Workshop on Antarctic Meteorites: Search, Recovery, and Classification

4019 MAGNESIAN ANORTOSITE: A NEW CLASS OF LUNAR CRUSTAL ROCK AND IMPLICATION FOR CRUSTAL GENESIS
T. Arai. Antarctic Meteorite Research Center, National Institute of Polar Research, Tokyo 173-8515, Japan. E-mail: tomoko@nipr.ac.jp.

Compositionally “pristine” non-mare rocks [1] are keys to understanding the composition and evolution of the lunar crust. They are generally classified into two groups: 1) Ferroan anorthosites (FAN) with high plagioclase abundance (>90 vol%) and low Mg/(Mg + Fe) [= Mg#] (typically 50–65), and 2) Mg-suite rocks with less abundant plagioclase (<7 vol%) and higher Mg# (>70–90), including troctolite, norite, gabbronorite, and dunite. Significant trace-element enrichment in Mg-rich norites [2, 3] and the younger ages than FAN led to the idea that Mg-rich rocks represent intrusive bodies into the early lunar crust, which is presumably ferroan anorthosite. Coexisting highly anorthositic plagioclase and Fe-rich mafic minerals in FAN have been explained by floated plagioclase cumulates from a relatively evolved, Fe-enriched magma ocean [4].

Lunar meteorite Dhofar 489 is a feldspathic crystalline impact-melt breccia including clasts of magnesian anorthosite (MAN) and spinel troctolite (ST) [5]. Large (2.8 mm across) grain size and twin lamellae of plagioclase of the MAN imply an igneous origin. The MAN consists of 96.5% calcic plagioclase (An02–07) and 3.5% of Mg-rich olivine (Fo85), while the ST includes 72% plagioclase (An90–95), 25% Mg-rich olivine (Fo44–45) with minor spinel, orthopyroxene, and augite. Their olivine-plagioclase dominated mineralogy, feldspathic compositions, and coarse grain sizes imply that the two rock types possibly formed as cumulates by differentiation of a common magma body.

The presence of MAN indicates that lunar feldspathic crust consists of not only FAN, but MAN. How are the MAN and FAN petrogenetically related? The olivine-dominated nature of the MAN is in contrast with the FAN mostly including orthopyroxene. When crystallization of a global magma ocean is assumed, noritic FAN and troctolitic MAN with spinel troctolite can be generated as a result of a common liquid line of descent in a magma ocean is assumed, noritic FAN and troctolitic MAN with spinel troctolite first crystallized, subsequently Mg-rich troctolite formed along the olivine-plagioclase cotectic, and eventually Fe-rich norite crystallized at the orthopyroxene olivine plagioclase peritectic point. This inference is consistent with distinct Mg/(Mg + Fe) [= Mg#] of plagioclase in the MAN (Mg# = 0.62–0.69) and FAN (Mg# = 0.0–0.41) despite their almost identical An content.

Can the MAN form by plagioclase flotation? Melt density (2.76–2.80 g/cm3) of the parent liquid for the MAN, which was estimated from Mg# of the parent liquid [4] in equilibrium with plagioclase [6] exceeds that of plagioclase (2.70 g/cm3), but to a lesser extent than that for the FAN (2.84–2.88 g/cm3). Formation of the MAN crust may require effective plagioclase separation/floation by vigorous convection of a magma ocean with higher relative proportion of liquid to solid than in the formation of the FAN crust at a later stage of magma ocean crystallization.


4031 RECOGNITION OF PLANETARY CUMULATE ROCK TYPES FOR ROVER CAMERAS

Introduction: Cumulate rocks, products of the precipitating and accumulating processes in a cooling magma, frequently contain coarse grain-sized rocks easily observable with high resolution cameras of rovers working on planetary surfaces (and probably in the future in Antarctica). We studied cumulates for rover recognition purposes. Three cumulate samples from the Moon and Mars were studied for Hsuer rover imaging field trip studies of rock textures.

Martian nakhlites represent the accumulation in a stratified magma in the bottom layers of the magma. For Martian cumulate nakhlites, the terrestrial counterparts were Abiti Belt pyroxenites, especially the Theo’s Flow [1]. The Yamato-000593 nakhlite has primary cumulate texture. Together with 6 other nakhlites it is a member of a sequence that formed in a Martian thick lava flow. Judging by the amount of mesostasis between the minerals of the cumulate pile, our sample, the Y-000593 nakhlite, represents the upper zone of the lava layer [2], from the middle of the sequence of MIL 03346 (upper), NWA 817, Y-000593, Governador Valadares, Nakhl, Lafayette (lower) series [3]. Rather uniform grain size is observable with the rover camera.

Martian lherzolitic shergottites represent the accumulation of large poikilitic pyroxene grains in the middle and bottom layers of a magma chamber. Their texture consists of two regions: one with poikilitic and other non-poikilitic parts. In the poikilitic part, large clinopyroxene oikocrysts include olivine chadacrysts. Poikilitic large pyroxenes are easily observable with rover cameras if they occur as surface rocks on Mars. ALHA77005 lherzolitic shergottite’s poikilitic clinopyroxene crystals form the cumulative texture in the shergottite block. Large olivine crystals also occur in piles in the non-poikilitic regions. Impact melts inside the shock-melted regions may help to gradually arrange them in a sequence of depth. (ALHA77005 has the highest shock stage (S6), Y-793605 and NWA 1950 have shock stages of S5, and LEW 88516 and GVR 99027 S4, which may also indicate depth gradation.

Lunar Anorthosite: Most cumulative rock form by sinking to the floor of a magma chamber, but anorthite accumulated at the roof of the magma chamber. 60025 anorthosite of the NASA Lunar Set is a monomineralic brecciated ancient cumulate rock with cataclastic texture, mixed from fragments of larger and smaller clasts. [5]. On Earth, Stillwater and Skærgaard Intrusion complexes are counterparts to lunar anorthosites. Textures of larger and smaller anorthite crystals are visible for rover cameras.

METAMORPHIC GRADE OF TYPE 3 CHONDrites As Evaluated By Raman Spectroscopy of the Polyaromatic Organic Matter

L. Bonal1, 2, E. Quirico2, M. Bourot-Denise3 and G. Montagnac4. 1HIGP/SOEST, University of Hawai‘i at Manoa, Honolulu, HI, 96822, USA. E-mail: bonal@higp.hawaii.edu. 2Laboratoire de Planétologie de Grenoble, Université J. Fourier, Grenoble, France. 3LEME Museum National d’Histoire Naturelle, Paris, France. 4LST ENS, Lyon, France.

Raman spectroscopy is a powerful tool to determine the degree of organization of the polyaromatic organic matter located in the matrix of chondrites. This degree of organization directly reflects the thermal history of the host meteorite on the parent body. It is then possible to evaluate the metamorphic grade of the object and to assign a petrologic type. This technique has been successfully applied to type 3 unequilibrated ordinary chondrites [1], carbonaceous CV [2], and CO [3] chondrites. Both falls and finds, from Antarctica [4] and elsewhere, have been analyzed.

The transformation of aromatic carbonaceous matter towards graphite is irreversible and appears to be independent of the mineralogical context and degree of aqueous alteration. The structural grade of the organic matter is then mainly controlled by the peak metamorphic temperature. Moreover, under the assumption of a common organic precursor, the degree of organization of polyaromatic organic matter allows to directly compare the metamorphic grade of objects from different chondritic groups. A unique petrologic scale is then obtained for at least UOC, CV, and CO chondrites.

The pertinence of the structural grade of the organic matter as a metamorphic tracer will be discussed in comparison with independent metamorphic tracers such as Fe-zonation in olivine phenocrystals in type I chondrules, petrography of opaque minerals, Cr content in olivines, the degree of recrystallization of the matrix, and the abundance of presolar grains.

Raman spectroscopy on organic matter is a reliable new technique to determine the metamorphic grade of type 3 chondrites, when applied in controlled experimental and analytical conditions. It appears to be particularly sensitive to the lowest petrologic types (3.0–3.2). This metamorphic tracer obviously requires the presence of polyaromatic organic matter in the chondritic matrix. For this reason, it appears difficult to extend it to high petrologic types (≥ 4). The technique is non-destructive and does not require specific sample preparation. It might be used as routine classification technique, in addition to standard ones like induced thermoluminescence.

Introduction: Icy meteorites are the less known matter of cosmic origin. These meteorites, due to their high temperature on impact, melt in any zonal temperatures except the two polar zones. Hence their findings is only possible in Antarctica where they are embedded in glaciers, which makes them detectable.

It is imperative to use an up-to-date technology for the detection, collection, and investigation of these objects to preserve their original state at their arrival in the ice. The radioactive isotope content of these so-called dirty ice balls, and their possible content of organic chemicals could in some way enrich and modify our concept about the environment in which our planet formed.

Results: Finding and gathering of water ice containing meteorites are technically different from those of iron and chondrite ones, because their virgin state must be preserved that is their condition on impact into the Antarctic snowfields and glaciers. Acoustic and electromagnetic techniques developed to a reliable working order are a prerequisite for searcher on the site in Antarctica. In addition there is a need for a matching logistics, i.e., refrigerated transport system as was the case with the Berezovskij’s mammoth finding, which was transported together with its heading of 15 t ice cube. A logistic of this type is a challenge in an inclusion environment as in Antarctica, especially when the specimen lies on a high plateau and in a steep sloping glacier.

For the search I propose an acoustic technology, based on the ice sonar technique of a short range radar which can be located on the ends of the drill hits boring into snow and ice. Passive type of acoustic sensor can be used which selects the reflected waves resulting from explosive changes in nearby ice fields.

The dielectric properties of ice meteorites are differing to a large degree from that of earthly ice dielectric constants. Finding ice meteorites therefore can be made by electromagnetic instruments working on long wave lengths (ultra low frequency, 10–40 Hz). The wave reflection, i.e., radar of water ice meteorites is more different from that of earthly ices. In addition to these techniques, a supplement of magnetometer and radar acoustic on site measurement, can also be used.

In the polar regions of the Moon our intention there is to use the perpendicular suspended LIDAR technique on the well known optical package as used by the military (US, Lantrin II. and so Gorizont Opticheskij Panel in Russ.), which works as laser optical localizers, solely on the use optical methods. The Mars surface is dusty and is not suitable for this technique.

Conclusions: An investigation of Antarctica origin water icy meteorites can provide a high value of information because of their isootope spectroscopy and probable cosmic originated organic molecules content.

HOT AND COLD WEATHERING: DETERMINING THE OXYGEN ISOTOPE COMPOSITION OF ACHONDrites

R. C. Greenwood, J. M. Gibson, and I. A. Franchi. Planetary and Space Sciences Research Institute, Open University, Milton Keynes, MK7 6AA, UK. E-mail: r.c.greenwood@open.ac.uk.

Introduction: It is well established that the oxygen isotope composition of meteorite finds can be significantly altered by terrestrial weathering [1]. Furthermore, the processes taking place in hot and cold deserts are markedly different and result in distinctive shifts in the primary oxygen isotope composition of finds [1]. Weathering in the Antarctic environment will displace oxygen isotope ratios toward lighter values, while hot desert weathering will move ratios towards heavier values [1].

Weathering effects are a particular concern for oxygen isotope studies of both primitive and differentiated achondrites. These meteorites occupy a small region of oxygen three-isotope space immediately below the terrestrial fractionation line. As a result only small isotopic shifts are required to displace samples out of their primary fields [2]. Furthermore, since most achondrite groups contain few falls, weathering processes can have major implications when attempting to define a meteorite group’s primary isotopic characteristics. As part of our ongoing studies of achondrites, we have been investigating various strategies for mitigating the effects of hot and cold desert weathering.

Methods: Dilute HCl is widely used in oxygen isotope studies as a means of removing weathering products. While undoubtedly effective, this treatment has the potential to leach primary, as well as secondary silicate phases. As an alternative, we have made extensive use of an ethanolamine thioglycollate (EATG) treatment, which is more selective, removing iron oxides, hydroxides and metallic iron, but not silicate-bound iron [3]. For a limited number of samples in this study we have undertaken a comparison between these two methods. Oxygen isotope analyses were performed by infrared laser-assisted fluorination following the procedures outlined by [4].

Results: Initial tests indicate that both EATG and HCl treatments are effective in removing the bulk of weathering products. Further work is in progress to evaluate in detail these two treatment methods.

EATG appears to be particularly effective for primitive achondrite samples. Thus, an apparent overlap between the brachinite and winonaites, groups seen in untreated samples, is resolved when samples are acid leached. Treated acapulcoite-lodranite samples display reduced levels of variation with respect to δ18O when compared to untreated samples, although ∆17O variation remains largely unchanged. In particular, the distinction between Antarctic (isotopically light) and non-Antarctic (isotopically heavy) finds is completely removed following acid leaching.

Conclusions: The value of meteorite finds for oxygen isotope studies is significantly enhanced if samples are acid leached prior to analysis. Work is in progress to establish the most effective procedures for minimizing the influence of terrestrial weathering. Initial results indicate that both HCl and EATG treatments are an effective means of removing the bulk of weathering products.

METAMORPHIC TEMPERATURES OF EQUILIBRATED ORDINARY CHONDrites RECOVERED BY THE KOREA EXPEDITION FOR ANTARCTIC METEORITES

J. M. Han, H. Choi, and B.-G. Choi. Department of Earth Science Education. Seoul National University, Seoul, 151-748, Korea. E-mail: hjmkeg74@snu.ac.kr.

Because it is important to determine the peak metamorphic temperatures of chondrites for understanding the thermal evolution of chondrite parent asteroids, various geothermometers have been applied to equilibrated ordinary chondrites (EOC) [1]. We measured the major element compositions of olivine, chromite and pyroxene of EOC recovered from Thiel Mountains, West Antarctica, by KOREAMET (Korea Expedition for Antarctic Meteorites [2, 3]) and calculated peak metamorphic temperatures using the pyroxene and olivine-spinel geothermometers [1].

Major element compositions of minerals of five OC [TIL 06001 (H6), 06002 (L6), 06003 (L6), 06004 (L5) and 06005 (H4)], found during the 2006/2007 field season, were measured using the JEOL 8900R electron-probe microanalyzer at the National Center for Inter-University Research Facilities, Seoul National University. The EOC (four H6, two L6, three LL5 and one LL6) from the 2007/2008 field season are now being studied; results will be presented at the meeting.

Olivine-spinel thermometry [4] yields the following peak metamorphic temperatures: TIL 06001 = 736 ± 24 °C, 06002 = 707 ± 13 °C, 06003 = 707 ± 16 °C, 06004 = 690 ± 43 °C, and 06005 = 665 ± 26 °C, where the errors are given as 1σ standard deviation. Pyroxene thermometry was applied to the type 6 chondrites using the QUILF95 program that is a modified window version of [5] and using the formula in [6] for Ca contents in OPX. The calculated temperatures generally agree with previous studies [1, 4]. Pyroxene thermometry gives about 900 °C for type 6 OC; olivine-spinel thermometry yields temperatures that are systematically about 150 °C lower. It has been known that pyroxene data for type 6 OC agree with temperatures obtained by O-isotope thermometry (900 ± 50 °C [7]). Lower temperatures obtained for type-6 OC with olivine-spinel thermometry and the small temperature differences determined between type 6 and type 4 OC with this method may indicate that the temperatures recorded in olivine-spinel pairs are not peak metamorphic temperatures, but instead represent the blocking temperature of cation exchange during cooling [1].

SEARCH FOR ICE METEORITE IN ANTARCTICA BY HUSAR ROVER

S. Hegyi1, B. Kovács2, Gy. HUDOBA1, Z. ISTENÉI1, Sz. BÉRCZI1, 1PTE TTK, Department Informatics and Technology, H-7624 Pécs, Ifjúság u. 6. Hungary, 2PTE TTK, Department Chemistry, H-7624 Pécs, Ifjúság u. 6. Budapest Polytechnik, College of Engineering, H-6000, Székesfehérvár, Budai út. 3.ELTE IK, Department Sofvaretechnology, H-1117 Budapest, Pázmány P. st 1/C. 5Eötvös University, Institute of Physics, H-1117, Budapest, Pázmány Péter tér any 1/a, Hungary. E-mail: bercziszani@ludens.elte.hu.

On the basis of the chemical condensation model of the solar system, icy meteorites were suggested to exist, they could survive impacts into the Earth, and could be recovered in Antarctica [1, 2]. Estimates of their ammonia and methane content may help identify them in ice fields [3, 4]. For the ammonia and methane material recognition, fiber-optic sensors were developed for Hunveyors and Husar rovers [5], and the instruments were adapted to icy conditions [6]. Here we report the program preparations to collect data about possible ice meteorite fragments in Antarctica by a Husar rover swarm equipped with these instruments.

Methods: Ammonia and methane may be clue materials in identification of ice meteorites. Husar rover works in an automatic Our Husar rover package consists of a drilling instrument, and conductivity and gas content measuring sensors, plus a robotic sampling arm. Measuring method is as follows: Drilling to 3 centimeters deep into the soil, and into the hole the gas sensor is placed. In the drill hole we measures 3 things: a) the conductivity of the ice soil, b) the ammonia and c) the methane content. Our gas content measuring sensors contain a fibre optic photo/fluorometer instrument. It contains a light source (light emitting diode or a laser diode). The incident beam of the light source passes through a splitter and through an optical fibre with lenses. The evaporating ammonia and methane molecules, reaching the sensing layer at the sensor head, are partially absorbed by the dye molecules of the sensor. When the light is reflected on the sensors mirror it returns back (on the same way) and is reflected to the primary silicon detector. In fluorescence mode a complete separation of the exciting and fluorescent light is used. When signals of detected ammonia (or methane) arrives, the robotic arm collects a sample from the vicinity of the affected region. GPS positioning helps returning to the site of ice meteorite candidate observation.

Strategy: Three equivalent Husar rovers works parallel in the field to cover a larger surface for search. More sensitive sensors allow tumbleweed rovers to join the program with such instrumentation they covering larger surface in Antarctica.

**4005**

**THERMAL HISTORY AND CLASSIFICATION OF CM CHONDRITES FROM Fe-Ni METAL: A PRELIMINARY REPORT**


**Introduction:** CM chondrites are classified as type 2 and they experienced progressive aqueous alteration [1]. Some of them were also subjected to thermal metamorphism after aqueous alteration, and heating stages I–IV were proposed [2]. Recently, we showed that the characteristic features of Fe-Ni metal, such as texture and composition, are very sensitive indicators that can be used to classify type 3 ordinary (UOC) and CO chondrites, and to explore their thermal histories [3]. Here we report our preliminary results on Fe-Ni metal in CM chondrites and discuss the implications for the thermal history and classification of CM.

**Petrography and Mineralogy:** We selected 15 CM and related chondrites to cover the entire range of aqueous alteration and heating stages I–IV. Although the abundance of metal in CM is usually low, it is present in chondrule phenocrysts and as isolated grains in the matrix. Fe-Ni metal grains in CM never show the intergrowths of kamacite and Ni-rich metal characteristic of UOC and CO above type 3.15 [3]. A few metal grains in Murchison and B-7904 show a fine-grained, plessitic texture, similar to that in Semarkona (type 3.01). Except for these, all of the metal in CM chondrites has a homogeneous texture. CM metal can be divided into three categories by the Ni-Co distribution: A) metal in Cold Bokkeveld and 4 other samples is kamacite to martensitic metal (3.7–15.8% Ni), and shows a positive correlation between Ni and Co with the solar ratio. B) Metal in Murray and 6 other chondrites is nearly homogeneous in composition (3.7–7.8% Ni). C) B-7904 and 2 other chondrites contain both kamacite and Ni-Co-rich metal (25.1–55.1% Ni and 0.3–2.3% Co).

**Discussion:** The metal features are not related to degree of aqueous alteration. However, categories A–C are related to the heating stage [2]. Metal of category A only occurs in unheated CMs and has similar features to those in Acfer 094 and CH and CR chondrites. The small amount of metal preserved in these CM chondrites may be primordial [3]. Samples with category B metal range from unheated to stage I to II. CM chondrites with category C metal belong to stages 3 and IV, which experienced secondary heating to >500 °C [2]. The Ni- and Co-rich metal that occurs in these CMs is also found in UOC and CO chondrites of less than type 3.15, and originated through sulfidation and oxidation process before accretion [3]. The Ni-rich metal in stage IV CM chondrites is more likely a secondary product of heating in the parent body after aqueous alteration [2]. At any rate, our observations indicate the metal composition in CM reflects the secondary heating process after aqueous alteration.


---

**4006**

**JAPANESE METEORITE SEARCH IN ANTARCTICA**

H. Kojima, N. Imae, and H. Kaiden. National Institute of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo, Japan. E-mail: kojima@nipr.ac.jp.

**National Institute of Polar Research (NIPR) takes charge of 16,201 meteorites from Antarctica. 15,741 of those were recovered by repeated search of the Japanese Antarctic Research Expedition (JARE). The remaining approximately 500 meteorites were collected in the Transantarctic Mountains region by a joint Japan-U.S. party. This huge number of meteorites started with the recovery of 9 meteorites by JARE-10 in December 1969. The inland traverse party accidentally found 9 meteorites on bare ice at the southeast end of the Yamato Mountains [1]. These meteorites were named Yamato (Y)-69 meteorites. They include an enstatite chondrite, diogenite, CK chondrite, and ordinary chondrites. Before the Y-69 meteorites finding, only six meteorites from Antarctica were known. If Y-69 meteorites consist of just one type of meteorite, later findings of a large number of meteorites do not. JARE-15 field party has done systematic meteorite search at first in a limited area at the southeast end of the Yamato Mountains in the austral summer of 1974, collected 663 meteorites of many types during just two weeks [2]. The field party of JARE-16 followed to visit the Yamato Mountains and collected 308 meteorites. JARE-20, -29, -39 [3] and JARE-41 [4] planned and carried out meteorite search as one of the main research programs of JARE. JARE-20, -39, and -41 successfully collected 3692, 4148, and 3581 meteorites, respectively, in the bare ice fields around the Yamato Mountains. JARE-29 collected 1949 meteorites in the Sor Rondane Mountains region. The field parties of JARE-14, -21, -22, -23, -24, -25, -27, -30, -33, and JARE-35 carried out meteorite searches as a side work of their main research such as glaciological, geological, and geomorphologic surveys.

The NIPR collection totals 16,201 meteorites. They include many new findings such as lunar meteorites and rare types of meteorites. New findings of such meteorites have been one of the great contributions from the recoveries of a huge amount of Antarctic meteorites by repeated searches of JARE parties. The identified meteorites include 25 irons, 3 pallasites, 4 winonaites, 1 angrite, 5 lodranites, 2 acapulcoites, 4 winonaites, 30 achondrites, 2 aubrites, 200 diogenites, 213 eucrites, 25 howardites, 34 ureilites, 1 angrite, 9 lunar meteorites, 9 Martian meteorites, 228 E chondrites, 5 R chondrites, 18 C chondrites, 5 CI chondrites, 198 CM chondrites, 7 CR chondrites, 26 CO chondrites, 25 CV chondrites, 2 CH chondrites, 18 CK chondrites, and 14,643 ordinary chondrites. Thirty achondrites, 18 C chondrites, and many ordinary chondrites were identified in hand specimen at the field and during initial processing.

Although JARE has not had a plan for meteorite search for last seven years, a new program to search for meteorites will start next year. Antarctic Meteorite Research Center of NIPR has a plan to have the JARE summer party search for meteorites. In the 2009 austral summer season, the field party of JARE-51 will look for meteorites in the bare ice field around the Sor Rondane Mountains.

CLASSIFICATION OF THE METAL-RICH (CH, CH/CB, CBA, CBB) CARBONACEOUS CHONDRITES
Alexander N. Krot. HIGP/SOEST, University of Hawai‘i at Manoa, Honolulu, HI 96822, USA. E-mail: sasha@higp.hawaii.edu.

The metal-rich carbonaceous chondrites (CH, CBA, CBB, and CH/CB-like meteorite Isheyevo) show many anomalous characteristics not observed in other chondrite groups, e.g., extreme enrichment in siderophile elements, extreme depletion in volatile elements, lack of interchondrule fine-grained matrix material, and large variations in metal abundances and chondrule sizes [1–3].

The CHs (Acerf 182, ALH 85085, PAT 91546, PCA 91467, NWA 470, 739, and 770) contain high Fe,Ni-metal abundance (~20 vol%), dominant cryptocrystalline chondrules of small sizes (~20 μm), and rare CAIs; the interchondrule, fine-grained matrix is absent; heavily hydrated matrix lumps are common instead [3].

The CBs contain much higher abundance of metal (~70 vol%) and bigger chondrules (0.17 mm) than CHs. Largely based on sizes of the chondritic components, the CBs are subdivided into the coarser grained CBa (Bencubbin, Gujba, Weatherford) and finer grained CBb (Hammadah al Hamra 237, QUE 94411/94627, and MAC 02675) subgroups, which, however, may represent two lithologies from the same parent asteroid [2]. In contrast to CHs, the CB chondrules have exclusively non-porphyritic (cryptocrystalline and skeletal) textures and magnesium compositions. Similar to CHs, the CBbs contain chemically zoned metal condensates and rare CAIs. Based on the young chondrule ages (4562.7 ± 0.5 Myr), lack of evidence for recycling of chondrules and zoned metal grains, it was concluded that CBs formed from a vapor-melt plume produced by a giant impact between planetary embryos [4].

The recently discovered metal-rich chondrite Isheyevo contains the metal-rich (>70 vol% Fe,Ni-metal) and the metal-poor (<20 vol% Fe,Ni-metal) lithologies which show mineralogical similarities to both CHs and CBs [3]. They contain zoned Fe,Ni-metal grains, porphyritic and non-porphyritic chondrules, heavily hydrated matrix lumps, and rare refractory inclusions; no fine-grained, matrix-like material is observed around these coarse components. Krot and Nakagawa [5] showed that magnesium cryptocrystalline chondrules in Isheyevo and CBbs have identical chemical and oxygen isotope compositions (Δ17O = –2.2 ± 0.9‰ and –2.3 ± 0.6‰, respectively) and concluded that Isheyevo contains several generations of chondrules formed by different mechanisms: (i) Fe-Mg and Al-rich porphyritic chondrules resulted from melting of precursors in the solar nebula, and (ii) magnesium cryptocrystalline (CC) and skeletal chondrules, formed in an impact-generated plume of melt and gas.

A possible close genetic relationship between the mineralogically diverse metal-rich chondrites (CH, CBA, CBB, and Isheyevo) and an apparently unique mechanism involved in the formation of metal grains and non-porphyritic magnesium chondrules in these meteorites (gas-melt plume produced by collision between planetary embryos) makes it difficult to classify these meteorites using traditional classification parameters for the chondritic meteorites [4], such as bulk chemical compositions, chondrule sizes, chondrule/matrix ratio, etc.

GROVE MOUNTAINS METEORITES: SURVEY, COLLECTION, AND CONCENTRATION MECHANICS

B. Miao1,2 and Y. Lin1. 1Key Laboratory of Geological Engineering Center of Guangxi Province, Guilin University of Technology, Guilin 541004, China. E-mail: miao88k@glit.edu.cn. 2Key Laboratory of the Earth’s Deep Interior, Institute of Geology and Geophysics, CAS, Beijing, China.

Introduction: Since the discovery of 9 meteorites in the Yamato Mountains in 1969 [1], about 35,000 meteorites have been collected on blue ice at about 58 meteorite-enriched sites in Antarctica [2]. Grove Mountains (GRV) is a new site with high concentration of meteorites, with a total number of 9834 meteorites collected during four expeditions. Here we report the field survey, collection of the meteorites, and possible concentrating mechanisms.

Grove Mountains and CHINARE: GRV’s area consists of 64 nunataks with 560 km² of blue ice, located in the Princess Elizabeth Land, East Antarctica. In 1998–1999, it was first explored by the field party of the 15th Chinese Antarctic Research Expedition (CHINARE-15) which discovered 4 meteorites. In the next field season, another 28 meteorites were found in the same area, one from Mars and another probably from asteroid 4 Vesta [3]. This indicated that Grove Mountains is a new meteorite-enriched region, and a meteorite search team was sent there again during CHINARE-19 resulting in the collection of 4448 meteorites, mainly along the Gale Escarpment [4]. Only 3 years later, another 5354 of meteorites were found in the region, and their coordinates were overlapped [5].

Collection: All Grove Mountains meteorites are curated in the Polar Research Institute of China in Shanghai. The majority of the collection is still kept frozen as in the ice field. Only 684 meteorites have been classified so far, including all 32 pieces collected by the first two expeditions, 453 by CHINARE-19, and 199 by CHINARE-22. Mass distribution of GRV meteorites is evidently different from those collected along the Transantarctic Mountains, with an average of 10 g for GRV collection in comparison with 239 g for ANTMET collection. In addition, most of GRV meteorites (80%) were found in moraines, different from ANTMET (20%). Based on the classified meteorites, the relative abundances are lower for LL-group and H-group and higher for L-group in comparison with literature data [2].

Concentration Mechanism: The large number of GRV meteorites indicates that Grove Mountains is one of the most meteorite-rich regions. Their much smaller size distribution and different relative abundances of H, L, and LL groups chondrites in comparison with ANTMET suggest a distinct mechanism of concentrating meteorites in Grove Mountains. In addition, spatial distribution of GRV meteorites correlates with the wind direction, suggestive of transportation of meteorites by wind.

Acknowledgements: This study was supported by the Knowledge Innovation Program (kzx2-yw-110) of the Chinese Academy of Sciences and the National Natural Science Foundation of China (40673055).

PETROLOGY AND GEOCHEMISTRY OF ANTARCTIC EUCRITES AND DIOGENITES, AND A-881394
D. W. Mittlefehldt. NASA/Johnson Space Center, Houston, TX, USA. E-mail: david.w.mittlefehldt@nasa.gov.

Introduction: Eucrites and diogenites are basaltic-gabbros and orthopyroxenites from the crust of a differentiated asteroid, widely considered to be 4 Vesta [1]. Study of these meteorites provides us with detailed knowledge of the igneous process that transmogrified chondritic precursors into differentiated bodies. I have done petrologic and compositional investigations of a suite of Antarctic eucrites, diogenites and the anomalous meteorite A-881394 from the Japanese and U.S. collections. I will describe my results in the context of howardite, eucrite and diogenite (HED) clan meteorites, and discuss implications for HED parent asteroid differentiation.

Diogenites: I have previously presented my preliminary data on some of the diogenites, including a number of anomalous samples [2]. Here I emphasize new data on MET 001060, Y-791194 and Y-791203. Orthopyroxenites in Y-791194 and Y-791203 have the same mg# (71) which is lower than typical for diogenites (74–76, [1]). The Ca contents are distinctly different (Wo0.9 in Y-791194; Wo1.5 in Y-791203), and the AI and Ti contents of the former are higher. Similarly, Ti and Al contents of chromite are higher in Y-791194 than Y-791203, while V contents are lower in the former. Thus, they are not paired. Y-791194 contains abundant plagioclase fragments in the breccia, including some in composite plagioclase-silica and plagioclase-phosphate fragments. Y-791194 is one of a few Sc-rich diogenites [2]. Compositionally, MET 001060 is a typical diogenite, although it has low Yb and Lu contents (similar to those of Shala), and high Co (but not Ni) and Sc contents.

Eucrites: As is common among Antarctic eucrites [3], several of the samples studied here have trace element contents that were affected by weathering. Most of the remaining stones are typical eucrites in composition. However, MET 01081, an unbrecciated eucrite, stands out. It is depleted in incompatible trace elements, and has a super-chondritic Eu/Sm. Its Ce/La content is like those of basaltic eucrites and distinctly higher than those of cumulate eucrites.

A-881394: This meteorite, originally classified as a cumulate eucrite [4], has anomalously low moderately volatile element contents [5]. My analyses confirm the low Na contents, low incompatible element contents, and super-chondritic Eu/Sm ratio [5]. Recent oxygen isotope ratio measurements have shown that A-881394 is anomalous compared to HED meteorites and was probably derived from a distinct parent asteroid [6]. My preliminary electron microprobe analyses show that pyroxenes in A-881394 have slightly lower Fe/Mn ratio than do eucritic pyroxenes, but it is not yet clear that the two pyroxene groups can be resolved.

MeteOrIte Search in East Antarctica: Beyond the Yamato Mountains

Hiroshi Naraoka1 and Hideyasu Kojima2. 1Department of Earth and Planetary Sciences, Kyushu University. E-mail: naraoka@geo.kyushu-u.ac.jp. 2Antarctic Meteorite Center, National Institute of Polar Research, Tokyo, Japan.

Introduction: The Japanese Antarctic Research Expedition (JARE) has conducted meteorite searches in Queen Maud Land, East Antarctica, since 1969, where more than 16,200 meteorites have been recovered from blue ice fields. Of these, most meteorites are collected near the Yamato Mountains, called as the Yamato Meteorite Field. The meteorite concentration is so high that thousands of meteorite specimens are found every several years. The Yamato Meteorite Field must be the most important field for the Antarctic meteorite search. The JARE also carried out a few systematic meteorite searches around the Belgica Mountains and Sor Rondane Mountains westward from the Yamato Mountains.

Belgica Mountains: The Belgica Mountains are located about 200 km west of the Yamato Mountains. Four Belgica meteorites were recovered in 1979. As a large bare ice field is developed southward, it is a target to revisit.

Sor Rondane Mountains: The Sor Rondane Mountains, located about 100 km west from the Belgica Mountains, bear a large bare ice field (Nansenisen), where ~2000 Asuka meteorites were collected in 1987–89. Asuka meteorites are generally large (the biggest is a 46 kg chondrite) and are various types of meteorites. As Nansenisen is at a higher elevation (~3000 m) compared to the Yamato Meteorite Field (~2000 m), different mechanisms may operate for the meteorite concentration. Since 20 years have passed since the last search, it is highly recommended to revisit the Sor Rondane Mountains.

Other Areas: In the Queen Maud Land, there are many mountains between the Yamato Mountains (east) and the Homefront Range (west). Of these, the largest mountain range is Fimbulheimen, located about 300 km west from the Sor Rondane Mountains. The Fimbulheimeen (comprising of three major ranges Hofmann, Orvin, and Wohltat Mountains) also bears a large bare ice field southward (Wegnerisen). Although the Wegnerisen ice field has never been visited, it is a possible target for meteorite search.

Concluding Remarks: Besides the Yamato Mountains area, there are several bare ice fields suitable for meteorite searches. Under severe climate conditions such as strong winds, Antarctic meteorites are subjected to weathering. It is favorable to collect “fresh” meteorites by frequent meteorite search programs.

Recovery and Classification of 16 New Thiel Mountains Meteorites by the Second Korean Expedition for Antarctic Meteorites


In the blue ice fields around Thiel Mountains, West Antarctica, 66 meteorites have previously been found [1–4]. The second Korean Expedition for Antarctic meteorites was conducted at Thiel Mountains from 19 December 2007 to 6 January 2008. Up to 60 cm of fresh snow fell in West Antarctica in early December 2007, covering most of the blue ice fields around Thiel Mountains. Sixteen meteorites (with a total mass of 10.6 kg) were recovered by the expedition: 12 at Moulton Escarpment, one at Bernet Escarpment, two at Mt. Walcott, and one at Mt. Powell. These include 10 ordinary chondrites (OC), three carbonaceous chondrites, one pallasite, one eucrite, and one lodranite. The meteorites were vacuum-sealed, kept in subzero temperatures, and shipped to the laboratory in Korea. They were slowly defrosted in a glove box filled with N2 gas, then cut with a dry saw. Polished sections were made for classification purposes.

The OC are all equilibrated (type 5 or 6) and include four H, two L, and four LL chondrites. All of the OC exhibit only minor amounts of iron oxide coating metallic Fe-Ni grains, consistent with a weathering grade of W1 [5]. However, one OC shows significant replacement of silicates by clay minerals, indicative of W5. Based on exterior rustiness, the meteorite can be classified as weathering category C. The dichotomy between the weathering of metal and silicates implies that silicates are more susceptible to weathering in the Antarctic environment; thus, the common weathering classification scheme [5] may not be applicable to Antarctic meteorites. Two reduced CV3 chondrites (18 g each) with strongly oriented fabrics were found; they are probably paired. They contain large (mainly >1 mm in diameter) chondrules; Ca-Al-rich inclusions and amoeboid olivine inclusions are large and relatively abundant. One heavily altered CM chondrite (723 mg) was also recovered; it contains abundant occurrences of tochilinite-crostenedite intergrowths (PCP), but no unaltered chondrules. A 3.5 kg specimen of a pallasite was found on a moraine near Mt. Powell; this may be paired with the Thiel Mountains pallasite found in 1962, but this potential pairing needs to be confirmed by chemical analysis. The eucrite (3.7 kg) is heavily brecciated; it has a shiny black fusion crust covering almost the entire surface and a relatively fresh interior. The lodranite is intermediate between normal lodranites and acapulcoites in terms of grain size and modal abundances of troilite and plagioclase.

The minerals in these meteorites will be analyzed by electron microprobe and their O-isotopic compositions will be measured by CO2 laser-fluoration techniques. Results will be presented at the meeting.

INTRODUCTION: Collection and curation of Antarctic meteorites for 30 years have resulted in identification of potential contaminants—both organic and inorganic—to meteorite samples. The intent of this contribution is to summarize the lessons learned from past experiences so that those building new collections can avoid problems and/or take advantage of successes.

FIELD: Organic matter (wind blown microorganisms or organic compounds), may be present in the ice [1–3] in which meteorites sit for ~100 ka. Careful collection involves use of teflon coated tongs, Teflon and/or nylon bags, and elimination of contact with gloves or skin. Some field teams use skidoos, and skidoo exhaust does not appear to be a contaminant [3]. Samples transported in isopods should be lined with carefully chosen materials to minimize contamination.

LAB: Frozen meteorites are transferred into freezers at JSC until they are thawed in dry GN2. During this stage, water can pyrolize nylon in some cases, and produce an amino acid contaminant [4]; use of Teflon bags can eliminate this problem [5]. Later heat sealing of bags can produce offgas various species such as CO (butyl rubber), isopropyl alcohol and SO2 (hylapon). Storage in nitrogen minimizes oxidation and reactivity of samples, but is not totally free of organisms, as anaerobic bacteria can survive in some samples [6]. Filtering of supply and exhaust is necessary to reduce hydrocarbons. Fabrication of processing cabinets (or other equipment) can utilize lubricants and other chemicals; an example is xylan, a complex amide, used in JSC processing cabinets in the 1980s [7, 8]. To learn more about the effects of bandsawing, a bandsawed pristine Apollo sample known to have low levels of organics [9, 10], was studied using a variety of microscopy techniques. Little organic contamination was found, but significant Ni and C contamination from the saw blade was found on the cut surface (C was also found by [11]).

SUMMARY: These are some known examples of contaminants introduced during the handling of meteorites. There may be others depending upon materials and procedures used by various groups. Collectors and curators are encouraged to evaluate their procedures to minimize unwanted effects, and also to curate examples of materials used in handling, storage or maintenance of facilities and equipment.


MOJAVE DRY LAKE CONSTRAINTS ON THE FLUX OF METEORITES TO THE EARTH

Alan E. Rubin1 and Robert D. Matson2. 1Institut of Geophysics, UCLA, CA 90095, USA. E-mail: acrubin@ucla.edu. 2Science Applications Int. Corp., 3030 Old Ranch Pkwy., Seal Beach, CA 90740, USA.

The flux of meteorites to the Earth follows a power-law distribution wherein small projectiles outnumber larger ones. For Antarctic meteorites ≥10 g, the flux is 1000 meteorites/km2/106 a [1]. The degree of weathering and the terrestrial ages of ordinary chondrites (OC) from a hot desert (Roosevelt County, NM) can be used [2] to derive a flux for ≥20 g samples of 159 meteorites/km2/106 a. For observed falls, which peak at ~4 kg, the flux is 1 meteorite/km2/106 a [3, 4]. Uncertainties are a factor of ~2.

Another potential source for determining the flux is the set of dry lakes (playas) in the Mojave Desert in Southern California. Lucerne Dry Lake (16 km2) has yielded 94 numbered meteorite specimens (average mass = 7.0 g). All specimens are chondrites; 82 have been classified. Based on chondrite group, petrologic type, olivine composition, shock stage, and weathering, we estimate that there are 16 individual meteorites. These include 38% H (relative to 31% among falls [5]), 44% L (35%), 12% LL (7%) and 6% CK (0.2%). The number of specimens per individual OC ranges from 1 to 12 and averages 2.7; there are 41 known specimens of the LV 028 CK4 chondrite (TKW = 98.5 g).

Masses of individual specimens range from 0.1 to 106.22 g; integrated masses of the separate meteorites range from 1.2 to 162.9 g. If we assume that the entire amount of each meteorite has been recovered, the average mass was 36 g prior to fragmentation. Mass distribution histograms suggest that some small specimens of individual meteorites are missing, but few large ones. We estimate that the average mass of the separate meteorites is ~50 g. Most specimens are covered with fusion crust, suggesting fragmentation occurred in the atmosphere [6].

The meteorites are not randomly distributed across the playa; 85% are concentrated near the SE shoreline. This may be due to wind-driven wave action during winter periods when water depths are several centimeters [7].

Most of the playas last held “permanent” water at the end of the Pleistocene, ~11,000 years ago; some contained shallow water for several decades during the Holocene [8]. The lakes are alkaline and corrosive; some meteorites are unlikely to have survived immersion in water (or water-logged sediments) for thousands of years. We take 10,000 years as the upper limit for the terrestrial age of the playa meteorites. The derived flux for 50 g meteorites is 100 meteorites/km2/106 a, consistent with previous flux estimates. Using the preferred –0.833 mass distribution [1] for the equation describing the number of meteorites (N) of mass M (grams) or larger falling per km2 per 106 a, we obtain log N = –0.833 (log M) + 3.42, similar to Huss’s “most realistic” estimate [1] in which they intercept is 3.833.

Contribution of Antarctic Ureilites to Reconstruction of Their Parent Body and the Formation Processes with Description of Three Ureilites from Antarctica

Hiroshi Takeda and A. Yamaguchi. Department of Earth and Planetary Science, University of Tokyo, Tokyo 113-0033, Japan. E-mail: takeda.hiroshi@it-chiba.ac.jp (Chiba Inst. of Tech.). National Institute of Polar Research, Tokyo 173-8515, Japan.

Introduction: Previous mineralogical and chemical analyses of Antarctic ureilites [1, 2] have shown it to be an especially important sample of the ureilite parent body. Recoveries of ureilites from Antarctica and hot deserts have increased drastically the number of known ureilites. Ninety-five Antarctic ureilites were recorded among 241 total ureilite samples. All non-Antarctic ureilites described originally contain pigeonite as a major phase, and their compositions vary within a limited range. Augite-bearing ureilites [2] and pigeonite-orthopyroxene pair in magnesian ureilites [3], both found in Antarctica, fall outside the original definition of ureilites, and ALH 78019 does not contain diamond [4]. We report more unusual examples in the NWA (Northwest Africa) ureilites at this meeting. We report three new Antarctic ureilites in this paper and discuss the formation mechanism of ureilites.

Samples and Experimental Methods: PTSs of Asuka (A)-881989, A-881931, and Yamato (Y)-980110 were obtained from NIPR. Our methods include an optical microscope and EPMA at Ocean Research Institute of the University of Tokyo and NIPR.

Results: Brief descriptions of two Asuka ureilites are given in the Meteorite Newsletter of NIPR, and preliminary data of the Yamato ureilite were informed by NIPR.

Chemical compositions of minerals. About 70% of the mafic silicate grains in A-881989 are olivines, and A-881931 is very rich in olivine (about 95%). A-881931 may have an affinity to the olivine-rich ureilites from NWA. The Fo values of the A-881931 olivine range from 78.3 to 78.8, and the pyroxene compositions range from Fs18.5Wo13 to Fs18.5Wo14. The Fo values of A-881989 (78.5–81.0) are similar to those of A-881931, but the pyroxene compositions are low in Ca (Fs14.5Wo12). A grain with lamellae texture shows some variations (Fs13.5Wo12–Fs13Wo14). Yamato-980110 is under investigation.

Structures of the low-Ca pyroxenes. The structural type of the low-Ca pyroxene in A-881989 is difficult to determine because of the shock effects. The Ca content of Opx coexisting with pigeonites has about Wo8. If it were low-Ca pigeonite, its crystallization temperature is very high. Opx in ALH 82106 [5] has complex beby texture similar to that of Yamato-980110.

Discussion: The pyroxene polymorphic pairs found in the Antarctic ureilites will help us to deduce their annealing temperatures and cooling histories. The above ureilites can be explained by a proposed model of the ureilite formation, as residues of disequilibrium partial melting, by combination of internal heating and planetesimal-scale collision, and grain-coarsening at high temperature, then final breakup of the parent body.

PETROLOGIC CLASSIFICATION AND THERMAL HISTORY OF EH3–4 CHONDRITES

M. K. Weisberg1, D. S. Ebel2, and M. Kimura3. 1Department of Physical Sciences, Kingsborough College City University New York, Brooklyn, NY 11235, USA. E-mail: mweisberg@kbcc.cuny.edu. 2Department of Earth and Planetary Sciences, American Museum Natural History, New York, NY 10024. 3Ibaraki University, Japan.

Introduction: Enstatite (E) chondrites are extremes in the nebular conditions that resulted in the properties of chondrites. Their silicate, sulfide, and metal compositions indicate highly reducing conditions [e.g., 1]. They contain higher amounts of FeNi than ordinary or carbonaceous chondrites, and their metal is Si bearing with more than 2 wt% Si in EH chondrite metal. The number of unequilibrated E chondrites has grown considerably over the last decade largely due to recovery of meteorites from Antarctica. However, a petrologic classification for the E3–4 chondrites is not well established and their thermal histories remain elusive.

Prinz et al. [2] defined and established the differences between E3 and E4 chondrites and presence and abundance of olivine was shown to be one of the key parameters. Weisberg et al. [3] showed that Cr in olivine is a useful indicator for degree of metamorphism in the least equilibrated E3 chondrites, as in O and CO chondrites [4]. Kimura and Lin [5] noted that Si content of metal was lower in EH than in EH4 chondrites. In this work, modal abundances of olivine and Si content of metal in several EH3–4 chondrites are explored as indicators of metamorphic grade.

Results: Modal abundances and metal compositions were determined in seven EH3 chondrites. Some data are preliminary and work on six more EH3s is in progress. Data on two EH4 and another EH3 are taken from [5]. Modal abundances of olivine in EH3 chondrites vary (in vol%) from Kota Kota (7.4) to Parsa (5.9), Yamato-691 (5.2) and Sahara 97096 (5.1) to ALHA77156 (3.4) and Qingzhen (2.8) to EET 83322 (2.7). In two EH4 chondrites, Y-791790 and Y-791810, olivine abundances are ~0.3% [5]. Average Si content of metal is lowest (wt%) in Kota Kota (2.3), Sahara 97096 (2.3), Yamato-691 (2.3) and Parsa (2.5) and higher in Qingzhen (2.6) and ALHA 77156 (2.6) and highest in EET 83322 (3.0). In the two EH4 chondrites the Si content of metal is 3.1 to 3.2.

Discussion: The EH3–4 chondrites appear to follow a general trend of decreasing modal abundance of olivine and increasing average Si content in metal. This trend is interpreted to represent compositional changes with increasing degree of thermal metamorphism in the EH chondrites and may be useful to help establish a petrologic classification for the EH chondrites. Previous work has shown that Kota Kota, Parsa, Sahara 97096 and Y-691 are among the least equilibrated EH chondrites [3] and the relatively low Si values of their metal and high modal abundances of olivine are consistent with this conclusion. More work is in progress to confirm these trends and establish a petrologic classification for EH chondrites. Similar work needs to be done for EL.


CLASSIFICATION OF ANTARCTIC ORDINARY CHONDRITES BASED ON NI AND CO IN THE METAL PHASE

K. C. Welten, R. DiBiase, B. Schipper, J. Perkins. Space Sciences Laboratory, University of California, Berkeley, CA 94720–7450, USA. E-mail: kcwelten@berkeley.edu.

Introduction: As part of an ongoing 36Cl terrestrial age survey of Antarctic chondrites, we routinely separate the metal phase from ordinary chondrites and measure the concentrations of cosmonogenic 36Cl as well as major elements (Fe, Co, Ni) in the metal phase. While Ni and Co in bulk ordinary chondrites decrease from H to L to LL chondrites [1], the concentrations of Ni and Co in the metal phase increase from H to L to LL chondrites. Metal Co and Ni contents are thus a useful tool for classification of equilibrated ordinary chondrites [2, 3], similar to the kamacite-Co content [4]. We report Ni and Co concentrations in the metal phase of 383 ordinary chondrites from the ANSMET collection. Based on the metal composition, we identified 85 meteorites that have been misclassified.

Method: Chondrite samples weighing 2–3 g were gently crushed and the metal was separated with a magnet. The metal was ultrasonically cleaned in 0.2N HCl and concentrated HF to dissolve attached troilite and silicates, respectively. Purified metal samples weighing 20–100 mg were dissolved in HNO3. After dissolution, small aliquots were taken for chemical analysis by atomic absorption spectrometry. The chemical analysis of a leached and unleached metal sample of the same meteorite show that the leaching procedure leads to higher metal-Ni and lower metal-Co concentrations (due to preferential dissolution of kamacite), but does not affect the classification of the meteorite sample.

Results: The metal compositions of 6 of the 160 H chondrites investigated clearly fall in the L-chondrite range. These meteorites include three relatively unequilibrated meteorites (type 3.7 to 4) and 3 meteorites that were classified based on the refractive index of olivine. More alarmingly, the metal compositions of 53 out of 171 L and 26 out of 52 LL chondrites suggest they have been misclassified. Interestingly, the number of misclassifications is highest among L and LL chondrites that were classified by refractive index only, which is clearly much less reliable than conventional microprobe analyses. We will discuss implications of misclassifications for studies of pairing, weathering and variations among Antarctic meteorite populations.

4028
TERRESTRIAL AGES OF ANTARCTIC METEORITES
K. C. Welten1, K. Nishiizumi1, and M. W. Caffee1. 1Space Sciences Laboratory, University of California, Berkeley, CA 94720, USA. E-mail: kcwelten@berkeley.edu. 2Department of Physics, Purdue University, West Lafayette, IN 47907, USA.

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 field activities. The determination of terrestrial ages using $^{36}$Cl (half-life $= 3.01 \times 10^5$ yr) is a long-term ongoing 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 $^{14}$C corresponds to a terrestrial age of ~35 kyr, so the longer half-life of $^{36}$Cl makes it a superb analytical tool for meteorites having terrestrial ages of 35 kyr to ~3 Myr. We have initiated a systematic $^{36}$Cl terrestrial age survey of Antarctic chondrites since 2004 with support from NASA Cosmochemistry Program (and support from NSF OPP at initial stage). The Antarctic Meteorite Newsletter is a timely means of reporting $^{36}$Cl terrestrial ages to the scientific community: we reported results for 200 chondrites. Previous surveys of Antarctic meteorites included $^{26}$Al and TL measurements. Although these techniques are non-destructive, the amount of material required for the $^{36}$Cl measurement is small and the chemical preparation is relatively easy. This technique provides definitive terrestrial age determinations and highlights those samples that warrant additional study.

Terrestrial Age Survey of Chondrites: For more than 90% of the ordinary chondrites, the measurement of $^{36}$Cl in the metal phase suffices to ascertain terrestrial ages. The $^{36}$Cl terrestrial age is calculated from the measured $^{36}$Cl concentration by assuming an average saturation value of 22.1 $\pm$ 2.8 (±2) dpm/kg [metal] [2]. We measured $^{36}$Cl in the metal phase of 260 ordinary chondrites and found concentrations ranging from 1 to 26 dpm/kg. For meteorites with $^{36}$Cl concentrations <15 dpm/kg, we also measured $^{10}$Be in the metal phase, which allows determination of the terrestrial age using the $^{36}$Cl/$^{10}$Be-$^{10}$Be method [3]. Many of the low $^{36}$Cl concentrations are due to terrestrial ages up to ~650 kyr, while some are due to high shielding conditions [4] or to very short CRE ages [5]. In addition to terrestrial ages, the $^{36}$Cl measurements also provide valuable clues for identifying large pairing groups and chondrites with short or complex exposure histories.

Terrestrial Ages of Achondrites: Terrestrial ages for achondrites are based on $^{14}$C, $^{36}$Cl, $^{41}$Ca or $^{81}$Kr–Kr [1, 6]. Recently, terrestrial ages of ~20 Antarctic diogenites were determined from $^{41}$Ca [6], while $^{36}$Cl is more suitable for terrestrial ages of achondrites and howardites. We measured $^{36}$Cl in more than 50 HED achondrites and derived terrestrial ages up to ~500 kyr. The observation that terrestrial ages of Antarctic achondrites and achondrites show very similar distributions, unlike for hot desert meteorites, suggests that weathering does not play a significant role in limiting the lifetime of Antarctic meteorites.


4015
VARIETY WITHIN EUCRITES AND IMPLICATIONS FOR THEIR CLASSIFICATION
A. Yamaguchi1, H. Takeda2, and J.-A. Barrat3, 4. 1National Institute of Polar Research, Tokyo 173-8515, Japan. E-mail: yamaguchi@nipr.ac.jp. 2University of Tokyo, Tokyo 113-0033, Japan. 3Université Européenne de Bretagne. 4UBO-IEEM, CNRS UMR 6538, place Nicolas Copernice, F-29280 Plouzané Cedex, France.

The discovery of many HED meteorites from hot and cold deserts provides a unique opportunity to further study this meteorite group. HED meteorites are characterized by their similar O-isotopic compositions and Fe/Mn values in their pyroxenes. There are three groups of eucrites: crystalline (unbrecciated), monomict, and polymict. We revisit the classification of these eucrites [1, 2].

Crystalline eucrites occur as unbreciated rocks or clasts in breccias of HED meteorites. They are noncumulate (basaltic) (e.g., HaH 262) and cumulate eucrites (e.g., Moore County), and intermediate types (Pomozdino, Yamato- (Y) 791438). On the basis of the bulk chemical compositions, they are classified into two chemical types (Stannern-trend, and main-group Nuevo Laredo trend). Noncumulate eucrites are metamorphosed rocks in varying degrees (types 1–7). Metamorphosed basaltic eucrites (types 4–7) are commonly classified as an ordinary eucrites because they are most abundant type [2]. Other type includes coarsely recrystallized breccias with grain sizes ~50–100 µm (granulitic eucrites) [e.g., EET 90020, A-881388]. Cumulate eucrites have Mg-rich pyroxene (~55 > Mg# > ~70) (Mg# = Mg/ (Mg + Fe) × 100). They may have geochemical evidence of crystal settling. The presence of inverted pigeonite in most cumulate eucrites indicates slow cooling. Some cumulate eucrites keep pigeonite (e.g., Y-791195). Coarse-grained eucrites were erroneously classified into cumulate eucrites in some cases. A rare type of crystalline eucrites includes impact melt rocks (e.g., NWA 1740) [3].

Monomict eucrites are monomict breccias of eucrites. The term monomict may loosely include unbreciated eucrite [1]. Textures of monomict eucrites are in most cases variable due to multiple brecciation, melting and recrystallization. Some of the eucrites may be metamorphosed impact melt rocks and/or polymict breccias (e.g., Millbillillie, Juvinas). Nevertheless, their low-Ca pyroxenes are pigeonite (or partly inverted pigeonite) with homogeneous Mg# values. Because of the homogeneity in the Fe/Mg ratios in pyroxenes, these rocks are called monomict eucrites.

Polymict eucrites contain <10 vol% of diogenite orthopyroxene (Mg# > ~70) [1]. Also, polymict eucrites may consist of different kinds of eucrites (basaltic and cumulative eucrites). Y-74159 type polymict eucrites (Yamato-1) are characterized by the presence of Bindy-type inverted pigeonite and various types of metamorphosed eucrites [2]. Polymict cumulate eucrites are a small group of brecciated eucrites (e.g., Y-791439). A diogenite Y-75032 and related breccias (Y-75032 type) are unusual rocks, and are mixes of cumulate eucrites and diogenites (or pigeonite cumulate eucrites) [2].