Here we report the results of optical microscopy observations after etching, accompanied with results of SEM/EDX analysis, and Mossbauer spectroscopy, and discuss the possible origin of metal structure.

Results: We observed a variety of metal microstructures. The metal clasts are polycrystalline, boundaries marked by secondary minerals make grains to look sharp. Part of coexisting metal grains is zoned with kamacite structure. These grains were found in both metal-rich and metal-poor lithology, have size up to 1 mm, and contain 12-4 wt% of Ni, 0.7-0.3 wt% of Cr. It was found that the gradient of Ni concentration is orientation-dependent: in zoned metal grains we observed the anisotropy of Ni, Cr gradients. Moreover, zoned metal grains contain numerous small spherical inclusions of another phase with Cr and S near the boundary area. These inclusions increase in size while approaching the hydrated boundary.

The neighboring grains can have different metal distribution and different texture. The unzoned kamacite grains with almost constant Ni 7.5-7.85 wt% and Cr 0.19-0.26 wt% were observed. Zoneless plessite grains with average Ni 7.5 wt% were found, along with few populations of metal-sulfide aggregates, including “kamacite (Ni 5.1 wt%, Cr-0.22 wt%, P 0.46wt%) with Neumann bands – troilite enriched in Cr”, “kamacite (Ni<7.8wt%) – taenite (44.9 wt%) – troilite”, and “kamacite (Ni 4.7wt%) - martensite (13.2 wt%) – troilite”. The Mossbauer spectroscopy confirmed the heterogeneous structure of Fe-Ni alloys and showed four main components in metal part of spectrum [7].

Discussion: The primitive meteorite Isheyevo has complex multistage history. Despite the fact that CALs [8] and osbornite [9] of very refractory nature in the Isheyevo carbonaceous are nebular products, we argue that unusual metal grain zoning may be connected with the process of secondary diffusion. We assume that the so-called “internal oxidation” took place within the metal grains starting from hydrated grain boundary sources, and produced the observed metallography features. Small inclusions located in the by-boundary areas of most zoned metal grains, and anisotropy of chemical gradients can prove this suggestion. The existence of “puzzle-shape” formed by zoned and unzoned metal grains can not be explained using nebular models.

WEATHERING OF ORDINARY CHONDRITES FROM THE ATACAMA DESERT, CHILE: FIRST RESULTS FROM MÖSSBAUER SPECTROSCOPY.
E. M. Valenzuela¹, Y. Abdu², R.B. Scorzelli², J.B. de Campos³, M. Duttine²*, D. Morata¹. ¹Dep. de Geologia, Universidad de Chile, Santiago, Chile, edvalenz@ec.uchile.cl; ²Centro Brasileiro de Pesquisas Físicas (CBPF/MCT), RJ, Brazil, scorza@cbpf.br; ³Instituto Nacional de Tecnologia (INT/MCT), RJ, Brazil. *On leave from Centre de Recherches en Physique Appliquée à l’Archéologie (CRPAA), Bordeaux, France.

Introduction: We report the first quantitative results of the study of 21 meteorites from the Atacama Desert, northern Chile. The meteorites are ordinary chondrites (OC) and include the three chemical groups (H, L, and LL). The goals of this study are the identification and quantification of the weathering products of these meteorites, in order to understand the weathering processes acting in the Atacama Desert, one of the oldest and driest deserts of the world, and compare these first results with samples from other deserts. As recently fallen equilibrated OC contain iron only as Fe⁰ (kamacite and taenite) and Fe²⁺ (olivines, pyroxenes and troilite), the abundance of ferric iron is directly related to the level of terrestrial weathering [1]. In this way, the characterization of weathering products of these samples using Mössbauer spectroscopy, X ray diffraction (XRD) and magnetic properties [2] allow us to have a complete picture of iron oxihydroxides nature and behavior.

Results: As Mössbauer spectroscopy is extremely sensitive to changes in Fe valence state, the technique, complemented by XRD, allows the recognition and quantification of all the Fe-bearing phases. The percentage of these phases was obtained for the primary minerals: olivine, pyroxene, troilite and Fe-Ni metal, and for the ferric alteration products which gives the percentage of oxidation of the samples. The subspectra arising from the presence of Fe³⁺ are generally fitted with a paramagnetic doublet and a magnetic sextet(s). The doublet can be associated with the paramagnetic phases: akaganéite, lepidocrocite and/or small-particle goethite, while the sextet(s) are due to the magnetically ordered phases: magnetite, maghemite, hematite, and large-particle goethite.

From the Mössbauer absorption areas of these oxides, the terrestrial oxidation of the Atacama OC was found to range from ~ 5% to ~ 60%. The amounts of silicates as well as the opaque phases (troilite and Fe-Ni metal) were found to decrease in a constant rate with increasing oxidation level. A histogram of percentage oxidation versus frequency shows a peak at ~ 30-35 % similar to that observed in the Sahara Desert OC [3]. Akaganite, the first product of Fe-Ni oxidation [4], is present only in some samples, deduced from XRD data.

Further low temperature Mössbauer measurements are in progress in order to better resolve the individual components of the oxide phases, especially the paramagnetic phases. The MS and XRD results will be correlated with the terrestrial ages of these weathered meteorites.

MAGNETIC ANISOTROPY OF CARBONACEOUS CHONDRITES AND ACHONDrites.

M. van Ginneken, J. Gattacceca, M. Gounelle. 1CEREGE, CNRS/University of Aix-Marseille 3, France (gattacceca@cerege.fr). 2LEME, Muséum National d’Histoire Naturelle, Paris, France (gounelle@mnhn.fr). 3IARC, Natural History Museum, London, UK.

Magnetic anisotropy has been shown to be a good proxy to the petrofabric of meteorites [1]. In particular the degree of magnetic anisotropy of ordinary chondrites increases with shock stage [2], indicating that hypervelocity impacts are the main phenomenon responsible for the foliation of ordinary chondrites.

The principal scope of the present work is to discuss the origin of the petrofabric in carbonaceous chondrites, using anisotropy of magnetic susceptibility (AMS) as a proxy to the petrofabric. Is the foliation of carbonaceous chondrites related to impacts as for ordinary chondrites? Can accretion and/or metamorphism be responsible for the foliation?

The dataset of AMS measurements on carbonaceous chondrites was until now rather limited (33 measurements including only 11 falls [2,3]). We measured the AMS of an additional 51 carbonaceous chondrites from the MNHN in Paris, including 27 falls. After discussing the experimental limitations of such measurements (in particular the effect of shape anisotropy), the total dataset will be interpreted in relation with porosity, shock stage, metamorphism, petrographic observations and magnetic mineralogy.

The significance of AMS data obtained on Rumuruti chondrites (characterized by very low degree of anisotropy) and achondrites (HED, SNC, aubrites, ureilites) will also be discussed in the light of new measurements.

AN UNIVERSAL METEORITE FORMATION PROCESS.

Varela, M. E. and Kurat, G. 1 Complejo Astronomico El Leoncito (CASLEO), Av. España 151 sur, J5402DSP, San Juan, Argentina, Institut für Geologische Wissenschaften, Universität Wien, Althanstrasse 14, A-1090 Vienna, Austria.

Our study of glasses in several types of meteorites show that all glasses have a common source, the solar nebula [1]. Glasses are the remnants of the liquid that facilitated growth of well-ordered crystals from the gas phase by the VLS growth process. The chemical (major and trace element) composition of all glasses have a surprising property: they do not show the signature of crystallization of the minerals they are associated with. Our key observation is that glasses do not have the composition of the residual melt from which the crystals (documented by glass inclusions), or aggregates and chondrules (documented by mesostasis glass), or the whole rock (documented by glasses that fills open spaces in achondrites) were formed [2-3]. These observations led us to develop The Primary Liquid Condensation (PLC) model [4] that utilizes the ability of dust-enriched solar nebular gas to directly condense a silicate liquid [e.g., 6]. Once a stable CMAS liquid nucleus is formed and growth into a droplet an olivine crystal can nucleate from the liquid. If the quantity of liquid is low, the crystal nucleus will continue growing where it is covered by the liquid. In this way a single crystal can be formed. Increasing the liquid/crystal ratio can create olivine aggregates and droplets of crystal-liquid mush, PO chondrules [7]. If condensation of liquid is faster than nucleation of an olivine crystal, a chondrule-sized droplet is formed, which at a high degree of undercooling will homogeneously or heterogeneously nucleate an olivine crystal. Instantaneously, a plate dendrite can be formed, the barred olivine (BO) texture. We have estimated the composition of the initial liquid droplet for such chondrules to be: SiO$_2$: 46.1 wt%, MgO: 38.5 wt%, Al$_2$O$_3$: 8.4 wt%, CaO: 7.1 wt%. The primary condensate liquid from which BO chondrules could be formed will condense in regions with a dust/gas ratio enhanced over the solar value by ~700 x CI dust - at T~ 1700 °C and p ~ 10^{-3} atm [8]. Variation in the chemical composition of, e.g., the mesostasis glasses, is achieved by continuing communication of the glass with the cooling nebula that will result in a variety of elemental exchanges. This way an infinite amount of individual chemical compositions for chondrules and other chondrite constituents is created – as it is observed.

A liquid of similar composition and origin also formed the olivine-anorthite intergrowth of angrites [9] and a chemically slightly modified liquid – increased Si/Mg but similar TE abundance – crystallized the eucrites [10].

Also, radiating pyroxene (RP) chondrules could form as droplet liquid condensates directly from a nebular gas [11]. Enstatite becomes a stable liquidus phase in a 800 x CI dust-enriched nebular gas at a p$_{H_2O}$ of 10^{-3} atm, after about 72 % of the originally present Mg was removed (as forsterite?) from the system.

In conclusion, the PLC model describes an universal process that can create all major chondrule types, PO, BO and RP, omnipresent in all chondrites, in the same region of the solar nebula. In addition, it can also create some common achondrites (e.g., ureilites, angrites, eucrites) directly in the solar nebula and does neither need parent bodies nor re-heating events. The PLC model describes chondritic constituents and their infinite chemical variability as well as the most common achondrites as consequent products of just a single-step cooling solar nebula.

AQUEOUS CORROSION TEXTURES ON WEATHERED CHAIN SILICATE SURFACES AS POSSIBLE TERRESTRIAL ANALOGS OF PYROXENE ALTERATION IN MARS METEORITES.

M. A. Velbel 1 and S. J. Wentworth 2. 1Department of Geological Sciences, Michigan State University, East Lansing, MI 48824-1115 U.S.A. E-mail: Velbel@msu.edu. 2ESCG, Mail Code JE23, Johnson Space Center, Houston, TX 77058.

Denticulated margins (also known in older literature as “sawtooth”, “cockscomb” or “hacksaw” terminations) are a common feature of pyroxenes and amphiboles. Large, well-developed denticles are visible in transmitted-light microscopy of grain mounts and thin-sections; smaller denticles are visible using scanning and transmission electron microscopy. Denticles are commonly the remnants of undissolved material that formerly constituted the walls between elongate etch pits (the characteristic aqueous-dissolution form of chain-silicate minerals) [1]. Similar processes create similar ranges of dissolution forms and dimensions on minerals of both pyroxene and amphibole groups [1]. Denticles are best expressed where a grain boundary, transmineral fracture or dislocation array transects the crystal at a high angle to the z-axis [1]. Denticles occur widely in terrestrial near-surface materials that have experienced low-temperature aqueous alteration, including chemically weathered regoliths, soils, sediments and sedimentary rocks [1]. Denticles in these materials are commonly tens of microns in length [1,2]. Denticles are much less common at the surfaces of chain-silicate crystals altered by aqueous solutions at higher temperatures.

Microdenticles microns rather than tens of microns long are developed on the lateral surfaces of larger “classic” denticles on hornblende from a weathered regolith in the southern Appalachian mountains (North Carolina, U.S.A.). Microdenticles share the shape and orientation of the larger more typical denticles, suggesting similar crystallographic controls on the corrosion process. However, because the elongate pointed forms are on surfaces closer in orientation to prism faces than to (001) termini of the chain silicate crystals, these arrays of microdenticles more closely resemble a surface covered with imbricate pointed scales than a sawtooth margin. The arrays of imbricate microdenticles are formed by aqueous alteration during weathering chain-silicates; they are later-stage corrosion forms on surfaces of chain-silicate minerals that show larger-scale evidence of typical weathering [3]. Furthermore, the scaly, imbricate microdenticles of the weathered terrestrial chain silicate are very similar in size, shape and distribution to micron-scale features reported from pyroxenes in several Mars meteorites [4,5]. The close similarity of these demonstrably aqueous weathering-related terrestrial chain-silicate microdenticles with only slightly smaller microdenticles on pyroxenes in several Mars meteorites supports previous proposals of a low-temperature aqueous origin of the Mars meteorites microdenticles [4,5].

WHOLE-ROCK OXYGEN ISOTOPE COMPOSITIONS ARE UNRELATED TO DEGREE OF AQUEOUS ALTERATION IN CM2 CHONDRITES.
M. A. Velbel1, E. K. Tomui2 and M. E. Zolensky3. 1Department of Geological Sciences, Michigan State University, East Lansing, MI 48824-1115. E-mail: velbel@msu.edu. 2Department of Earth and Space Sciences, UCLA. 3Astromaterials Research & Exploration Science Office, NASA Johnson Space Center.

Introduction: This paper re-examines published whole-rock oxygen isotope data for CM2 chondrites [1], including nine non-Antarctic falls and 25 Antarctic finds, and revisits previously published relationships between whole-rock oxygen isotope compositions and aqueous alteration of CM chondrites [2].

Oxygen isotope compositions of Antarctic CM2 finds: Antarctic CM2 finds and non-Antarctic CM2 falls plot on the same mixing line (slope 0.70) on an oxygen three-isotope plot [1]. If oxygen isotopes of Antarctic CM2 finds were affected by terrestrial weathering, then (1) their pre-weathering compositions would have plotted off the mixing line, and (2) the composition of each Antarctic find would have been shifted from its pre-terrestrial composition, along a line with a slope corresponding to mass-dependent fractionation, to its present composition on the mixing line. Furthermore, this would had to have happened for each Antarctic CM2 on the mixing line, by precisely and only the amount required to move each sample’s plot from its pre-terrestrial composition to its measured composition. A simpler scenario is that (1) Antarctic CM2s plot (like their counterpart non-Antarctic CM2 falls) on the mixing line before arrival in Earth’s environment, and (2) the oxygen isotope compositions of Antarctic CM2 chondrites [1] are their pre-terrestrial compositions, unmodified by terrestrial weathering.

Oxygen isotope composition and degree of aqueous alteration: Non-Antarctic CM2 falls Murray and Murchison, and Antarctic CM2 finds QUE93005 and ALH83100, all have nearly identical oxygen isotope compositions [1]. Murchison and Murray are two of the least altered CM2 chondrites known [2]; ALH83100 [3] and QUE93005 [4-6] are among the most altered CM2s known. The wide range in degree of alteration exhibited by four CM2 chondrites [2-6] with nearly identical oxygen isotope compositions [1] suggests that oxygen isotopes do not reflect the degree of aqueous alteration of these CM2 chondrites.

Conclusion: Distribution of oxygen isotope compositions of Antarctic CM2 finds and non-Antarctic CM2 falls along the same preterrestrial mixing line on an oxygen three-isotope plot suggests similar (pre-terrestrial) controls on oxygen isotope compositions of both non-Antarctic CM2 falls and Antarctic CM2 finds. Whole-rock oxygen isotope compositions of CM2 chondrites do not reflect mass-dependent effects of pre-terrestrial aqueous alteration, and therefore are not related to other previously suggested measures of aqueous alteration [2].

ISOTOPE ANALYSES OF THE COARSEST GRAIN-SIZE FRACTIONS OF ORGUEIL NANODIAMONDS.

1Open University, Milton Keynes, UK. a.verchovsky@open.ac.uk. 2Vernadsky Institute RAS, Moscow, Russia.

Introduction: The best evidence of the existence of several populations of meteoritic nanodiamonds has been obtained by separating them into grain-size fractions using centrifugation [1]. The diamond fractions of Efremovka CV3, Boriskino CM2 and Krymka LL3.1 are systematically different in $^{13}$C with a total range from -22 to -40‰ with the lowest values corresponding to the coarsest fractions [2]. Using model calculations for a mixture of two diamond populations with different average grain sizes it is possible to calculate isotopic compositions of the end-member carbon components [2, 3]. In order to substantiate the efficiency of the modeling procedure it is clearly desirable to try and obtain the coarsest diamond fraction possible. In this study we have separated and analysed the coarsest grain-size fractions of nanodiamond from the Orgueil CI meteorite.

Separation procedures: Colloidal diamonds from 46g of bulk Orgueil sample have been obtained using standard procedures [4]. The coarse materials, such as spinel and SiC, have been separated from the colloid by prolonged centrifugation. An additional long-duration centrifugation of the colloid allowed us to obtain a sediment fraction which seems to contain nanodiamonds originated from AGB stars [5]. The residual colloid has been treated to centrifugation at 13500 g in 4 steps, with durations from 1 to 6 hours. It allowed us to obtain 4 coarse fractions which we analysed for C, N, Ne, Ar and Xe isotopes and concentrations and He concentration simultaneously using the Finesse machine [6]. We have not directly measured the grain size of the fractions however their relative sizes can clearly be deduced from the sequence of the centrifugations.

Results: Our isotope data undoubtedly suggest that in this separation we obtained the coarsest fraction of nanodiamonds produced so far. It follows from the carbon isotopic compositions of the fractions and the noble gas (particularly for Xe-P3 and Xe-HL) concentrations which are known to show significant variations in the grain-size fractions due to implantation effects [1]. Interestingly, the highest concentration of Xe is observed, not in the coarsest fraction, but in the one previous to this in the centrifugation sequence. This means that the average grain size of the coarsest fraction is larger than the implantation range of Xe. The highest concentration of Xe obtained in the study is 8.2x10$^{-6}$ cc/g which is 15 times higher than for the bulk Orgueil diamonds [7]. The overall $^{13}$C of the coarsest fraction is -50‰, but is as low as -55‰ in certain temperature steps. A diamond population with such a light carbon isotopic composition is supposed to be a carrier of P3 noble gases and formed in the protosolar nebula [8]. And the carbon isotopic composition of the population is well within the range evaluated for the Sun [9].

Vesta's surface is surprisingly pristine. Although its basaltic surface is roughly similar to the lunar surface, which is intensely space weathered, its surface remains unaltered. It has been shown recently that solar-wind irradiation dominates asteroidal space weathering with a timescale on the order 10^4-10^6 yr. Recent ion irradiation experiments on pyroxenes have shown significant reddening and darkening of the collected spectra with progressive irradiation [1]. Since pyroxene is a major surface component of Vesta as determined by spectroscopy, we aimed to test whether the solar wind irradiation alters significantly the optical properties of the surface of Vesta. Consequently, we performed an ion irradiation experiment (using Ar ions with 400 keV energy) on an eucrite meteorite (Bereba), which characterizes the surface of Vesta well, in order to simulate the solar wind irradiation on this asteroid. Using an irradiation typical for a solar irradiation over a 10^2 to 10^5 yr timescale we found an IR spectra typical for the lunar surface but strongly reddened with respect to the Vesta surface spectra. On the contrary present Vesta spectra match perfectly the fresh Bereba spectra [2].

Our result implies that, if solar wind ions had reach the surface of Vesta since at least 10^4-10^5 yr, its reflectance spectrum should be much redder and its albedo lower. Explaining this lack of irradiation record by an impact resurfacing in statistically highly unlikely considering the timescale and the need for resurfacing the near totality of Vesta surface. In particular the very large polar impact invoked for Vesta is much too old to have played a role [3]. The only mechanism left is the presence of a magnetic field (throughout present time) shielding the surface from solar wind ions. This magnetic field should be produced by the remanent magnetization recording a now extinct dynamo (functional at 4.5 Ga, while the metallic core was liquid). Important paleo-fields (about 10 µT) recorded in eucrite and howardite support this assumption [4]. This is the first remote detection of the magnetic field of an asteroid based on its color.

A SOURCE OF THE POPIGAI IMPACT FLUIDIZITES: DATA ON TRACE ELEMENTS S. Vishnevsky, S. Simakin. 1Inst. of Mineral. & Petrol., Novosibirsk-90, 630090, RUSSIA, <svish@uiggm.nsc.ru>; 2Inst. of Microelectronics & Informatics, Yaroslavl-7, 150007, RUSSIA, <simser@mail333.com>.

Introduction: The Popigai impact fluidizite dykes originate by jetting of hot volatile+melt mixtures (VMMs) at ~0.8-3.3 GPa residual shock pressure [1-4]. They made up of water-rich (1.11-8.97 wt. % of H2O) glass particles, fragments of host gneisses, and crypto-grain matrix. 3 types of the glasses are found: type I – homogeneous similar to target gneisses in terms of bulk geochemistry; type II – heterogeneous, (fine banding of “femic”, “salic” and type I glasses); type III – “salic” glasses, rich in Si, K and Na. The VMMs were derived from complex Archean basement rocks [4] but their source is still open. In order to solve the question, the trace (TE) and rare earth (REE) elements were studied in individual particles of the fresh glasses by means of ion probe (20 runs, namely: 14 type I glass particles, SiO2 57.2-60.14 wt. %; 1 type II glass particle, including 1 “salic” K-Na-Ca band, and 2 type I glass bands, SiO2 58.61 and 58.83 wt. %; 3 type III glass particles: lechatelierite (L), and 2 high-silica (HS) particles, SiO2 88.71 and 89.94 wt. %). All data are in ppm ± st. dev. Data on TE are reported here; data on REE are in [5].

Observations: TEs in type I glasses are found as (16 runs): V 138±10.03; Zr 188±23.4; Rb 91±5.5; Sr 224±26.3; Ba 783 ±107; Ta 1.29±0.23; Nb 13.74±0.93; Hf 5.25± 0.68; Y 34.1±7.4; Th 14.9±2.45; U 1.61±0.27 and Cr 165± 16.8 for 13 similar runs; in 3 others Cr is detected as 365, 1166 and 2404 ppm). Most of TEs in “salic” K-Na-Ca glass show poor amounts: V 39, Zr 0.65, Ta 1.59, Nb 0.22, Hf 0.37, Y 1.13, Th 0.02, U 0.09 and Cr 19; but feldspar-isomorphic TEs are higher: Rb 172, Sr 468, Ba 3730. TE amounts in HS-glasses are varying: V 26 & 99.7, Zr 4.8 & 33.5, Rb 32 & 73, Sr 21 & 41, Ba 58 & 220, Ta 0.2 & 0.4, Nb 4.8 & 11.9, Hf 0.2 & 0.8, Y 2.4 & 2.6, Th 0.6 & 0.7, U 0.07 & 0.3, Cr 17 & 101. Lowest amounts are in L: V 2.2, Zr 0.8, Rb 1.6, Sr 1.5 Ba 3.7, Ta 0.08, Nb 0.19, Th 0.05 U 0.01 and Cr 4.

Conclusion: Compared to data by [6], type I glasses are very similar to both the granulites of Khapchan series and diaphthorites of amphibolite facies derived from them, in amounts of Th, U and their ratio, Th/U = 9.33±0.94. Our REE data [5] also support the same source of the glasses. Khapchan granulites are very “dry” (L.O.I. = 0.36÷1.31 after [6]), so diaphthorites derived from the granulites were the most possible source rocks for the VMMs. Amounts of V, Zr and Nb in type I glasses are also similar to those found [6] for Khapchan rocks. Compared to data by [6] for the granulites, higher amounts of Sr, Ba and Nb in the glasses are, probably, caused by diaphthoresis; data on Hf and Y are absent in [6]. Amounts of TEs in K-Na-Ca and L-glasses are similar to those for quartz and feldspars. Intermediate TE amounts in HS-glasses are explained by mixing. Anomalously high Cr amount in type I glasses is probably related to projectile.

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A TARGET SOURCE OF THE POPIGAI IMPACT FLUIDIZITEST: DATA ON REE.
S. A. Vishnevsky1, S. G. Simakin2. 1Inst. of Mineral. & Petrol., Novosibirsk-90, 630090, RUSSIA, svish@uiiggm.nsc.ru; 2Inst. of Microelectronics & Informatics, Yaroslavl-7, 150007, RUSSIA, simser@mail333.com.

Introduction: The Popigai impact fluidizite glasses and their ion probe studies are described in [1]. Below the data on REE (all in ppm) are reported for the fresh glass particles of the rocks.

Observations: REE spectra in type I glasses including their bands in type II particle are very similar and show the next features (see Fig): i) REE totals are 186.4÷305.9; ii) fractionation degree, LaN/YbN, is average (6.5÷9) or relatively high (9÷12.25); the “heavy” (Gd-Yb) spectra are semi-horizontal, whereas the “light” (La-Sm) ones are more step (LaN/SmN 4.23÷5.46), showing the enrichment for La-Sm; iii) the “light” vs. “heavy” REE totals ratio is 10.05÷12.33; iv) 13 runs show weak/moderate negative Eu-anomaly (Eu/Eu* = 0.58÷0.88); 3 other runs show weak positive anomaly (Eu/Eu* = 1.08÷1.15). REE spectrum of K-Na-Ca glass band in type II particle is complex, with low total (7.83), but high fractionation degree (LaN/YbN = 39.17); the “light” vs. “heavy” REE totals ratio is 3.28; Eu shows strong positive anomaly (Eu/Eu* = 10.5). REE spectrum of lechatelierite (L) is complex with low total; the spectra of high-silica glasses (HS) are slightly higher and co-ordinate with type I glass spectra.

Conclusion: Following to our data, type I glasses with negative Eu-anomaly are rather similar to clinopyroxene gneisses of the Khapchan series (carbonate Archean granulites of the Anabar shield, [2]), but type I glasses with positive Eu-anomaly are similar to hypersthene plagiogneiss layers occurred within Khapchan strata. In both the cases, using the data by [2], no REE fractionation had taken place during the shock origin of the volatile+melt mixtures of the fluidizites. The spectrum of K-Na-Ca glass band is similar to feldspar ones, but higher REE-totals and presence of Fe (1.21 wt. %) and Mg (1.45 wt. %) show imprint of the type I melt. Negative Ce-anomaly (Ce/Ce*=0.37) in the glass differs from those of typical feldspars and could be related to Pre-Cambrian diaphthoresis of the source granulites. REE-spectrum of L-glass is similar to typical quartz ones. Higher REE amounts in HS-glasses and similarity of their spectra to type I glasses can be explained by impurity of type I melt.

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RE-EVALUATION OF HIGH RESOLUTION $^{40}$Ar/$^{39}$Ar AGES OF PLAGIOCLASE SEPARATES FROM IAB SILICATE INCLUSIONS AND IMPLICATIONS FOR THE THERMAL HISTORY OF THE IAB PARENT BODY

N. Vogel and P.R. Renne. 1Berkeley Geochronology Center, CA 94709, USA. nvogel@space.unibe.ch. 2present address: Institute of Physics, Space Research and Planetary Sciences, University of Berne, Switzerland.

Introduction: In order to contribute to the understanding of the formation and thermal evolution of the IAB parent body, we present Ar-Ar ages of silicate inclusions from Caddo County (CC), Campo del Cielo (CdC1,2), Landes (L), and Ocotillo (O). From each inclusion plagioclase separates of different grain sizes (l, m, s) were produced to monitor their influence on the age of a sample and to minimize complexity of the Ar-Ar age spectra.

Results: Fig. 1 shows the ages of all separates. While ages within one inclusion vary significantly, all inclusions show one common age information around 4.43 Ga (shaded area). CC and L show additional higher ages, whereas CdC1 and 2 also show clear evidence for a later event around 4.3 Ga, probably local impact reheating. Highest ages within one inclusion are not necessarily correlated with largest grains as expected from diffusion theory. We assume that during thermal events small amounts of plagioclase-rich melt formed within parts of the inclusions. These larger younger plagioclase grains were probably separated from smaller older plagioclase by our grain size sorting.

Discussion: A thermal event ~4.45 Ga erased all previous K-Ar age information from CdC1,2 and O, whereas L and in particular CC were less affected and parts of them preserved higher ages. Thus, the temperature during this event cannot have been exceedingly high, in agreement with the fact that Rb-Sr, Sm-Nd, and I-Xe ages were not reset at this time [e.g., 2]. Since separation of high- and low-age plagioclase is not quantitative, “end-member ages” are probably more extreme than our actual ones. The CC age of 4536 $^{\pm}$ 32 Ma is thus a lower limit for K-Ar closure after the thermal event dated also by Rb-Sr, Sm-Nd, and I-Xe. This might have been the mixing of metal and silicates by impact(s) few Ma after the start of the solar system [3,4]. Taking into account the 2σ uncertainty of our highest CC age, the discussed K-Ar age bias of old meteorites cannot be larger than ~50 Ma and is almost certainly distinctly smaller.

CHARACTERIZATION OF PRESOLAR SILICATE GRAINS BY COMBINED NANOSIMS/TEM STUDIES.

C. Vollmer1, P. Hoppe1, F. E. Brenker2, R. M. Stroud3 and C. Holzapfel4 1Max-Planck-Institut für Chemie, D-55020 Mainz, Email: cvollmer@mpch-mainz.mpg.de, 2JWG – Universität, D-60054 Frankfurt, 3Naval Research Laboratory, Washington DC 20375, 4Universität des Saarlandes, D-66041 Saarbrücken.

Introduction: Silicates condense in the outflows of evolved O-rich stars or supernova ejecta and are detected as presolar grains in primitive solar system materials by high resolution mass spectrometry [e. g. 1, 2]. Detailed mineralogical information of this type of presolar grains obtained by transmission electron microscopy (TEM) is rare due to their small size and required elaborate extraction methods and is available for only 7 grains to date [2-6]. Here we report on our continued search for presolar silicates in the matrix of Acfer 094 and the successful lift out of two of these grains for further investigation by TEM.

Methods: Anomalous silicate grains have been identified by NanoSIMS ion imaging described in [7]. To produce electron transparent sections the focused ion beam method (FIB) with an in situ nano manipulator has been used [8, 9]. The ~100 nm thin sections were then investigated by TEM (200 kV) applying bright and dark field techniques and EDX analysis.

Discussion: A total of 17 presolar silicate grains have been detected in Acfer 094 giving a matrix normalized abundance of ~140 ppm based on the size in the SEM. One ~1 µm large silicate described already in [7] encloses a subgrain of presumably Al2O3. Theoretically nucleation seeds of Al2O3 or TiO2 are predicted for silicate condensation [10] and there is also spectroscopical evidence for composite grains [11]. The O isotope composition of the silicate and the subgrain are different even within error ranges, which might shed new light on isotopic heterogeneity in the disks of evolved stars. The FIB section of this grain revealed no large extension in depth pointing to a flat ellipsoidal shape. Research on this section is still in progress. The occurrence of this composite grain underlines furthermore the unique primitive nature of Acfer 094. TEM investigation of a second presolar silicate (~350 nm, O isotope group I) yielded a glass of non-stoichiometric composition containing abundant specks of a crystalline Fe-rich phase, which could be seen in dark-field imaging mode. Broad beam EDX analysis of a large part of the grain showed an S content in the percentage range indicating a GEMS-like composition. Confirmation of this grain to be indeed the presolar grain identified in the initial NanoSIMS search has to be confirmed in a further NanoSIMS measurement.