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Papers presented to the

45th ANNUAL
METEORITICAL SOCIETY MEETING

St. Louis, Missouri
13-16 September, 1982

Co-sponsored by
McDonnell Center for the Space Sciences, Washington University,
and
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Hosted by the McDonnell Center for the Space Sciences,
Washington University

Universities Space Research Association
Lunar and Planetary Institute

METEORITICAL
SOCIETY/1982

ST. LOUIS - 1982

FORTY-FIFTH ANNUAL MEETING OF THE METEORITICAL SOCIETY

SPONSORED BY

McDonnell Center for the Space Sciences, Washington University
Lunar and Planetary Institute

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McDonnell Center for the Space Sciences, Washington University
St. Louis, Missouri

September 13-16, 1982

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PREFACE

This volume contains the abstracts which have been accepted by the Program Committee for oral presentation at the 45th Annual Meteoritical Society Meeting.

The Program Committee included Robert Walker (Chair), Ghislaine Crozaz, Larry Haskin and Charles Hohenberg (*Washington University*); Michael Lipschutz (*Purdue University*); Harry McSween (*University of Tennessee*) and Pamela Jones (*Lunar and Planetary Institute*).

The Organizing Committee for the meeting consisted of Ghislaine Crozaz (Chair), Phil Fraundorf, Marilyn Lindstrom, Kevin McKeegan, Frank Podosek, Scott Sandford, Barbara Wilcox and Ernst Zinner, all of Washington University.

Invaluable assistance was provided by: Eloise Arvidson, Vince Bork, Marc Caffee, Mary Haskin, Kris Henrick, Masahiko Honda, Margaret Israel, Frank Kramer, Esther Koenig, Tina Kornmeier, Randy Korotev, Craig Leff, Harold Levin, Dave Lindstrom, Linda Miller, Deborah Meinke, Norbert Pailer, Peter Salpas, Kristina Semkow, Ina Steinberg, Steve Sutton, Pat Swan, Tim Swindle, Betty Weiss.

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ROCHECHOUART: A FLAT CRATER FROM A CLUSTERED IMPACT.

P. Lambert (NRC), SN6, NASA/Johnson Space Center, Houston, TX 77058

Compared to other terrestrial impact craters, the Rochechouart structure, 20 km in diameter, (Limousin, France) (1) features several unusual characteristics which are difficult to reconcile with the current model of cratering by a single body impact, but rather suggest an impact of several clustered objects. (a) The crater floor, i.e. the boundary between impact deposits and the target, is flat and is not raised in the center nor depressed at the periphery. The elevation of the contact varies ≈ + 50 m within the 13 km wide central zone where the crater floor is exposed. In that zone, the circular symmetry of the impact deposits is maintained despite the thinness of the preserved deposit (average thickness <12 m). Remnants of impact deposit are exposed even at the center of the structure. (b) Impact deposits in the crater have never been thick (≈100 m). (c) No clear stratigraphic relationships exist between the different breccias preserved in the crater deposits. (d) There is no regular pattern of shock attenuation in the target, nor a concentration of strong deformation locally in the center of the structure. There are some external maxima and, conversely, unshocked areas in the center (2). (e) Isobars of maximum shock recorded in the target correlate with the extent of the preserved ejecta deposit and attenuate very rapidly at the periphery of the structure. (f) Correlations between (i) rock type and (ii) shock level can be established across the crater floor (1).

Characteristics (a) and (b) have been observed in single craters produced in the laboratory by hypervelocity impact of fragmented projectiles (2). These and earlier (3) experiments have shown that the ejection mechanism is more complex than in a single body impact which may be responsible for (c) in Rochechouart. Comparison with cratering experiments is not possible for (d)-(f). These characteristics, however, are more difficult to interpret as the result of a single point-source shock wave attenuating as a function of the radius of a single projectile than as the result of clustered point sources and multiple shock waves attenuating over a short distance because of the small radius of the individual projectiles.

If Rochechouart resulted from impact of multiple bodies, the objects must have been clustered tightly enough to produce a single crater. In addition, individual objects must have been large enough to retain their cosmic velocity and to be able to produce significant amounts of melting. These constraints are not independent; both are likely to be satisfied by either of the two plausible mechanisms responsible for clustered impact collision in space and/or atmospheric break up (4, 5) by minimizing the effects of aerodynamic dispersion of meteoroid fragments. This assumption seems reasonable if one considers the size of the Rochechouart structure, which places the projectile (either iron or chondrite) radius in the 100-300 m range, i.e., near the critical radius for atmospheric effects (5).

REFERENCES: (1) P. Lambert, Earth Planet. Sci. Letters 35, p. 258-268 (1977); (2) P. H. Schultz, pyrex experiments, personal communication (1982); (3 P. H. Schultz, LPI Technical Report 81-01, p. 120-122 (1981); (4) Q. R. Passey, H. J. Melosh, Icarus 42, p. 211-233 (1980); (5) H. J. Melosh, Multiring Basin, Proc. Lunar Planet. Sci. 12th, p. 29-35 (1981).

A PRELIMINARY VIEW OF THE SOUTHERN GULF OF ST. LAWRENCE AS AN IMPACT STRUCTURE

Jack B. Hartung*, NASA Headquarters, Washington, D.C.

The southern part of the Gulf of St. Lawrence has been suggested as the site of a large impact since the 1950s. During the summer of 1981 a visit was made to New Brunswick and Nova Scotia in search of evidence bearing on the impact hypothesis. Based on conversations with geologists and geophysicist expert in that area and on first-hand investigation of selected outcrops the following conclusions were reached.

1. The roughly circular (300 km. diameter) shoreline of the southern Gulf of St. Lawrence and the concentric arrangement of Prince Edward Island may correspond to similar features related to multi-ring basins on other planets.

2. Older rocks of the region are "shattered." Detailed mapping shows numerous complex faults. Most outcrops display slickensided surfaces. Extensive block faulting to reestablish an equilibrium state is inferred. Disequilibrium may have been produced by a large impact.

3. An important unconformity, which may correspond to the possible impact, occurs in the stratigraphic record in middle-to-late Devonian time. Conglomeratic rocks overlie this unconformity throughout the region, but no evidence of shock was found in them.

4. Younger Carboniferous rocks grade upward to evaporite deposits followed abruptly by normal marine limestones. It was concluded previously by others that the protecting walls of a large inland lake, the surface of which was below sea level, were suddenly breached allowing "normal" sea water to fill the saline lake. The topographic low may have been an impact basin.

5. Gravity and magnetic data are inconclusive. Seismic refraction, "depth-to-basement," data show a pronounced asymmetry; a deep, subsided trough under the eastern part of the Gulf, a shallow, shelf-like character for the western part. This result appears inconsistent with an impact hypothesis, but it may be reconciled if the post-impact subsidence is controlled by the different characteristics of the rocks present at the different locations before the impact.

6. A more satisfactory "explanation" for the southern Gulf of St. Lawrence in terms of simple tectonic processes does not exist.

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NICKEL-IRON OCTAHEDRAL CRYSTALS IN NORTH AMERICAN MICROTEKTITES;

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Ni-Fe octahedral crystals, approximately 1 to 2 μm across, have been found in five North American microtektites from the equatorial Pacific Ocean (Deep Sea Drilling Project sites 69A, 166, and 167). The microtektites containing the crystals are transparent to translucent and pale green in color. All of them are spherical in shape, but generally badly corroded. Major element abundances were determined by energy dispersive x-ray analysis. They are distinct from both the "normal" North American microtektites (1, 2) and the clinopyroxene-bearing spherules described by John and Glass (3). They have lower SiO_2 and Al_2O_3 and higher CaO, Na_2O, and K_2O contents than the "normal" microtektites. They have similar SiO_2, Al_2O_3, CaO, and TiO_2 contents to the clinopyroxene-bearing spherules, but their MgO contents are much lower and their Na_2O and K_2O contents are 2 to 3 times higher.

The number of crystals in a microtektite varies from a few to more than a hundred. Polished sections of the microtektites exposed several crystals in three of the microtektites. All of the crystals are nickel-rich. In one microtektite, the crystals contain about 75% Ni and 15% Fe. In another, the crystals contain about 66% Ni and 33% Fe. In the third, the crystals contain about 80% Ni and 15% Fe. Many of the crystals contain up to a few percent copper and one has a few percent chromium. Unfortunately, the cobalt content could not be determined because the Co K_α peak was masked by the Fe K_β peak. Ni-Fe octahedral crystals similar in size to the ones reported here have been found in lunar glasses. Very little chemical data are available for the lunar crystals, but what data are available indicate that the lunar crystals are iron-rich instead of nickel-rich (e.g., see 4).

The lunar Ni-Fe crystals are thought to be contamination from impacting meteoroids. This may be the explanation for the Ni-Fe crystals in the North American microtektites. If so, this would support the impact origin for tektites. The high nickel content can be explained by the fact that during oxidation of a Ni-Fe melt, the nickel goes preferentially into the remaining metal phase (5). Thus, ablation debris from iron meteorites is often enriched in nickel; and nickel concentrations as high as 91.9% have been observed in Ni-Fe spherules in Henbury impact glasses (6). However, the high Cu (and Cr) contents in the crystals do not support a meteoritic origin for the crystals, since Cu (and Cr) are both trace elements in iron meteorites.

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SILICON ISOTOPES: EXPERIMENTAL VAPOR FRACTIONATION AND TEKTITES.

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Silicon isotope ratios have been measured in a silicate glass of tektite composition heated to 2800°C for 45 minutes in a solar furnace [1] and in two Indochinite tektites, one of which is a Muong Nong (layered) type. Silicon and oxygen isotope ratios in the gases O_2 and SiF_4 released from a single charge of freshly reacted sample are shown in Table 1 for tektites and three separates of Run 4 from [1]: Bottom (high Si), Top clear (low Si), and Top opaque (low Si). Using the product yields to calculate the abundance of silicon and oxygen in the reacted samples reveals that the silicon isotope ratios $^{29}Si/^{28}Si$ and $^{30}Si/^{28}Si$ increase with decreasing silicon content, reflecting loss of silicon by volatilization. Similar enrichment of heavy isotopes was reported for oxygen by Walter and Clayton [2].

The extent of vaporization was estimated for the glass samples by normalizing silicon to aluminum. An 80% loss of silicon was calculated for the top glasses and even the bottom glass has lost half of its silicon relative to the starting material. In this case the fractionation of silicon isotopes in the residual glass can be approximated by a Rayleigh distillation process where the fractionation factor, α, for the $^{30}Si/^{28}Si$ ratio is small, $\sim$1.001 at 2800°C.

Measurements of the silicon isotope ratios in tektites may yield information about the temperature and duration of heating events or atmospheric conditions during tektite formation, but the two Indochinites studied here do not have a large enough spread in silica content to allow any conclusions to be drawn about the effects of vapor fractionation of silicon in tektites.

Table 1

Sample	Silicon (wt %)	$\delta^{29}Si$	$\delta^{30}Si$	Oxygen (wt %)	$\delta^{17}O$	$\delta^{18}O$
		(‰ wrt NBS28)			(‰ SMOW)	
Indochinite	30.7	0.09	0.17	51.4	5.29	10.11
Muong Nong	32.0	0.06	0.12	52.3	5.33	10.27
Bottom	33.0	0.47	0.94	50.6	7.00	13.50
Top clear	26.7	0.93	1.79	47.3	7.73	14.85
Top opaque	24.4	1.40	2.66	48.2	7.56	14.54

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THE EARLY IMPACT HISTORIES OF IRON METEORITE PARENT BODIES. K.L. Rasmussen, Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024, USA.

The observation of the existence of local bulk Ni and P variation in iron meteorites has been interpreted as caused by delayed nucleation of kamacite (1,2). Delayed nucleation is nucleation of kamacite bands in a host taenite enriched in Ni relative to the initial composition, and can thus not be described solely as due to undercooled nucleations (non-equilibrium nucleation). The host taenite is though, at least infinitesimally, out of equilibrium during the time interval in which kamacite nucleations occur. The factor controlling the evnetual kamacite nucleation is most likely an external event dispersing a substantial amount of energy in the lattice (2), though other explanations are also possible. The impact rate on the parent body surface was probably high in the early solar system, thus impacts are the most likely cause of kamacite nucleations. It is therefore possible that the measurements of the distribution of local bulk Ni contents can be interpreted as reflecting variations of impact events with time, i.e., the impact history. The recovery of the impact history relies on the assumption that either no undercooling took place prior to kamacite precipitation, or that the exact amount of undercooling can be determined. Recently 8 members of group IVA have been investigated (2), and based on this, it is concluded that group IVA originated in at least two parent bodies. About 15 local bulk Ni and P values were estimated in each meteorite, too few to yield reliable statistics. Undercooling was not observed in 5 of the 8 and seems to be a minor problem for 2 of them, but in Boogaldi, a member of the high-Ni IVA group, undercoolings of up to 160 K were observed.

In general one should not base the impact history of a parent body on a single meteorite, but rather combine data obtained from several meteorites supposed to originate from the same parental core. Unfortunately this task seems almost impossible in the low Ni IVA group, since these meteorites show a wide range of cooling rates, and no detailed thermal model is available for the IVA parent body. In the high Ni IVA group it seems possible to combine the impact histories, but too few data is available at the present time.

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DIAMOND-BEARING IRON METEORITE ALHA 77283: IMPLICATIONS FROM NOBLE GASES.

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ALHA 77283 is the second well-documented case for the occurrence of diamonds in iron meteorites (1). The other case is that of the Canyon Diablo meteorite, the generally accepted explanation for the occurrence of diamonds in Canyon Diablo being shock transformation from graphite upon impact on the earth's surface (2, 3). For this mechanism the meteoroid has to be large enough to hit its target with essentially its cosmic velocity ($>10^5$kg for the earth as a target).

We have analyzed samples taken from different positions within ALHA 77283 for the abundance and composition of cosmogenic noble gases. In conjunction with the systematics of noble gas production by spallation reactions in iron meteorites (4, 5), the results indicate a preatmospheric depth of $<$15cm for all samples analyzed at present. It thus appears that the preatmospheric mass of this meteorite was well below 1000 kg.

These noble gas results agree with the conclusion of CLARKE et al. (1), based on textural evidence, that the ALHA 77283 diamonds were not produced during impact on earth. They rather appear to be the result of some shock event earlier in the history of the meteoroid.

In addition, results from the analysis of a diamond-containing inclusion will be reported.

We thank R.S. Clarke Jr. and the Meteorite Working Group for providing samples.

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EFFECTS OF ALKALI-RICH INCLUSIONS ON AR-39/AR-40 AGES OF SHERGOTTITE-RELATED ACHONDRITES.

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Argon-39/Argon-40 age dating is being carried out on whole rock and phase separates of four (4) Shergotty-related achondrites: Shergotty, Zagami, ALHA77005, and EETA79001, as part of a collaborative investigation which also includes petrology, chemical compositions, and Rb-Sr and Sm-Nd dating. The presence of small inclusions of alkali-rich glass in ferromagnesian minerals in at least three, and possibly four, of these meteorites complicates the interpretation of Ar-39/Ar-40 ages. Rounded inclusions of glass and devitrified glass up to 50 μm in diameter, with K_2O concentrations of up to 1%, exist in ALHA77005 olivines. Irregular glass inclusions up to 10 μm long, with K_2O concentrations up to 7%, exist in Shergotty pyroxenes. Inclusions in Zagami pyroxenes appear nearly identical to those in Shergotty. These inclusions dominate the incompatible element budget of these ferromagnesian minerals.

Maskelynite (shock-converted feldspar) separates from Shergotty and Zagami suggest Ar-39/Ar-40 ages of 0.25 Gy. These ages are slightly older than Rb-Sr isochron ages of 0.18 Gy, and they suggest that the shock event experienced by these meteorites caused greater resetting of the Rb-Sr isochron than degassing of Ar from feldspar. Pyroxene separates from Shergotty and Zagami gave similar but complex Ar-39/Ar-40 releases, suggesting ages between 0.3 and 3 Gy. The complexity of these Ar release curves is attributed primarily to the existence of tiny, K-rich inclusions and the large differences in Ar diffusion properties between feldspar and pyroxene. Average Ar-39/Ar-40 ages for Shergotty and Zagami pyroxene separates are 1.2 and 0.9 Gy. These ages are slightly younger than the "best estimate" formation age of 1.3 Gy based on Sm-Nd. With the assumption that these pyroxenes contain no extraneous Ar-40, these ages would be lower limits to the formation age. The Ar-39/Ar-40 age spectrum from a whole rock sample of ALHA77005 suggests an average age of 1.0 Gy for the K-rich phase(s). The pyroxene/olivine phase (K/Ca ~ 0.005) shows a much higher apparent age of 2.2 Gy and may contain extraneous or diffused Ar-40. Analyses for Ar-39/Ar-40 are currently underway on mineral phases, whole rock samples, and shock-produced glass from the EETA79001 meteorite, and these data will also be presented.

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COSMIC SPHERULES FROM THE JURASSIC PERIOD, ELECTRON MICROPROBE STUDY.

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The interest in 'Cosmic Spherules' and their origins has extended over many decades. Our study began with an attempt to find older analogs to the abundant (but costly to recover) deep-sea spherules (SRs). Because the mean life of the SRs in ocean sediments is relatively short, we looked for other sources. A broad collection of SRs from different periods of the past might give some indication of the composition of the parent bodies and of their relative influx throughout the millennia. One place where the ancient sea floor was uplifted and forms a mountain range, the Dolomites, is in N. Italy. In a sample from the Jurassic Period (~170 M.a.) exists a discontinuity in the normal carbonate sedimentation, similar to the C-T boundary (1), with few exceptions: it is rich in Mn and Fe, contains sizable SRs, and its noble metal content is not yet known. There are many other such discontinuities in different time periods and localities, which we are currently investigating. These are called 'hard-grounds' and all may have a very slow rate of deposition, thus they can serve as natural enrichment zones for SRs and other dense extra- and terrestrial components. Many SRs showed signs of corrosion; some were so fragile that they broke up during recovery and handling, with a few revealing hollow centers. Some of the SRs had mineral inclusions, and one was found to have a Ni-rich globule (#3). Fe, Ni, Cr, Mn, Ti, Al, were the major elements detected and analyzed. Part of the data is listed in Table I. The sum of metal oxides: Fe_2O_3, NiO, Cr_2O_3, MnO, TiO_2, Al_2O_3, is also given. For comparison, the mean elemental abundance ratios of Stony-Iron meteorites, Cl Carbonaceous Chondrites (2), and Mafic rocks (3), are also included.

Conclusions: The microanalyses show that the Jurassic SRs can be divided into two groups: Ni-rich and Ni-poor. The Mn/Fe ratio often used as a spot check for terrestrial origins (3) falls well below the mean 0.02 terrestrial ratio, and 0.01 for unequilibrated Cl chondrites. Since Ni is often depleted in the magnetite bearing phases during ablation, its absence does not preclude an extraterrestrial origin, but the presence of metallic Ni-Fe globules indicates a meteoritic origin (3). Therefore the elemental resemblance of these SRs to meteorites can not be overlooked or underestimated. However, to give additional proof as to their origin, measurement of terrestrially depleted siderophiles, such as Ir, Pt, Au, Co, etc., by INAA and RNAA in the SRs, and in the 'hard-grounds' themselves is being pursued.

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TABLE I. Representative Electron Microprobe Data on Jurassic Spherules

No.	Size (μm)	Fe %wt	Al/Fe $\times 10^{-4}$	Ti/Fe $\times 10^{-4}$	Cr/Fe $\times 10^{-4}$	Mn/Fe $\times 10^{-4}$	Ni/Fe $\times 10^{-2}$	ΣMet. Ox.%	Remarks
3	270	64	0	1.6	19	4.7	6.7	97	
3	270	65	0	4.6	22	0	10	101	Globule
3	270	18	70	0	5.4	65	170	67	Glob.wht.reg.
5	330	68	-	-	44	8.9	7.1	94	Fe as FeO
15	170	71	5.6	2.8	8.5	0	0.14	102	
15	170	66	7.2	3.0	6	6	0.18	96	Diff.reg.
17	280	72	63	0	5.6	2.8	0.24	104	Hollow
Cl, C.C.		18	450	21	130	100	5.3		
S-I.m.		51	450	9.6	-	-	14		
Maf.r.		-	-	-	-	200	0.2		

SANIDINE SPHERULES IN A PACIFIC KT BOUNDARY.

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Sanidine spherules associated with the Cretaceous-Tertiary (KT) boundary in a north Pacific giant piston core (GPC-3) are similar to sanidine spherules reported by Smit and Klaver in the KT boundary in Caravaca, Spain. GPC-3, an abyssal clay section (30°N, 157°W, 5705 m depth) is a unique sample of the KT boundary in that its extreme depth places it well below the carbonate compensation depth in what is usually an oxidizing environment with extremely low sedimentation rates ($\lesssim 0.5$ m Ma^{-1}). The sanidine spherules were discovered during a detailed analysis of the KT section.

In this experiment, 59 samples comprising a section from 20.0 to 20.9 m depth are being analyzed by INAA with 1 cm resolution around the anomaly. Preliminary results (detection limit $\lesssim 2$ ng/g) indicate a very well defined Ir peak from 20.6 to at least 20.4 m (peak concentration 13 ng/g @20.56 m). The base of the anomaly coincides with a change from finely laminated sediments below to a uniform brown clay in the enriched section.

In a preliminary study of the coarse (>208 μm) fractions of the boundary we found numerous white spherules up to 1 mm diameter in samples from 20.45-20.60 m, coincident with the Ir anomaly. Only two were found from 20.60-20.65 and no spherules were in samples below (20.65-20.70) or above (20.22-20.26). X-ray diffraction analyses of 9 spherules indicated that 5 were composed of sanidine, 2 had patterns tentatively identified as high albite (but not sanidine) and 2 gave only clay mineral patterns. The sanidine composition has been confirmed by SEM analysis and confirmation of the other phases is in progress.

Smit and Klaver interpreted the Caravaca sanidine as being quenced droplets derived from the impacting body. We consider it more likely that sanidine is derived from terrestrial materials involved in the accretionary event, either as quenched droplets or, more likely, devitrified glassy spherules. The GPC-3 spherules are mineralogically more diverse than the Spanish samples and we speculate that the end members of the spectrum may be relatively primitive. In any event, their occurrence over at least 15 cm supports our suspicion that the >20 cm thick Ir anomaly resulted from bioturbation smearing an initially thin deposit.

THE POSSIBLE RELATIONSHIP OF THE BRITO-ARCTIC TERTIARY IGNEOUS PROVINCE (BATIP) TO THE CRETACEOUS TERMINAL EVENT

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Rocks of the BATIP and nearby older formations are amongst the most heavily sampled regions for paleomagnetic studies. Despite voluminous and widely scattered igneous activity, and radiometric ages spanning more than 10 million years, the igneous rocks of the province almost universally display reversed polarities, although frequent polarity reversals characterize early Tertiary times. Also, stratigraphic relationships within the igneous centers which do display mixed polarities indicate that activity in each center began during a reversed polarity epoch(1), suggesting that emplacement of the line of centers comprising the province was contemporaneous, as well as being short-lived (2). Thus, the apparent spread in radiometric ages, beginning at about 65 AE, would appear to result more from subsequent hydrothermal activity and/or later reheating, rather than reflecting the true temporal extent of igneous activity(3)

The proximity of at least the earliest stages of this igneous activity to the C-T boundary has led to the suggestion that these voluminous volcanic eruptions may have contributed to the terminal Cretaceous extinctions, through contamination of sea water by toxic doses of volcanogenic trace metals (4). However, the global distribution of excessive quantities of trace metals at the C-T boundary has more recently been attributed to an extraterrestrial source (5). Now, a survey of paleomagnetic results from pre-Tertiary country rock in regions bordering the BATIP has revealed that these rocks also often display the southern, shallowly inclined, reversed directions characteristic of many igneous rocks in the province, even though these older samples are often far removed from sites of Tertiary activity. Furthermore, the degree of resetting in this common direction appears to be a function of both the coercivity of the country rocks (6,7) and their proximity to two complementary arcuate features, one composed of the eastern shores of the Outer Hebredes, and centered on the igneous complex of Skye, and the other consisting of the western shores of the Orkneys and the northern coast of Scotland, centered on the small islands of Skule Skerry and Stack Skerry. As both experimental (8) and field studies (9) have shown that the acquisition of shock remanence is related to coercivity of the target rock and its proximity to the point of impact, it seems reasonable to suggest that the reversed remanence displayed by the country rock may be of impact origin, and that the two arcuate features represent the remnants of contemporaneous craters, or, a single complex crater now bisected by transcurrent faulting, and emplaced during the Gubbio G- Polarity Chron. The other igneous centers could then represent the impact points of smaller associated bodies of a fragmented asteroid or comet, or their rapid emplacement could have followed wide-scale fracturing of the crust (10).

A final intriguing aspect of the province's C-T connection is the presence within early Tertiary volcanic rock of large masses of nickel-iron and cohenite on Disko Island, West Greenland (11), which is the westernmost BATIP center. Although this occurence is now commonly held to be of chemical origin, strong arguments have been presented against this conventional interpretation (12).

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THERMOLUMINESCENCE OF SHOCKED ROCKS FROM METEOR CRATER, ARIZONA, S. R. Sutton, McDonnell Center for Space Sciences, Washington University, St. Louis, MO 63130.

Preliminary thermoluminescence (TL) measurements on shocked Coconino sandstone and Kaibab sandy dolomite from Meteor Crater, Arizona, indicate that these materials are promising candidates for TL dating. The TL of quartz from a sample is used to determine the total radiation dose experienced since impact heating. The dose-rate received by the quartz is determined independently from radioactivity analyses of the sample and its environment and the age is calculated by dividing the dose by the dose-rate. The heat generated by the impact has been sufficient to reset the TL clock in these samples and TL growth with laboratory dose is close to linear.

A major complication is accurately determining the dose-rate received by the quartz from the heterogeneously-distributed, low level radioactivity in these shocked sedimentary rocks. Work is in progress to evaluate the dose-rate by computer-scanning maps of the radioactivity distributions.

The sandy dolomite appears to be the most promising for accurately dating the event since it contains the highest concentration of radioactive elements. The Coconino sandstone radioactivity is sufficiently low that the dose-rate to near surface samples (such as ejecta) will be largely due to cosmic ray ionization. As a result, the TL of such specimens may eventually provide a measure of the cosmic radiation intensity at the surface averaged over the age of the impact.

Other TL properties, such as sensitivity and emission spectrum, are under investigation with the goal of obtaining semiquantitative determinations of shock "grade".

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SHOCK-INDUCED DEHYDRATION AND IMPLICATIONS FOR CARBONACEOUS METEORITES

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Hydrous minerals comprise a major phase in matrix material of carbonaceous chondrites (1,2,3,4). The most common water bearing phases include Mg-rich and Fe-rich phyllosilicates (3, 4) and mixed layer structures of serpentine- and brucity-like material (5). These phases are often poorly crystallized or amorphous (PCP) and are characterized by spongelike or fernlike structures (1,3,4). Barber (3) concludes that the existence of and close association of PCP and serpentine minerals in carbonaceous matrix material is beyond proper interpretation at present.

We report shock recovery experiments on antigorite serpentine ($Mg_3\ Si_2\ O_5\ (OH)_2$) and brucite ($Mg\ (OH)_2$) in the pressure range between 15 to 60 GPa (6). The major goals of this study are to (i) identify possible similarities between morphologies observed in shocked hydrous minerals and matrix phases of carbonaceous meteorites which might explain some of the observed features in PCP and (ii) establish relations between the amount of shock-induced water loss and shock pressure which may serve as a measure for the degree of shock suffered by carbonaceous matrix phases.

Fig. 1 gives the amount of shock-induced water loss as a function of shock pressure in antigorite and brucite. Shock pressures required for a given amount of dehydration decrease with increasing porosity of the shocked material (Fig. 1; 7). A major morphological feature in shock-loaded antigorite is the presence of vesicles as observed in SEM analysis. Vesiculation is structurally controlled (grain boundaries, fractures) but becomes more and more independent of crystal structure with increasing shock pressure. The presence of vesicles and their morphology suggests that they represent the major path for circulating H_2O vapor.

We conclude that the morphology of shocked hydrous minerals resembles features seen in PCP and might be indicative of shock experienced by the matrix materials of carbonaceous meteorites. The amount of structural (post-shock?) water in hydrous phases of carbonaceous matrix material may yield a direct estimate of the degree of shock loading experienced during the history of this material.

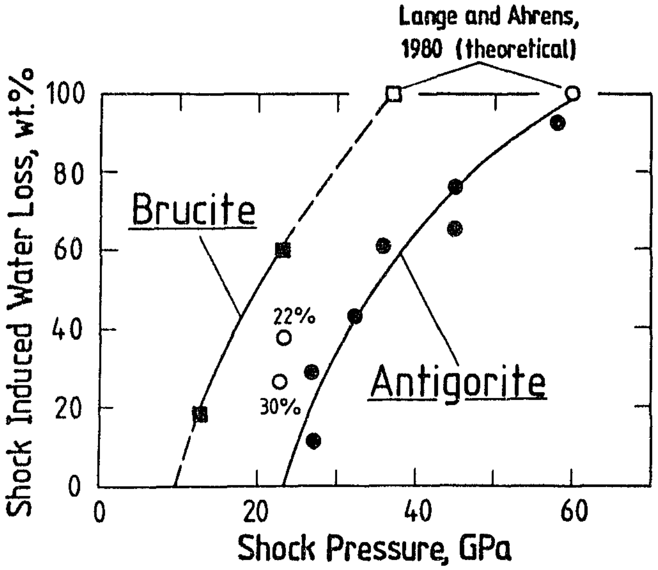

Figure 1: Shock-induced water loss in antigorite and brucite as a function of shock pressure in present experiments. Numbers on open symbols indicate initial porosities of shocked samples.

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SHOCK EXPERIMENTS IN PYROXENES, AND SOME OF THEIR ALTERATION PRODUCTS.

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Both pyroxenes and shock are important in meteorite but there is little observational data on experimentally shock loaded pyroxenes. Therefore experiments have been carried out with the 20 mm flat plate accelerator at NASA JSC using the impedance match technique and multiple shock reverberations. Materials are Bamble orthopyroxene and Stillwater gabbroic anorthosite. Bamble samples are 90-95% single crystal of bronzite ($\sim$En$_{86}$), 10-5% alteration products including various fibrous ortho and clinoamphiboles, talc, Ca-Mg carbonates and traces of muscorite plus minor amounts of magnetite. Stillwater samples are $\sim$50% anorthite (An$_{85}$), $\sim$50% pyroxenes, essentially augite and bronzite, plus minor amounts of other pyroxenes found as exsolution. Achieved pressures are 19.6, 30.2, 39.3, 48.3, 50.3, 55,5, 59.6, 65.6, 71.7 and 78.8 GPa for the Bamble series, and 18.4, 28, 34.8, 40.8, 45, 50.8, 55.5, 61, 63 and 71 GPa for the Stillwater series.

From optical microscope and SEM observations, microreflectivity measurement, microprobe and X-ray energy dispersive analysis (EDAX) of the recovered samples it is concluded:

A. Pyroxenes (1) There is no significant difference in behavior and characteristics for Opx and Cpx; (2) they retain essentially that crystalline state, even those shocked in the upper pressure range; (3) there are no change of refractive indices; (4) in all shots, pyroxenes are strongly fractured. Therefore the apparent density of fracture does not significantly vary with increasing pressure. A slight decrease of apparent fracture and dislocation densities above $\sim$70 GPa might result from annealing. (5) The correlation between the development of a mosaic texture and increasing pressure is weak: it can only be noticed that strong mosaicism is developed in the range 30 GPa and up; (6) locally highly disordered to brecciated zones occur, but not systematically, above 30 GPa; (7) blackening along fractures, at grain boundaries, and in the dislocation zones is the only characteristics which consistently shows a tendency to increase with increasing pressure. It appears above $\sim$25 GPa and is complete above 55 GPa. As deduced from SEM observation blackening is strongly related to melting, including both local melting and melting plus injection processes. Under SEM there is a distinction between (a) vesicular, (b) poorly vesicular homogeneous phases in which the pyroxene steochiometry is apparently maintained. Vesicles are submicron in size; (c) highly vesicular phases with high Al and high Ca, Fe, Mg; (d) vesicle-free phases containing metallic spheres, and conversely silicate spheres in metallic matrix representing injected demixed melt of the silicate and the container; (e) exceptionally, vesicle free glass splashes of apparent homogeneous and mixed composition pyroxene + stainless steel.

B. Fibrous Phases (talc and amphiboles), (1) very few changes are characteristic under $\sim$50 GPa; (2) deformation features (fracture, bending or kinking) are poorly represented over the entire pressure range; (3) progressive blackening occurs along the fibers, at the boundaries with the pyroxene, and along the few fractures in the range 50-70 GPa; (4) Above 70 GPa fibrous minerals are completely opaque. As deduced from SEM observation, blackening is associated with incongruent melting. Under SEM there is a distinction between talc phases in which small and even spherical vesicles are scattered in a patchy mass, and amphiboles in which vesicles are irregular in shape and in dimension, and where patchy phases, vugs and crystalline phases are present. A highly vesicular phase of apparently homogeneous composition has been observed in association with a partially transformed orthoamphibole (48 GPa shot). It may represent an unusual case of congruent melting of the amphibole.

ORDERED FeNi, TETRATAENITE AND SHOCK EFFECTS IN CHONDRITES

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The FeNi ordered phase with superstructure L1o(tetrataenite) has been identified in metal particles of chondrites (1,2). The detection of this ordered phase by Mössbauer spectroscopy is based on the fact that the superstructure exhibits an asymetrical spectrum due to a quadrupole splitting arising from a non-cubic environment of the Fe atoms in this Fe-Ni alloys.

Distinct values for the quadrupole splitting (ΔE) have been observed,changing from 0.25mm/s for the Fe-Ni alloy with high degree of ordering to ~ 0 for the disordered alloy. The hyperfine field (H_i) and the width of absorption lines (Γ) tend to increase with increasing disordering of the alloy. Similar results have been obtained with iron meteorites and attributed to different cooling rates below 320C (3).

Shock effects can modify the degree of ordering of tetrataenite. In a detailed study by Mössbauer spectroscopy of the metal particles extracted from about 20 chondrites we observed a correlation between the distinct values of the hyperfine parameters and shock history of chondrites.

On the basis of the values of the quadrupole splitting we classify the chondrites in 3 distinct groups.

The chondrites Tieschitz,Bjurböle,Appley Bridge,Allegan,Soko Banja,S.Sévérin,Olivenza,present the value of ΔE in the range 0.25 to 0.19mm/s (± 0.02),no evidence for shock or reheating is reported; the average value for the H_i is 291kOe and Γ=0.38mm/s. The ordered phase is in a high degree of order in the metal particles.

Chondrites moderately shocked or with some evidence for reheating such as: L'Aigle,Dhurmsala,Parnallee,Parambu,Lake Labyrinth present the ΔE in the range 0.16 to 0.12mm/s. The H_i=295kOe and Γ =0.45mm/s.

Strongly reheated chondrites and with severe shock evidence such as: Ergheo,Paragould black,Paragould gray,Knyahinya, Peetz,Shaw,the value of ΔE is practically zero or no evidenat all for the presence of tetrataenite is observed,such as in Paragould (black and gray phases) or in Knyahinya.The H_i=307kOe and Γ=0.48mm/s.

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ELEMENTAL FRACTIONATIONS AMONG CV CHONDRITES

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The CV chondrites have been the subject of intense study over the past ten years, but mostly concerning their large refractory-rich inclusions. They are one of the most petrographically diverse chondrite groups, containing a wide range of chondrules (0.5-2 mm), amoeboid and Ca,Al-rich inclusions (sometimes >1 cm) and opaque minerals (metal, sulfides, magnetite) mixed with greatly varying amounts of matrix materials (20-50%). Members span petrologic types 3-5, and several are breccias. McSween (1) divided the CV chondrites into two petrographic subgroups: 'reduced' and 'oxidized'. The 'reduced' subgroup has high contents of metal and chondrules and Ni-poor sulfides, while the 'oxidized' subgroup has greater amounts of magnetite, fewer chondrules and Ni-rich sulfides.

Our ongoing study of the carbonaceous chondrites by INAA and RNAA includes nine CV group members. The data suggets a compositional basis for the two CV subgroups. The 'reduced' subgroup members appear to have very low Cd contents (35-60 ng/g) compared to 'oxidized' subgroup members (250-450 ng/g). Some chondrites from both subgroups show anomalous compositions. Coolidge (CV4) has moderately volatile element abundances 10-40% lower than normal CV values. Kaba appears to be relatively rich in volatile siderophiles, but poor in refractory siderophiles. Replicate analyses of Grosnaja show it to be very heterogeneous for many elements, though the overall averages are often close to normal CV values. Several of the group members studied (Arch, Coolidge, Leoville, Yamato 69003) show variable depletions in Na, K and Ca, probably reflecting weathering effects. Despite such deviations from normality and their diverse petrographic character, the CV chondrites seem remarkbly well-defined compositionally, especially for the refractory and common lithophiles.

The CV chondrites form a separate clan from the other carbonaceous chondrite groups based on refractory lithophile abundances (2,3). This probably means they formed in their own region of the solar nebula at a unique heliocentric distance. The major formation mechanisms which shaped the petrographic features of the two CV chondrite subgroups were likely nebular in origin and probably affected the sharp Cd fractionation. Compositional deviations by individual CV chondrites probably resulted from local perturbations of those mechanisms.

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CHEMICAL FRACTIONATIONS IN ENSTATITE CHONDRITES

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Larimer (1) suggested that enstatite chondrites formed at high C/O ratios. Certain similarities between abundant modal minerals in E chondrites and major element condensates at high C/O ratios support this suggestion. Does a more detailed comparison of the major and trace element chemistry also support this interpretation? Can the trace element chemistry as a function of C/O ratio help constrain the formation conditions of the E chondrites?

Chemical equilibrium calculations for major and trace elements at C/O ratios > 0.6 (solar) are being done to try to answer these questions. We report preliminary results of this work at C/O = 1.2 and P = 10^{-3} bars. So far, 83 compounds of the elements Ta, Nb, Zr, V, W, Hf, Ba, and Sr plus several hundred compounds of the elements H, C, O, N, Mg, Si, Fe, S, P, Al, Ca, Ti, F, Cl, and Na have been studied.

Carbides. The elements Ti, Zr, Hf, V, Nb, Ta, W, and Si first condense as carbides. Condensation of pure phases was calculated, but several of the elements (Ta, Nb, W, and Zr) may form carbide solid solutions with each other. Graphite is also stable over a wide P-T range. The unusual shape of the graphite stability field is illustrated in the figure. The initial Ti-bearing condensate is dependent on the C/O ratio. Perovskite ($CaTiO_3$) is the initial condensate up to C/O ≈ 0.96. Osbornite (TiN) is the initial Ti condensate from C/O ≈ 0.96 to 0.99. TiC is the initial Ti condensate at C/O ≥ 0.99. If the condensation behavior of trace elements is as sensitive to the C/O ratio, then their distributions in enstatite chondrites may be potential indicators of the C/O ratio under which these meteorites formed.

Nitrides and Nitrogen. Larimer (1) suggested that Ti, Zr, and Hf first condense as nitrides. However, we find that they first condense as carbides. In only two of the cases studied do the nitrides subsequently form at much lower temperatures. TiN and VN form at 1021 K and ≈ 779 K, respectively. Because reactions between N_2 and carbides are probably very slow, they may not occur to an appreciable extent. Al first condenses as the nitride $Al_4N_4O_2Si$ (15R-sialon) at 1437 K. Si_2N_2O (sinoite) may form at 1142 K and Mg_2SiO_4 may form at 1146 K. The mineral which actually forms first cannot be determined due to the combined uncertainties in the thermodynamic data for the two compounds. If Mg_2SiO_4 forms first, then sinoite will not form. Also, reactions between SiC and nebular gases that form either mineral may be kinetically unfavorable. N_2 solubility in Fe_3C or in a Fe-Ni-C melt, which are the initial Fe condensates (depending on the pressure), is less than that in pure Fe metal.

Sulfides. Condensation of Mg, Ca, Sr, and Ba has been studied. All four elements initially condense as sulfides. The condensation temperatures of pure MgS, CaS, SrS, and BaS are 1075 K, 1313 K, 1148 K, and 1149 K, respectively. SrS and BaS probably condense in solution in CaS rather than condensing as pure phases.

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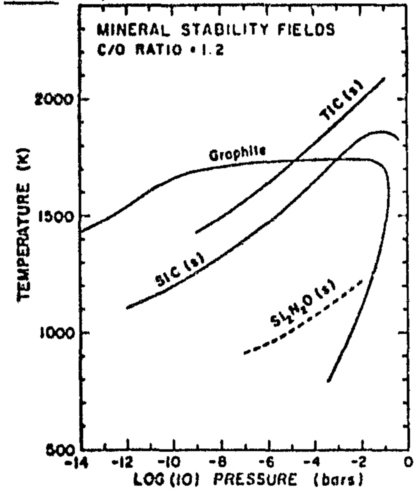
Trace Element Condensation
10^{-3} Bars, C/O Ratio = 1.2

Mineral	Temperature (K) Condense	Disappear
TaC	2097	≈ 825
$NbC_{0.98}$	2094	≈ 735
WC	2085	
ZrC	2074	1159
HfC	1996	1150
$VC_{0.88}$	1697	≈ 779
ZrO_2	1159	
HfO_2	1150	
BaS	≈ 1149	
SrS	≈ 1148	
Ta_2O_5	≈ 825	
VN	≈ 779	
NbO_2*	≈ 735	

*Nb_2O_5 can form at essentially the same temperature.



RELICT GRAINS IN ENSTATITE CHONDRITES

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We have initiated a study of textures and mineral compositions in chondrules from the E4 chondrite Qingzhen [1,2]. Some chondrules in Qingzhen consist of large, unzoned ($\simeq$ .4% FeO) enstatite laths that are elongated parallel to the chondrule surface and contain round inclusions of forsterite, zoned with FeO decreasing from core to edge of the grains. These forsterites have FeO/(FeO+MgO) ratios consistently lower than the host enstatites. Forsterite also occurs as euhedral grains similar in zoning and composition to those included in enstatite and surrounded by a cryptocrystalline material rich in Al, Ca and Na.

In highly unequilibrated ordinary chondrites, chondrules with similar textures are more oxidized and the olivines have FeO/(FeO+MgO) ratios consistently higher than the coexisting enstatites and increasing from core to edge of the grains [3]. Two of these chondrules in Qingzhen contain olivine grains that have corroded outlines, dusty Fe-rich cores and clear Fe-poor rims. These dusty olivines appear to be relict grains that were only incompletely melted during the chondrule formation process and are similar to the dusty olivines in chondrules of highly unequilibrated ordinary chondrites. The dusty inclusions consist of Fe-rich (Fe $\gg$ 98%) metal.

If the dusty metal inclusions were produced by reduction of the fayalitic component of the olivine, the occurrence of these grains inside chondrules of E4 chondrites seems to imply that the chondrule precursor material was initially more oxidized and that the reduction process occurred at a later stage, possibly during chondrule formation.

These results pose significant constraints on the models of formation of enstatite chondrites.

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RARE EARTH AND TRACE ELEMENT DATA FOR SIX ENSTATITE METEORITES

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Rare earth and trace element data has been collected for three E6 chondrites, Blithfield, Khairpur and Pillistfer (Fig. 1) and three enstatite achondrites, Khor Temiki, Mayo Belwa and Pena Blanca Spring (Fig. 2). Data for Bishopville and Norton County was reported earlier, (1). Except for Pena Blanca Spring and Pillistfer the normalized rare earth patterns tend to be flat, and with the exception of Norton County, exhibit positive Eu anomalies. The Pena Blanca Spring and Pillistfer rare earth patterns are interesting in that they both show a positive slope with depleted light rare earths. Norton County is the only enstatite meteorite to show a negative Eu anomaly, but this is shown in five separate samples of the meteorite and agrees with previous reports (2). The enstatite achondrites show more spread than the E6 chondrites.

The enstatite achondrites exhibit REE levels similar to the E4 chondrites which show flat patterns slightly depleted relative to chondrites (3). The E6 chondrites are enriched relative to the E4 chondrites. If all the enstatite meteorites are related, as is usually assumed because of their major similarities in chemistry and mineralogy, the existence of the Eu anomaly and the changes in the abundance of the REE in the E6 chondrites and the enstatite achondrites imply these meteorites have undergone further evolution relative to the E4 chondrites.

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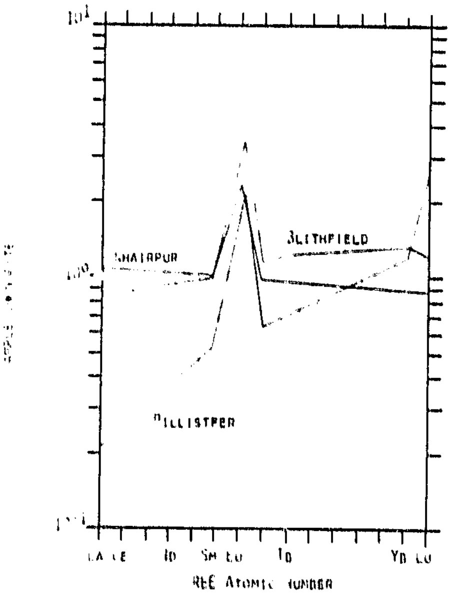

Fig 1. REE plots for the enstatite chondrites.

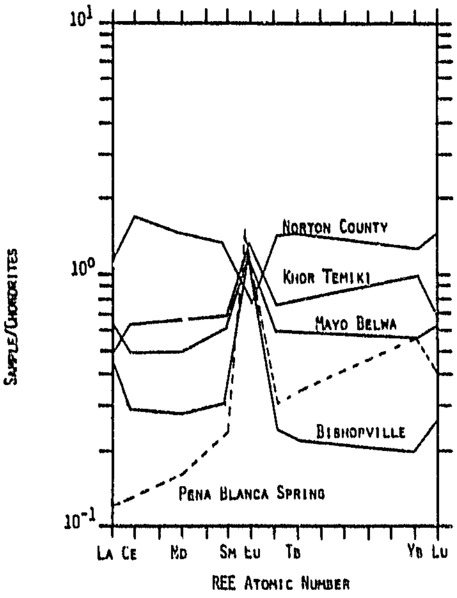

Fig 2. REE plots for the enstatite achondrites.

TRACE ELEMENTS IN FORSTERITE CHONDRITES AND METEORITES OF SIMILAR REDOX STATE, R. M. Verkouteren and M. E. Lipschutz, Dept. of Chemistry, Purdue Univ., W. Lafayette, IN 47907.

From a systematic mineralogic/petrologic study of 9 inclusions in the Cumberland Falls aubrite, Neal and Lipschutz (1981) reported that these inclusions constitute a new primitive chondritic suite, 8 being of petrologic type 3 and 1 of even lower type. Mineral compositions in these inclusions vary systematically and Neal *et al*. (1981) denoted these as *forsterite (F) chondrites* - a term used earlier by Graham *et al*. (1977) for 4 other meteorites - which, however, have different oxygen isotopic compositions (Clayton and Mayeda, 1978a,b). Neal *et al*. (1981) concluded that forsterite chondrites acquired their chemical characteristics during nebular condensation and accretion into a parent object which later collided with the enstatite meteorite parent body, being then shocked and mixed.

Here, we report data for 16 trace elements (mainly volatile/mobile ones)- Ag, As, Au, Bi, Cd, Co, Cs, Ga, In, Rb, Sb, Se, Te, Tl, U and Zn - in: 9 forsterite chondrite samples studied by Neal *et al*. (1981) and others; Kakangari and Pontlyfni (putative forsterite chondrites of Graham *et al*., 1977); Acapulco and ALH A77081 (with similar redox state); a chondritic inclusion from the aubrite ALH A78113.

Relative to other chondritic groups, trace element contents of F chondrites are unusually coherent-with only Bi, Cd, In and Tl varying in ≥10x - and distinct. Few elements in F chondrites vary with Fs content of low-Ca pyroxene or with the ferromagnesian silicate disequilibrium parameter. Five elements (Cd, Rb, Sb, Se and U) are present in F chondrites at ordinary chondrite levels; siderophiles and chalcophiles are generally lower and Cs, Rb and Te are higher than in other type 3 chondrites. The composition of F chondrites differs markedly from those of other populations considered, indicating ≥ 2 parent populations of similar redox state. Chemically, chondritic inclusions in Cumberland Falls and ALH A78113 differ; mineralogic information should shed further information on the latter.

The trace element data are consistent with the idea that F chondrites are a unique primitive chondritic group, little - if at all - affected compositionally by the considerable shock generated during the collision between their parent body and that of enstatite meteorites. Thus, F chondrites deserve additional study to advance further our knowledge of nebular condensation and accretion conditions.

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OXYGEN ISOTOPES IN ORDINARY CHONDRITES: WHAT IS THE ORIGIN OF THE IRON GROUPS?

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It is difficult to reconcile two primary facts concerning the oxygen isotopic abundances in ordinary chondrites: (1) for bulk meteorites, there is a distinct difference in ^{16}O-content of H-chondrites, on the one hand, and L- and LL-chondrites, on the other; (2) for individual chondrules from unequilibrated ordinary chondrites (UOC) there is a much wider range of ^{16}O-contents, which shows no correlation with the iron group of the host meteorite. Resolution of this apparent discrepancy may provide information on the nature of the matrix of UOC, on the chemical interaction between matrix and chondrules and metal, and on the genetic relations between equilibrated and unequilibrated chondrites.

Analyses of five H4, eight H5, and six H6 meteorites gave a grand mean $\delta^{18}O = 4.05‰$, $\delta^{17}O = 2.84‰$, with no measurable difference from one petrographic grade to another. H3's, on the other hand, are mostly enriched in the heavier isotopes, along a mass-fractionation trend. Analyses of two L4, four L5, five L6, and one L7 meteorites gave a grand mean $\delta^{18}O = 4.57‰$, $\delta^{17}O = 3.50‰$. Two L4's (Bjurböle and Cynthiana), five L3's, and three LL3's are enriched in the heavier isotopes along a mass-fractionation line. Thus, in general, the bulk isotopic compositions of the "equilibrated" chondrites differ from those of the UOC of the same iron group, and hence can be derived from a UOC precursor by metamorphism only if the metamorphic processes were open to loss or gain of oxygen compounds. An attractive possibility is the loss of carbon monoxide by reaction of elemental carbon with Huss matrix leading to reduction of ferrous iron to metal.

Direct isotopic analysis of UOC matrix has been attempted, using the "holy smoke" samples of Rambaldi et al. (1981). Four samples (Weston 1-8 μm, Allegan 7-15 μm, Rupota 1-8 μm, and Hamlet 1-4 μm) have oxygen isotopic compositions indistinguishable from the bulk meteorite. Tieschitz (0.08-8 μm) is enriched in the heavier isotopes relative to the bulk meteorite. Several meteorites or clasts within meteorites, all containing graphite-magnetite matrix, have been provided by E. R. D. Scott. They are all depleted in the heavier isotopes, along mass-fractionation lines, relative to the corresponding equilibrated H or L compositions. Such a depletion is to be expected if the magnetite has undergone isotopic exchange with its host silicates.

The cause of the substantial differences in oxygen isotopic composition between H and L chondrites remains unknown. Although analyses of chondrules from UOC have shown that H-chondrules, L-chondrules, and LL-chondrules have been drawn from the same population, it is conceivable that the mean of the H-chondrules is significantly different from the mean of the L- and LL-chondrules. However, with the relatively wide range of isotopic composition within each iron group (on the order of 3‰ for both δ^{17}O and δ^{18}O), a much larger number of chondrule analyses than the 43 now available would be required to establish such a difference with statistical significance. With the data at hand, the mean composition of L-chondrules is similar to that of their parent L-3 meteorites, whereas the mean of H-chondrules (essentially the same as that of L-chondrules) may be ^{16}O-depleted relative to the parent H3's. Further study of H3 matrix is warranted as a likely determinant of the H-L distinction, both chemically and isotopically.

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EXTREME PU-U AND POSSIBLE PU-REE FRACTIONATION IN UNEQUILIBRATED CHONDRITES

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The purpose of this study is to understand actinide chemistry in chondrites and to evaluate unequilibrated chondrites for either Pu/U or Pu/Nd chronology. Using fission track radiography for Nadiabondi (H5) [1], Dhajala (H3,4), Sharps (H3), Bremervörde (H3), and Tieschitz (H3), we find that U is primarily located in chondrule glass (50-500ppb, average of ~100ppb). Apatite from the unequilibrated chondrites contains 150-200ppb U while whitlockite contains <17 ppb (low compared to type-6 chondrites which have 1-6 ppm U in apatite and ~200ppb in whitlockite [2]). Nadiabondi phosphates are intermediate [1]. These observations suggest that the phosphate U content increases with petrologic type [2], with U obtained from chondrule glass during metamorphism.

Etched thin sections of Bremervörde show very few tracks in olivines adjacent to glass or to any other phase. In one case, a conservative upper limit is 0.1ppb ^{244}Pu in glass at the time of olivine track retention. If Pu and U are entirely in glass, olivine is required to retain tracks ~200 my after chondrule formation. With no other evidence for an extensive high temperature history, it seems more reasonable to conclude that Pu/U in glass is depleted by a factor of ~10, possibly greater. Phosphate-olivine contacts are inconclusive because of loss of material during etching, but etched phosphates (1min., 0.25% HNO_3) give results consistent with Pu concentration in phosphates: In the SEM, Bremervörde whitlockites have random surface pits (6-10 x $10^7/cm^2$) which could be spallation recoil tracks, but given the relatively high densities, these are better interpreted as annealed ^{244}Pu fission tracks. If true, ^{244}Pu concentrations of ~10ppb are indicated, comparable to concentrations obtained by fission Xe on whitlockite from equilibrated chondrites [3]. The density of long tracks (>1μ) in replicas of a large whitlockite grain is ~5 x $10^6/cm^2$. Replicas from St. Severin whitlockite counted in the same way give 6 x $10^6/cm^2$, in agreement with literature ^{244}Pu track densities [e.g. 2]. The Bremervörde phosphate track results qualitatively indicate ^{244}Pu concentrations comparable to phosphates in equilibrated chondrites. Quantitative interpretation of track data in terms of Pu concentrations is difficult in all meteorites. Although complications remain, it appears that Pu is incorporated into chondritic phosphates early as they form and/or grow in size during metamorphism [1]; whereas U remains in glass during the early stage. This conclusion is definitely valid for Nadiabondi (20ppb Pu in whitlockite [1] and Pu/Nd = 1.8 x 10^{-4}, weight [4], identical to St. Severin.) Nd has followed Pu into the phosphates of Nadiabondi and St. Severin, but, possibly not for unequilibrated H-chondrites. Chondrules from unequilibrated chondrites generally show REE enrichment over C1 levels [e.g. 5]; however, many Richardton (H5) chondrules are depleted with positive Eu anomalies [6] which is a pattern complementary to phosphates from Richardton and type-6 chondrites [7]. This suggests REE migration from chondrule to phosphate during metamorphism [6]. Sm is correlated with Al in unequilibrated chondrules [5]; so the REE might be with U in glass. Alternatively, the REE carrier may be phosphates within chondrules; however, chondrules are depleted in metal and phosphates. Thus, REE and U in unequilibrated chondrites may be in glass with Pu in phosphates.

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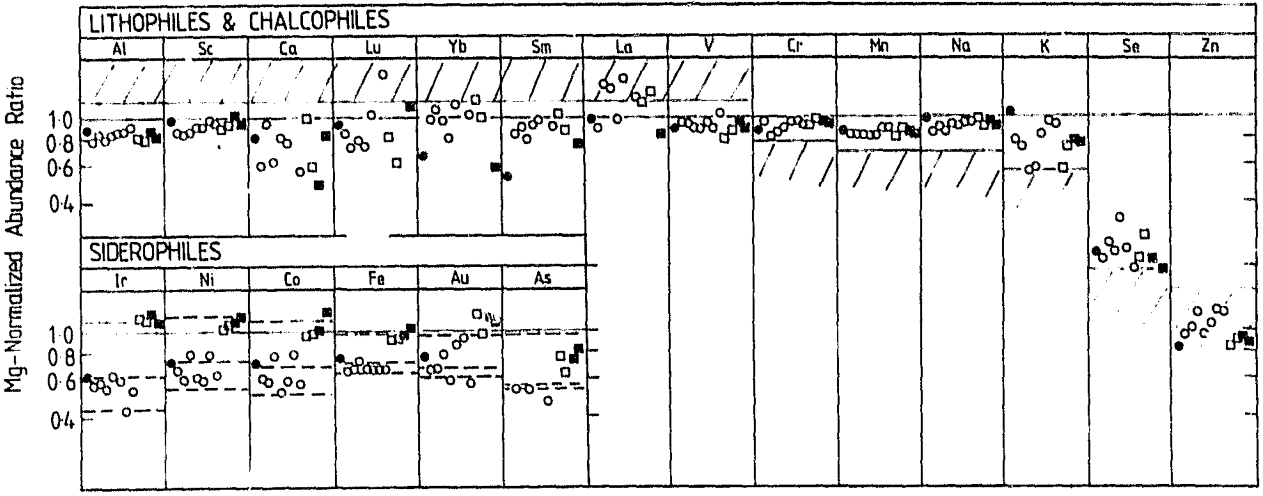
INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS OF TYPE THREE ORDINARY CHONDRITES. Derek W.G. Sears, Department of Chemistry, University of Arkansas, Fayetteville, Arkansas 72701, USA.

We have started a program to study the type 3 meteorites by complementary physical and chemical techniques. Here we report some preliminary INAA data on samples which have previously been studied by thermoluminescence. We analyzed six type 3 chondrites from Allan Hills (three of which may be paired), Yamato Y74191, Mezö Madaras and Quinyambie. BCR-1 and Allende standard rocks and three equilibrated Chinese chondrites were also included and they show good agreement with literature values. For all but Quinyambie, for which only one 40 mg sample was available, two 150 mg fragments were analyzed in separate irradiations.

The data are shown in the figure below. In the recent past, some carbonaceous chondrites have been misclassified as ordinary chondrites. Our lithophile element data clearly indicates that all of the present samples are ordinary chondrites. Elements more refractory than Cr have lower abundance ratios than the carbonaceous classes, while Cr and the more volatile elements are more abundant than in carbonaceous classes. Chalcophile Zn has similar abundances in both carbonaceous and ordinary chondrites, while Se has higher abundance in our samples than in the carbonaceous classes. All elements are in the ordinary chondrite range.

Our siderophile element data suggest that, contrary to Wlotzka and others (1, and references therein), it is meaningful to divide type 3 ordinary chondrites into the H and L classes. With the exception of Au, there is a hiatus in the siderophile element content of our samples which separates H from L chondrites. Our data also suggest that type 3 chondrites contain lower siderophiles than equilibrated members of the same class, a point discussed at length by Dodd (2,3). Investigating a possible relationship between siderophile elements and metamorphism will be an important aspect of future studies.

1. Wlotzka F. (1981) Meteoritics 16, 403-404.
2. Dodd R.T. (1976) Earth Planet. Sci. Lett. 28, 479-484.
3. Jarosewich E. and Dodd R.T. (1981) Meteoritics 16, 83-91.



Abundance data for (left to right) Junan, Allan Hills A77015, A77167, A77214, A77278, Mezö Madaras, Quinyambie, Yamato Y74191, Allan Hills A77299, A78084, Jilin and Xingxang (underlined may be paired). Circles - L chondrites, squares - H chondrites. Filled symbols - equilibrated, open symbols - type 3. Cross hatching - abundance range for carbonaceous classes. Horizontal broken lines - H (upper), L and LL (lower) group means.

COMPOSITIONAL STUDY OF 19 L AND LL CHONDRITES.

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Our precise instrumental neutron activation analysis (INAA) studies of the carbonaceous chondrite groups revealed several previously unresolved intergroup differences in elemental abundances. This is our first report of the application of these techniques to ordinary chondrites. Several authors have suggested that the largest group of chondrites, the L group, may be a composite. Other researchers have noted anomalously low siderophile contents in some chondrites assigned to the L group on the basis of olivine and pyroxene composition.

We studied 16 "L" and 3 "LL" chondrites by replicate INAA. All are observed falls except Barratta, a relatively unweathered find. Seven are recent falls from China. The remainder were chosen on the basis of literature reports showing one or more of the following characteristics: Na, K, Zn or siderophile contents outside the normal range for the group; extreme FeO/(FeO+MgO) ratios in the olivine and pyroxene; high friability; or extreme Pu contents.

To obtain petrographic controls we sawed single chips weighing ∿3 g into several 2-3 mm slices with a low-speed saw. Alternate slices were used for thin sections and for INAA. The surfaces of each sample were examined for evidence of heterogeneity. In the thin sections olivine compositions were determined by electron probe and metal and troilite concentrations by point counting.

Our preliminary data show few anomalies. One sample, Rugao, was highly enriched in metal and FeS, and is not representative of the whole rock. No Zn concentrations fall outside the range 35-58 μg/g; Bromine concentrations are $\leq$0.5 μg/g in all chondrites except the type 3 and 4 members Barratta (2.5), Bo Xian (0.8), Manych (1.4) and Tennasilm (1.1). The K concentration in one chondrite is outside the range 0.78-0.93 mg/g; Bo Xian contains 0.2 mg/g. No Na values are outside the range 6.7-7.9 mg/g. Pellas reported low Pu in Barwell, high Pu in Alfianello and Leedey; we find similar REE fractionation patterns in all samples, but slightly (∿20%) higher REE levels in Barwell.

We observe LL siderophile levels (Fe < 190 mg/g, Ni < 11 mg/g, Ir < 370 μg/g, Au < 140 μg/g) in the "L" chondrites Albareto, Knyahinya, Manych and Leedey, suggesting that their classification needs reconsideration. It appears that there is no hiatus in siderophile concentrations between the L and LL groups, and that a detailed petrographic-chemical study of chondrites near the L-LL interface is warranted. Other than the siderophile data there are no indications in our preliminary data set of a need to revise the classification of the L chondrites.

TRACE ELEMENTS IN CHONDRULE RIMS; L.L. Wilkening, D. Hill and W.V. Boynton, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721

As a follow-on to our previous studies of the petrography and major element composition of chondrule rims (Allen et al., G.C.A. 44, 1161, 1981) we have studied a suite of 20 elements in chondrule rims from Chainpur. The experimental procedure involves separating chondrules, irradiating them, abrading the surfaces of chondrules in four steps, counting abraded samples, and finally examining remaining segments of the chondrules in thin-section. As this is a very tedious process, only four chondrules provided useable data. Our data for the four abrasion steps show that the biggest change in abundance pattern takes place between the outermost (A) and next (B) samples (Fig. 1). Examination of chondrules during the experiment showed the rim to be substantially removed in the first step. In Fig. 2 are plotted rim/interior ratios for 13 elements in the four chondrules. Note that sample sizes were not known. Nevertheless, a pattern of enrichment in the rims of siderophiles and volatiles is evident. We will discuss implications of our results for hypotheses about the sources of volatiles in chondrites.

FIGURE 1

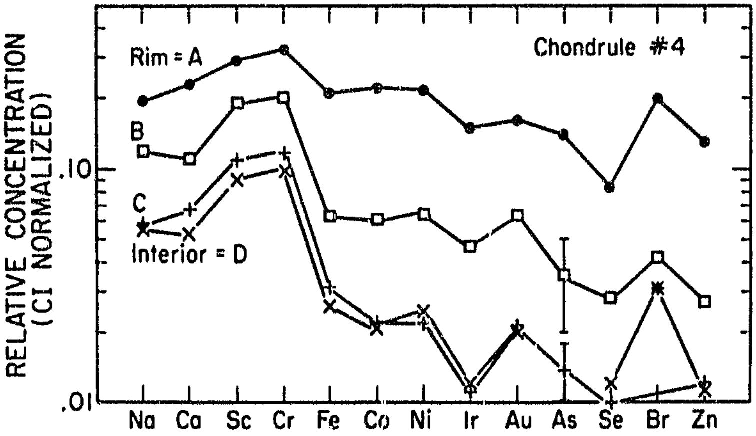
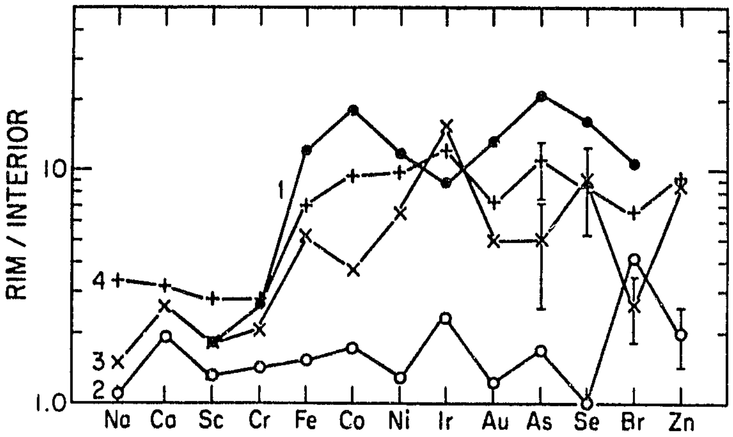


FIGURE 2



LOW-Ca PYROXENES AND THE THERMAL HISTORY OF UNSHOCKED L-GROUP CHONDRITES

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From a study of 10 H-group chondrites (1,2) it was concluded that they represent material which accreted at 700-900°C. Petrologic type was probably determined by cooling-rate; type 3 represents rapidly cooled material, type 6 slowly cooled material. The uniformly low (<0.5 wt.%) modal Ca contents of low-Ca pyroxenes throughout the petrologic sequence were probably determined by the crystallisation from chondrule liquids of large amounts of very low-Ca protopyroxene. Rapid cooling caused inversion to twinned monoclinic pyroxene, slow cooling to orthorhombic pyroxene, while an intermediate cooling rate produced 'striated' orthorpyroxene. It was noted (1) that higher modal Ca contents occurred in the pyroxenes of Beaver Creek (H4) and Ambapur Nagla (H5), both of which have been shocked and/or rapidly cooled.

Dodd (3) and Heyse (4) concluded that increasing Ca contents of low-Ca pyroxenes in the series L3-L6 and LL3-LL7 are indicative of equilibration at increasing temperatures. However, members of both groups are shocked or brecciated, and for comparison with H-group data it might be necessary to select unshocked L-group chondrites. Khohar was chosen as an unequilibrated L-group chondrite. Saratov (L4) is unbrecciated and has an Ar-Ar age close to 4.5 Ga (5); this is also true of Barwell (L5-6). Marion (Iowa) was chosen as an L-6 example with an old plateau Ar-Ar age (6). In a polished thin-section of each of the four chondrites some 40 low-Ca pyroxenes were analysed by microprobe. During each run orthopyroxenes of Kernouve (H6) were also analysed. Analyses were carried out along traverses which ensured that only one crystal per chondrule was selected.

The Ca content of Khohar pyroxene cores peaks between 0.0 and 0.5 wt%, with a minor peak near 2.0%. Saratov pyroxenes also peak between 0.0 and 0.5 wt% Ca. These data are consistent with Dodd's for L3 and L4 pyroxenes (3). Barwell pyroxenes have Ca contents which peak strongly between 0.5 and 0.75%, the minimum encountered being 0.44% (precision, $2\sigma = 0.06$ wt%Ca). Marion (Iowa) has not yet been analysed. Barwell low-Ca pyroxenes tend to be more calcic than those in Kernouve (H6).

Although comparison of data obtained by different 'probe techniques may not be strictly valid, it appears that Barwell (L5-6) pyroxenes are more calcic than in most L5's and L6's (3). Barwell is unshocked and so the higher Ca in its low-Ca pyroxenes cannot be due to shock-heating. Dodd's conclusion that Ca distribution between pyroxenes differs between H-group and L- and LL-group chondrites is apparently confirmed. Perhaps the higher Ca in Barwell pyroxenes compared to H-group results from the higher Fe in the L-group mineral coupled with slower cooling, as shown by Hewins et al.(7) in an experimental study of Manych chondrules.

(1) Hutchison, R., et al. (1980) Nature 287, p. 787-790. (2) Hutchison, R., et al. (1981) Proc. R. Soc. Lond. A 374, p. 159-178. (3) Dodd, R.T. (1969) G.C.A. 33, p. 161-203. (4) Heyse, J.V. (1978) E.P.S.L. 40, p. 365-381. (5) Turner, G., et al. (1978) Proc. Lunar Planet. Sci. Conf. 9th, p. 909-1025 (6) Turner, G. (1969) in Millman, Ed., Meteorite Research, Dordrecht, p.407-417. (7) Hewins, R.H., et al. (1981) Proc. Lunar Planet. Sci. Conf. 12B, p. 1123-1133.

II-12

NI-RICH TAENITE IN EXTENSIVELY RECRYSTALLIZED YAMATO LL CHONDRITES

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Many LL chondrites have been known to show brecciated textures and contain various types of clasts, including well recrystallized clasts such as those observed in Yamato-74160 (1). Yamato-74160 has been classified as an LL7 chondrite because of its coarse crystalline texture and compositions of silicate minerals. Metal in this chondrite is very rich in nickel and the Ni/Fe ratio is nearly 1:1; the metal is possibly tetrataenite, which is an ordered FeNi (2). In the present study, nickel-iron minerals in some Yamato LL chondrites have been systematically studied in order to examine the correlation of the occurrence and composition of Ni-rich taenite with the mineralogical textures.

Yamato-790256 is an LL6 chondrite and weighs 381 gms. A polished thin section shows relatively well recrystallized texture with poorly defined chondrules. Microprobe analyses show olivine (Fa$_{30}$) and pyroxene (Fs$_{24}$) of uniform composition. Metal is commonly rich in nickel (Fe 59-65, Ni 34-38, Co 1-2 wt%), though kamacite grains associated with the nickel rich metal were also observed.

Yamato-791067 (235 gms in weight) is composed of subangular clasts, some of which show coarse-grained crystalline textures. The thin section for this specimen indicates extensive recrystallization; chondritic textures are absent. Olivine (Fa$_{31}$) and pyroxene (Fs$_{24}$) are of uniform composition, while plagioclase (An$_{10-11}$) is rarely found. Metal grains are sparse and small, most of which are 10 to 20 microns across. Microprobe analyses show all the metal grains are very rich in nickel (Fe 45-49, Ni 49-53, Co 1.5-2.5 wt%); no kamacite grains were found in the thin section examined.

Coarse-grained crystalline portions in Yamato-74160 chondrite contain only a small amount of metal (Fe 50, Ni 47, Co 2 wt%). The thin section shows that irregular interstices between olivine or pyroxene are filled with plagioclase, into which euhedral crystals of pyroxene or olivine have grown. The plagioclase is of variable composition from one interstice to another, while the cmposition within each interstice is nearly uniform. These textural and compositional features of silicates imply that at least a portion of the meteorite has been molten. This meteorite has textural similarities to Yamato-791067.

Taenite and kamacite coexist in Yamato-790256 LL6 chondrite which is well recrystallized but still preserves a faint chondritic texture. On the other hand, extensively recrystallized LL chondrites (Yamato-791067 and Yamato-74160) contain only nickel-rich taenite, suggesting that the composition of the metal phase has converged in some way to the point that the Ni/Fe ratio is 1:1. Based on the occurrence and composition of the metal and the extensively recrystallized textures of these chondrites, it is presumed that the LL chondrites have experienced such a high temperature that their original chondritic material was once partially molten. As the chondritic material was then cooled down, Fe in metal phase tended to migrate into silicates, resulting in relative enrichment of Ni in the metal phase. When the Ni/Fe ratio became 1:1, it seems that no more relative concentration of Ni occurred in the metal phase.

(1) Takeda, H., Duke, M.B., Ishii, T., Haramura, H. and Yanai, K. (1979) Mem. Natl Inst. Polar Res., Spec. Issue, 15, p.54-73.
(2) Clarke, R.S.,Jr. and Scott, E.R.D. (1980) Am. Mineral., 65, p.624-630.

THE COOLING OF SHAW (L7) AND ITS Ar-Ar AGES; E.K. Jessberger, Max-Planck-Institut f. Kernphysik, P.O. Box 103980, Heidelberg, F.R. Germany.

The petrographic typification of chondrites suggests to some to be the natural product of an onion-shell structure of the parent body: low metamorphic type chondrites from near-surface regions, high metamorphic type chondrites from the deep interior. The L7-chondrite Shaw, recrystallized at 1300°C (Onuma et al.,1972) and apparently slowly cooled between 300°C and 30°C (Pellas and Storzer,1979), then represents one of the key interior samples from a chondritic parent body. Others, however, regard Shaw as a breccia composed of dark unmelted and light impact-melted material and interpret the slow (fission-track derived) cooling rate as being due to a mild and short reheating ∿250 Ma after the formation of the breccia (Taylor et al.,1979). The later publication initiated the third ^{40}Ar-^{39}Ar study of that meteorite differing from the former (Turner et al.,1978; Flohs et al.,1979) in that now the dark and light portions were dated separately.

Feldspar in both samples, indicated by the plateau K/Ca ratio and comprising 50-60% of ^{39}Ar, have identical plateaux at 4.42±.01 AE followed by ^{39}Ar-recoil reduced ages. The spectrum of the dark portion recovers to yield 3.39±.02 AE (1330°C, 1420°C; 30% of ^{39}Ar), the time of the last total degassing of Shaw in a high temperature event. Notably different are the ^{39}Ar-diffusion characteristics of the two materials. Accepting for both the cooling parameter $\beta=(1/t)\ \ln(T/T_o)= -4\cdot10^{-3}\ \mathrm{Ma}^{-1}$ inferred from Pellas et al. (1978) and assuming that the diffusion properties measured in the laboratory between 450°C and 920°C from irradiated samples can be extrapolated to 130°C, the feldspar ages should differ by 40 Ma which readily could be resolved by the experiment, but what is not observed. If the high temperature age of the dark material has been frozen in at 650°C, the light feldspars should be ≈200 Ma younger than 4.4 AE which is not the case. Consequently, the Ar-Ar ages measured appear not to be compatible with the slow cooling for this meteorite. A late mild temperature spike (500°C for 1d) results in a loss of radiogenic Ar to be measured of only 2%, compatible with the data.

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COMPACTION OF CHONDRITES

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Magnetic anisotropy and porosity of various chondrites were measured. Magnetic anisotropies of C chondrites whose main magnetic mineral is magnetic, are much smaller than those of O and E chondrites which contain kamacite, suggesting that large anisotropies of E and O chondrites are mainly due to elongated kamacite grains. Magnetic anisotropy and porosity are negatively correlated among each (E, H and L+LL) class of chondrites. For chondrites with similar porosities, the anisotropies for E and H chondrites are smaller than those for L and LL chondrites. Anisotropy and porosity do not strongly depend on the metamorphic grade of chondrites. It seems that strong anisotropy and compaction of chondrites were mainly imposed by impacts.

STATISTICAL TREATMENT OF CLASSIFICATION IN YAMATO-75 CHONDRITIC METEORITES

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Statistical analysis of petrologic subdivision was applied to the Yamato-75 chondritic meteorites which were tentatively classified by Miura and Matsumoto (1981, 1982).[1,2] This is because there are ambiguous descriptions in Van Schmus and Wood (1967)'s classification, especially between type 4 to 6,[3] and because it can be discuss how many chondritic meteorites Yamato-75108 to -75257 are possibly related to broken fragments of one single original meteorite.

The results of statistical analyses of the six essential items to determine the petrologic type, homogeneity of olivine and orthopyroxene (opx), and class and type are shown in Table 1.

It is found that there are two different ways of descriptions of petrologic type. One is type number having maximum value of percent of observations and measurements. The other is average type number, 4 (including 4 and 4-5) or 5 (including 5-4 and 5). It is advisable for petrologic type to be described as the following; that is, type 5-4 or type 5(66.7%) in Yamato-75135,95 (see Table 1).

[1] Miura, Y. and Y. Matsumoto (1981), *Mem. Natl Polar Res., Spec. Issue*, 18, p.53-68.
[2] Miura, Y. and Y. Matsumoto (1982) *Proc. Antaertic meteorites 7th* (Tokyo), pp. 1-2.
[3] Van Schmus, W.R. and J.R. Wood (1967) *Geochim. Cosmochim. Acta*, 31, pp.747-765.

Table 1. Statistical analyses of six essential items to determine the petrologic type,homogeneity of olivine and pyroxene compositions,and type descriptions.

Sample No.	*Percent of obs. and meas.* 4		5		Type of Max. value	Average type (%)	%Fa* in olivine	%Fs** in opx	Class
	4	4-5	5-4	5					
Yamato-75119,91	33.3	33.4	-	33.3	4-5	4(66.7%)	21-24	18-27	L
-75124,91	16.6	16.6	16.8	50.0	5	5(66.8%)	23-25	19-22	L
-75125,91	16.6	50.0	16.8	16.6	4-5	4(66.6%)	22-26	18-21	L
-75126,91	33.3	50.0	16.7	-	4-5	4(83.3%)	23-26	19-23	L
-75128,92	50.0	33.3	16.7	-	4	4(83.3%)	24-27	20-23	L
-75133,93	50.0	16.7	33.3	-	4	4(66.7%)	24-28	21-25	LL
-75102,74	33.3	33.3	16.7	16.7	4-5	4(66.6%)	23-26	20-22	L
-75135,93	33.3	-	50.0	16.7	5-4	5(66.7%)	23-25	19-21	L
-75136,93	50.0	33.3	16.7	-	4	4(83.3%)	23-26	21-23	L
-75140,50	33.3	50.0	16.7	-	4-5	4(83.3%)	24-25	19-22	L
-75140,51	33.3	33.3	16.7	16.7	4-5	4(66.6%)	24-27	20-23	L
-75146,91	33.3	50.0	16.7	-	4-5	4(83.3%)	23-25	20-23	L
-75271,91	33.3	50.0	16.7	-	4-5	4(83.3%)	22-25	19-21	L

* *Olivine composition in mole percent* Fe_2SiO_4 *(Fa).*
** *Orthopyroxene composition in mole percent* $FeSiO_3$ *(Fs).*

WHAT HAVE IGNEOUS METEORITES TAUGHT US ABOUT PETROLOGY AND PLANETARY EVOLUTION?

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Studies of suites of basaltic meteorites have led to reconstructions of the igneous evolutions of their parent bodies and of the characteristics of the interiors of these bodies. Valuable because they provide insight into the evolution of bodies outside of the earth-moon system (extending back to the earliest history of the solar system and to bodies presumably much smaller than the earth and moon), these studies also permit generalization of some of the petrological concepts that have developed principally through investigations of terrestrial igneous rocks and their occurrences.

Eucritic meteorites, like the most abundant terrestrial and lunar basalts, are approximately saturated with olivine, pyroxene, and plagioclase at their 1 atm. liquidi. This suggests that this feature, and the igneous processing at low P that it indicates, can be expected among the dominant basalts of other bodies, large and small. For small bodies, all igneous processes take place at relatively low P; for large bodies, high P igneous processes are important, but most magmas that arrive at their surfaces evolve as they pass through the thermal and mechanical barriers imposed by crustal rocks.

Gravitational separation of crystals and liquids appears to be the dominant mechanism by which diversity develops in meteoritic, lunar, and terrestrial igneous rocks. The efficiency of this fractionation process is expected to be a function of planet size since it depends on the magnitude of $\vec{g}$. The rarity of primary magmas (those that are erupted or emplaced without having evolved since separating from their source regions) among terrestrial rocks contrasts with their apparent abundance and the relatively limited range of fractionation observed in the eucritic suite. This may be related to the fact that the magnitude of $\vec{g}$ on the parent body (or bodies) of the eucrites was much smaller than that on the earth. Although primary magmas are found on earth, they are rare and are probably rare on other large planet. Despite the small $\vec{g}$ on the parent body of the eucrites, melts were able to segregate from source regions and move toward the surface and cumulates did form; i.e., conventional igneous processes can occur on very small bodies. In addition, metal may have segregated downward from source regions in the parent body of the eucrites prior to the upward segregation of melt; no terrestrial, lunar, or meteoritic basalts appear to have been in equilibrium with metal when they left their source regions although all of these bodies probably contain free metal.

The diversity amongst eucritic and related meteorites and the complexity of the igneous processes by which they have evolved are restricted relative to those of terrestrial igneous rocks. This probably reflects the limited duration of igneous activity on their parent bodies and thus the limited opportunities for the development of heterogeneous source regions and for multistage evolutions, the volatile-poor source regions, and the limited range of pressures and tectonic environments of these bodies.

Young igneous meteorites have many features in common with igneous rocks found on earth and expected on other large bodies (e.g., young ages; complex, multistage evolutions; diversity; apparent efficiency of crystal-liquid fractionation; certain geochemical features). Speculation about their provenance, especially the possibility that they come from Mars, has aroused interest in these rare meteorites, but they also teach us something important about the earth: There is another body in the solar system that has produced basalts nearly indistinguishable petrologically and geochemically from terrestrial basalts. Explanations of how terrestrial basalts and their source regions have developed these characteristics must not rely on processes or conditions unique to the earth.

THE THREE AGES OF BRECCIATION.

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Impact brecciation is a fundamental planetary process. One can define three epochs of brecciation in solar system history that have profoundly affected planets, satellites and asteroids: accretion, bombardment, and post-bombardment. The record of these periods is preserved (usually cryptically) in lunar and meteoritic breccias.

Accretion: The assembly ∿ 4.5 Gyr ago of planetary bodies from submicron-sized dust to planetesimals 100 km in diameter involved a number of complex processes. One of these obviously was impact, though presumably most impacts occurred at low velocities. Meteorites almost certainly contain some evidence about the accretion process. Some type 3 chondrites, for example, are breccias that could have formed when km-sized planetesimals gathered to form larger bodies. There is also evidence that peak metamorphic temperatures in ordinary chondrites were attained in 10-km sized planetesimals which subsequently accreted to form 100-km sized (ordinary chondrite) parent bodies. Some chondrite breccias may have formed when the planetesimals crashed into the growing parent body. In a sense, then, chondrite parent bodies assembled as megabreccias. A similar story for forming mesosiderites has recently been suggested. Continued study of meteorite breccias will reveal the most likely candidates to be products of accretion; these samples contain direct information about planet formation.

Bombardment: The period between 4.5 and ∿ 3.9 Gyr ago was marked by an intense bombardment of the planets and other solid bodies in the solar system. Studies of lunar breccias demonstrate that the bombardment terminated around 3.9 Gyr and suggest that there was a dramatic pulse in the flux of impacting projectiles between ∿ 4.0 and 3.9 Gyr. These impacts significantly affected the planets. The upper few kilometers of the Moon was churned over, crushed, mixed and remelted in part, forming a megaregolith and also destroying much of the direct eividence about the early evolution of the lunar crust. Chondrite parent bodies (asteroids) were broken apart and reassembled, further brecciating them; a major challenge is to distinguish meteoritic breccias formed during this period from those found during accretion.

Post-bombardment: After the intense bombardment had ceased about 3.9 Gyr ago, the surfaces of airless bodies were pummeled by projectiles at much more modest rates. Depending on their size, strength, and location they developed on their surfaces varying amounts of solar-wind irradiated regolith. Meteoritic and lunar regolith breccias and samples of lunar regolith (especially cores) contain, in principle, the record of surface processes during the past 3.9 Gyr. The trick in extracting the record will be to date the time a specific sample was exposed on the surface.

A long-standing goal of breccia and regolith studies is to trace variations in the Sun's output. Research on lunar regolith samples suggests, for example, that the nitrogen isotopic composition of the solar wind has changed by ∿ 30% during the past ∿ 3 Gyr. The extent and time scales of solar variations are unknown, however. But by identifying solar-irradiated breccias that formed during each of the time periods discussed above, it may be possible to trace the Sun's evolution in considerable detail.

CONCENTRATION OF METEORITES BY ICE FLOW Ian M. Whillans, Dept. of Geology and Mineralogy, Inst. of Polar Studies, 125 S. Oval Mall, Ohio State Univ., Columbus, Ohio 43210

Relevant basic concepts in glaciology are reviewed. To a first approximation, glaciers flow according to their surface slope and thickness, and flow lines can be readily traced for a steady glacier (one whose thickness and velocity do not change with time). Second order effects lead to steps or undulations in the glacial surface. Very little is known about the meteorology of the Allan Hills and similar sites.

Limited data are available for the ice sheet near the Allan Hills. Rough mapping of the ice thickness has been completed by the NSF-SPRI-TUD radar sounding program (1), and snow accumulation rates have been measured at Dome C, 1000 km up-glacier from the Allan Hills (2). At the Allan Hills, ice velocity and ablation rates have been measured by Nishio and Annexstad (3).

Two groups have recently proposed models for the concentration of meteorites near the Allan Hills. Nishio and others (4) studied the metamorphic fabric of the ice, assumed that retrograde metamorphic effects could be ignored, and concluded that the maximum depth of burial for the ice was 500 m, and hence calculated the ice at the Allan Hills to be 20 000 years old. This is much younger than some terrestrial ages for the meteorites and they propose that the ice sheet has thinned dramatically. They also suggest that the meteorite influx has not been constant.

Whillans and Cassidy (5) started by assuming a steady glacier and a steady meteorite influx and calculated the age of the ice (up to 600 000 years) and the meteorite influx (60×10^{-6} kg m^{-2} a^{-1}, which is in approximate agreement with other estimates). They put more importance on retrograde metamorphism and argue that the pattern of air bubbles indicates that the ice traveled deeper than 1000 m.

If either model is at least partly true then the Allan Hills region is a find of major significance to glaciology. It would be possible to assess the past stability of this part of the ice sheet and to describe climatic changes for the past 20 000 or 600 000 years.

Once the models for the Allan Hills have been tested, criteria for meteorite concentration can be established that would help meteoriticists locate other such sites of concentration. At the Allan Hills it should be possible to derive accurate estimates of meteorite influx, perhaps according to type and perhaps according to time interval.

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FROM MYTH TO TRUTH: SOME HISTORICAL ASPECTS OF METEORITICS

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The similarity of the Greek word for iron (sideros) and the Latin word for stars (sidera) implies the belief that the metal iron had come down to Earth from the sky. In other languages as well, the name of iron has a definite connection with the sky (1). The fall of a meteorite, however, is a rather rare occurence and only a very small percentage of the world's population is fortunate enough to see such an event. It is astonishing that even in ancient times the celestial origin of meteorites seems to have been common knowledge.

The fall of a meteorite is in most cases a spectacular phenomenon. Surprise, shock and fear are common feelings of an observer. Having not a simple explanation for this unique event, the fall of meteorites was taken as a miracle (see e.g. (2)). A miracle, however, is "the dearest child of faith" (Goethe) and thus some meteorites became objects of religeous adoration.

Even primitive man used meteoritic iron for tools, weapons and crafts; a number of such artifacts are found in museums. Only since about 1800, after E.F.F. Chladny's paper on the Pallas iron (3, 4), have meteorites become demythologized and objects of scientific studies. Surprisingly, compared to other natural phenomenon meteorites are rarely mentioned in literature or depicted in the fine arts.

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THE EIGHTEENTH CENTURY METEORITE CONTROVERSY: ASPECTS AND EPISODES,

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Resistance to the recognition of meteorites is often seen as one of the classic examples of "scientists' resistance to scientific discovery." (1) But accounts of the recognition of meteorites have seldom been detailed enough to include many of the important social processes of science which were involved. Furthermore, some of the accounts of the controversy which have appeared are in error in one or more aspects. For instance, the often-quoted remark of Thomas Jefferson appears to be apocryphal. The author of the present paper undertook a study of the meteorite controversy from original sources as a study in the reaction of science to accounts of anomalous events. In this paper the author suggested that the recognition of meteorites did not show resistance to "scientific discovery" so much as resistance to "social intelligence" about anomalous events. (2) Social intelligence consists of those processes by which the experiences of individuals are transmitted, collated, and evaluated by society. (3) In the present paper the author considers three instances in which information about meteorite falls was suppressed or incorrectly evaluated in the 18th century context. He then traces how accumulating evidence and theoretical developments changed the parameters of the social intelligence system, as meteorites were transformed from hypothetical anomaly to scientific fact. He concludes with some general observations on social intelligence about anomalous events.

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EVIDENCES OF AMERICAN INDIAN AWARENESS OF METEORITIC EVENTS: THE SKIDI PAWNEE CASE, V.D. Chamberlain, Smithsonian Institution, Washington, D.C. 20560.

The Skidi Band of Pawnee Indians, residing in what is now east central Nebraska along the Platte River and its tributaries, based their lives upon an unusual "astrotheology." They believed the stars to be their ancestors as well as their gods. Their earthlodge houses were models of their concept of the universe. One of their sacred possessions was a chart of the heavens painted on animal skin. This artifact, now at the Field Museum of Natural History in Chicago, contains recognizable star groups and other features depicting natural objects and phenomena. The extant mythology, ethnographic materials and artifacts of these people indicate an unusual polarity on the sky.

Meteors, fireballs and meteorites apparently played an important role in the development of Skidi concepts, beliefs and practices. Their mythology frequently refers to the fall of meteorites and they kept objects which they believed to be meteorites wrapped up in sacred bundles belonging to the Band. They also had special bundles belonging to individuals, which were made specifically to house supposed meteorites and these were referred to as "meteor bundles."

The Skidi associated meteorites with some of their principal deities: Tirawahat, the primary god said to dwell at the zenith; Great Star, also called Morning Star, considered to be the literal father of the first human child; and Big Black Meteoric Star, one of four star deities said to hold up the heavens and to be associated with certain directions, seasons, trees, animals and periods of life. Meteorites were also associated with flint, projectiles, projectile points and fire.

The Skidi were aware of meteor showers generally and the 1833 Leonid shower specifically. Meteors were said to be messages from friends and meteorites were called "children of Tirawahat." The Skidi also composed songs about meteors.

This paper will review Skidi Pawnee meteoritic concepts and argue that these concepts originated from observations of natural phenomena.

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LUNAR PHENOMENA REPORTED BY GERVASE OF CANTERBURY (1178 AD). J.A. O'Keefe, NASA Goddard, Greenbelt, MD 20771

J.B. Hartung (1) has drawn attention to the report by Gervase of Canterbury of a curious lunar phenomenon seen after sunset, on June 18, 1178 (Julian calendar). The upper half of the crescent moon appeared to split; a "flaming torch" appeared in the division between, and the lower part of the moon "writhed"; later the moon "throbbed like a wounded snake". Hartung proposes to explain these phenomena as observations of the event which formed the ray crater Giordano Bruno, which is on the moon's far side, just out of sight from the earth. This hypothesis was utilized by Calame and Mulholland (2) to explain Calame's finding (3) of a free libration of the moon.

Using the tables of Tuckerman (4) it is found that on that date the moon was 5.5 arc degrees above the horizon at sunset. It was about 18 degrees of arc away from the sun, and therefore was seen as a very narrow crescent, less than 1 minute of arc in width.

Minnaert (5), p. 58, describes and pictures similar distortions of the moon's image, caused by atmospheric refraction, and visible under similar circumstances, specifically when the moon is a "slender crescent" and at low altitudes. Since occasions to see the moon under these circumstances are relatively rare, it would be surprising if a huge meteorite impact had occurred just then. I think we are compelled to discard the hypothesis of a relation to Giordano Bruno, and to seek other explanations for the moon's free librations.

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ON THE USE OF IRON BY THE ESKIMOS OF GREENLAND

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In the large archaeological material which has been collected upon Greenland and which is now in the National Museum, Copenhagen, there are a few implements that, surprisingly, have been fabricated from iron or have cutting edges of iron. A systematic examination of 70 arrowheads, ulos (woman-knife) and similar samples reveals that it is possible - in spite of a general very poor state of conservation - with modern methods, such as metallography and electronmicroprobe analysis, to determine the composition and origin of the specimens.

One part is meteoritic iron with 7,5-8,5% Ni. It is slightly to heavily coldworked and has attained hardnesses of 275-350 HV. Some samples may have been ground or polished to final shape, but forging or heat treatment has not been applied. The origin is probably the Cape York iron meteorite, a group IIIA medium octahedrite.

Another part is native iron with 1-4% Ni. It is ferritic with cementite inclusions, and is coldworked to 180-230 HV. The original pea-sized native iron minerals of Disko Island have lower hardnesses, 130-160 HV.

The third part of the old tools contains wrought iron made in Denmark and Norway in the medieval ages; it is speculated that the Eskimos acquired it by trading with the Norsemen, 1000-1400 A.D., and in a later period by excavating the abandoned farms of the Norsemen.

The Eskimos are thus unique in having utilized three different types of iron for their tools.

THE FALL AT ENSISHEIM, 1492: TWO CONTEMPORARY VIEWS

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Most meteoriticists are familiar with at least one version of a woodcut by Sebastian Brant (c. 1457-1521) depicting the fall of the meteorite at Ensisheim in Alsace in 1492. Brant issued a broadsheet publicizing the event. Below the woodcut are 22 couplets, rendered in Latin and German, describing the awesome spectacle and telling how all the peoples from Burgundy to the Alps took it as a portentious sign. At the bottom of the sheet there is a shield inscribed with the Austrian eagle and an apostrophe, in 11 German couplets, to Maximilian, the "Roman King."

Brant may have had a "best seller," or his work may have been pirated. In any case, four versions of the broadsheet exist, all over Brant's name, but differing in details of illustration, text, and typography. Three show approximately the same scene: at left is the walled city of Ensisheim with its drawbridge down; in the center the meteorite is plunging out of the clouds and also lying on the ground; at right in the background is the village of Battenheim, and in the foreground a man on horseback, followed by a spear-carrier, rides out of a forest toward the city. Two of these three bear a printer's initials, J.P.; the third the name Johanes Bruss [sic] (Johannes Prüss of Strasbourg). This version also has extra flourishes in the margins and a decorative device across the bottom. The fourth broadsheet has completely different illustrations. Across the top are three small woodcuts. The one at left shows an outsized man, almost as tall as the city gate, looking out over the wall but facing away from the meteorite, which again is shown both falling out of the sky and lying on the ground. To the right is a closed tower labeled Battenheim. This sheet bears the name of the printer Michel Greiff (of Reutlingen). In these four prints the meteorite varies in shape from angular and knobby to almost oval.

Sebastian Brant was not the only contemporary who commemorated the fall. Diebold Schilling (b. 1460) included a vividly colored drawing in his Lucerne Chronicle of 1513. Schilling's design shows a large, gray, furrowed object plunging from fiery clouds toward two men who are harrowing and sowing a field. The city appears in the background. In his text Schilling says the stone had the shape of a Greek omega with three corners--everybody in the world was astonished. He adds that the stone was supended in the church for eternal memory, but many pieces were broken off while it was there and so it was carried to the countryside. In time, part of it was returned to the city, where a 56-Kg piece is exhibited in the Rathaus. The original stone weighed about 127 Kg; today only about half of it is accounted for.

The Diebold Schilling Chronicle is a little known illustrated ms. held by the Central Library in Lucerne. This masterwork illustrating the daily life and important events of the Swiss 15th century, consists of 342 bound parchment folio pages with text by Schilling and tempera and ink drawings by Schilling and another artist. A few of the drawings depict natural phenomena--the Ensisheim fall, the two comets of 1474, and a hailstorm over the city. I have obtained prints and slides of the three drawings from the Schilling Chronicle and all four broadsheets after Brant. These will be presented along with translations of the verses and captions.

SORTING OUT THE MANY FALLS OF THE TULIA-DIMMITT AREA

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Since the first two Tulia specimens were described in 1927 (1), more than 500 specimens (here called the Tulia-Dimmitt meteorites) have been collected from this area of the Texas Panhandle. Among the stones thus far investigated, 28 separate falls have been identified. During the process of identifying specimens from the area, the suspicion arose that a number of the Tulia-Dimmitt specimens in collections may not be correctly identified. The Field Museum specimen of Tulia is an L6 rather than an H5 chondrite. The <u>Catalogue of Meteorites</u> says of Dimmitt that "the fall may be identical with Tulia." (2) In the early days of collecting, all specimens were assumed to belong to the Tulia fall. The Dimmitt fall was identified in 1950; however, the extent of the overlapping of falls was not discovered until more recently. Many uncut meteorites were distributed as Tulia or as Dimmitt, their identification being based solely upon location of find. Specimens in many collections may be incorrectly labeled as Tulia or as Dimmitt when they may belong to the other fall, or may belong to a fall as yet unidentified.

To facilitate correction of the problem, the American Meteorite Laboratory will provide free of charge 35mm color slides showing structural details of the Tulia and the Dimmitt falls to any institution wishing to verify the identity of its specimens.

Slides showing structural details of 18 of the more obvious falls will be shown.

Comprehensive study of the 430 Tulia-Dimmitt meteorites from the Monnig collection now at Texas Christian University in Ft. Worth should be undertaken.

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THE PENWELL METEORITE REVISITED

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In the abstracts of the 44th Annual Meeting of the Meteoritical Society a new stony-iron meteorite found at Penwell near Odessa, Ector County, Texas was reported. This meteorite was characterized by a high concentration of cliftonite graphite.

Additional study of this meteorite shows that the non-metallic phases are similar to those found in silicate inclusions of the Odessa iron meteorite. Table 1 compares the analysis of some minerals from Penwell with those reported for Odessa and those analyzed in samples identified as Pseudo-Penwell. Pseudo-Penwell is a sample of several stones collected after Penwell was first reported. It was made available to us by James DuPont. The original Penwell and the Pseudo-Penwell have different macroscopic and microscopic characteristics. Penwell appears to be more coarsely crystalline with a granoblastic texture than Pseudo-Penwell or Odessa silicate inclusions.

It thus appears that it is possible that the parent meteoroid of the Odessa iron contained various inclusions which may have broken free during entry and been scattered over a moderately large area. Different inclusions experienced differing histories in the parent body as indicated by the textures observed.

Table 1. A comparison of mineral compositions in meteorites from the Odessa Area

	PENWELL	ODESSA Silicate Inclusions	Pseudo-Penwell
Olivine (Fa)	4.9 ± .3	3 - 4	6.4 ± .5
Plagioclase (An)	11.8 ± 2.2	9 - 14	15.6 ± 1.4
Orthopyroxene (Fs)	6.6 ± .4	6 - 8	6.9 ± .2
Kamacite (%Ni)	4.6 ± .3	4.5 (inclusions) 6.3 (matrix)	6.9 ± .2

THE SOUTH DAHNA, SAUDI ARABIA, IRON METEORITE. A. A. Almohandis, King Saud University, Riyadh, Saudi Arabia, and R. S. Clarke, Jr., Smithsonian Institution, Washington, D.C. 20560

The South Dahna, Saudi Arabia, iron meteorite is a 275 kg severely weathered remnant of an ancient meteorite fall. It was found in 1957 in the Rub'al Khali (22°34'N, 48°18'E) on a low platform of limestone in numerous pieces within an area of a few meters. The pieces appear to have resulted from the weathering of a single large individual. The recovery was described by Holm (1962).

Apparently all of the kamacite and most of the other minerals that were originally present have been converted to weathering products, but remnant structures and mineral associations provide sufficient information for classification. It landed as a carbon-rich octahedrite, undoubtedly a coarse octahedrite of chemical group I.

X-ray powder photography indicates that the matrix now consists of goethite and maghemite (and/or magnetite) in subequal amounts. Remnant, badly corroded taenite and plessite lamella, and comb plessite areas are distinguishable. The few indications of kamacite band widths that remain are consistent with a coarse octahedrite structure. Much of the plessite appears to have been pearlitic. Several small areas and one large inclusion of troilite were observed. The troilite is surrounded by remnant schreibersite, followed by cohenite. Cohenite is an important mineral, and in a few cases is well preserved. Schreibersite also occurs in association with cohenite that was within kamacite lamella, as individual moderately large inclusions, as grain-boundary schreibersite, as taenite-border schreibersite, and as rhabdites. Large graphite crystals are present within decomposed cohenite and at previous cohenite-kamacite borders.

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QUARAT AL HANISH: IRON METEORITE FROM WESTERN DESERT OF EGYPT.

J. R. Underwood, Jr., Dept. Geol., Kansas State Univ., Manhattan, KS 66506; Robert Giegengack, Dept. Geol., Univ. Pennsylvania, Philadelphia, PA 19104; and D. J. Malvin, Institute of Geophysics and Planetary Physics, Univ. California, Los Angeles, CA 90024.

A 593-gm iron meteorite 9.5 cm long, 6.6 cm wide, and crudely spoon shaped was discovered June 25, 1979 at lat 25° 9.5'N, long 25° 35.1'E (1). Elemental concentrations are: Co, 5.4 μg/g; Ni, 127 mg/g; Cu, 210 μg/g; Ga, 16 μg/g; Ge, 30 μg/g; As, 27 μg/g; W, 0.3 μg/g; Ir, 0.86 μg/g; Au, 2.8 μg/g (2).

The meteorite is a fine octahedrite and is compositionally similar to group IIICD; because the content of Ir is four times the expected level, the meteorite is classified as an anomalous member of IIICD. Kamacite band width is 0.4 mm; about 30-40 percent of the section is covered by plessite fields. Thin borders of taenite surrounding the plessite are altered to martensite. Carbide inclusions, probably haxonite, are common. No silicates, chromite, or troilite have been identified.

The convex side of the meteorite displays a myriad of microscopic ablation ridges that on Earth weather away in a few hundred years even in desert environments (3). Thus, the meteorite fell to Earth in the very recent past, and it is mere coincidence that the meteorite was found within the distribution field of Libyan Desert glass, a natural high-silica glass of unknown origin that has been dated by fission-track analysis at 28.5 million years (4, 5, 6).

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A LODRANITE IN THE YAMATO COLLECTIONS

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A second lodranite has been identified in the Yamato collections. This meteorite is a small, irregular fragment partly coated with dull black fusion crust, and shows light brown olivine grains, in much darker metal and pyroxene. The specimen is granular, friable, and consists largely of olivine and pyroxene, with lesser nickel-iron and minor amount of phosphate, chromite, troilite, plagioclase, and an alkali-Al rich silicate phase. Weathering is considerable, with brown limonitic staining around metal grains and in the fractures of the silicate minerals.

Modal analysis of 2490 points was carried out under the polarizing microscope on a 7 x 4 mm, polished thin section. Preliminary results give olivine 41.8%, orthopyroxene 38.8%, nickel-iron 9.8%, phosphate 3.7%, chromite 3.1%, troilite 1.5%, and plagioclase 1.3%. Traces of an alkali-Al-rich silicate are present.

Compositional analyses on the constituent minerals were carried out by automated JEOL733 electron microprobe, using 3 spectrometers. The results give olivine composition averages Fa11.6 (range Fa10.2-13.5), orthopyroxene Fa12.2 (average) with little variation; plagioclase is An16.3-18.6. The metal composition averages 6.5% Ni with 45% Ni in taenite.

Microscopically, the meteorite shows granoblastic texture; olivine is euhedral to subhedral (max. 1.5 mm in diameter) and has several small orthopyroxene inclusions. Orthopyroxene has similar grain size to olivine, but is subhedral and contains small rounded grains of olivine. Metal appears to enclose the other minerals. Chromite, troilite, phosphate, and plagioclase occur as subhedral and anhedral grains. Some plagioclase shows clear albite twins. The meteorite is similar to the Lodran meteorite in texture and mineral assemblage, but is slightly different in mode and mineral compositions (Bild R. W. and Wasson, J. T., 1976 Prinz et al., 1978).

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RESULTS OF THE 1981-82 ANSMET by R. F. Fudali, W. A. Cassidy, Ghislaine Crozaz, Ursula Marvin, and John Schutt. United States Antarctic Research Program S-058.

Based on previous experience in the Allan Hills meteorite collecting areas, Antarctica, some promising blue ice areas were identified, on air photos, within helicopter range of the seasonal field camp in North Victoria Land (72°12'S, 164°12'E). A possible impact crater at Littel Rocks (71°22'S, 162°0'E) was also noted. In November and December extensive helicopter and ground searches failed to find a single meteorite on these ice fields. Examination of the crater at Littel Rocks was also negative.

At Allan Hills (76°45'S, 159°40'E) in December and January, the Main Ice Field and the Near-Western Ice Field (18 km west of Allan Hills) were searched systematically on the ground and a one-day ground reconnaissance was carried out on the Mid-Western Ice Field (~30 km west of Allan Hills). About 375 meteorites and meteorite fragments were recovered, most of them from areas that have been searched before. Preliminary field examination identified two irons, six achondrites, four carbonaceous chondrites and several enigmatics. Most of the remainder are ordinary chondrites. A large number of meteorites remain on the Near-Western and Mid-Western Ice Fields for future collecting. Presumably, a much larger number lie beneath the snow cover separating the three ice fields.

As part of the on-going effort to determine the meteorite concentration mechanism at Allan Hills, gravity measurements were made at all stations of the previously established triangulation network across the Main Ice Field. The gravity data were used to model the ice-bedrock interface and reveal what should be a major subsurface barrier to eastward ice movement. The top of this bedrock barrier is 10 km west of the Allan Hills and its base may be another five to ten km farther west. This is certainly consistent with the surface occurrence of abundant meteorites ~35 km west of the apparent (exposed) barrier, but is seemingly contradicted by the rapid horizontal, eastward ice movement reported for the westernmost stations of the triangulation network (1). Further work is necessary to resolve this problem.

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CHONDRULES DID NOT FORM BY IMPACT ON PARENT BODIES.

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There is a growing consensus that chondrules formed by melting of pre-existing solids, rather than by direct gas-liquid condensation in the solar nebula. There is no agreement, however, about the source of heat for melting. Nevertheless, some mechanisms for melting chondrule precursor materials can be ruled out. Specifically, properties of lunar, meteoritic and terrestrial breccias and the lunar regolith are totally inconsistent with the notion that most chondrules formed by impact on chondrite parent bodies.

The discovery of glass spheres and quench-crystallized impact melts in lunar soils and regolith breccias was taken by some investigators to imply that chondrules in chondrites formed by impacts on the regoliths of chondrite parent bodies. Although molten droplets can certainly form by impact, most chondrules did not, for the following reasons: 1) "Chondrules" are far less abundant in the lunar regolith, a few %, than they are in chondrites, about 50%. The abundance of compound chondrules and their absence on the Moon suggest that chondrule number densities during formation were much higher than the corresponding number densities of lunar spherules. Similarly, impact-produced spherules are rare (<1%) in achondrite regolith breccias. 2) Glass spherules in the lunar regolith are always accompanied by greater amounts of agglutinates, yet chondrites, even chondrite regolith breccias, contain few, if any, agglutinates. 3) The most efficient regolith process is comminution. The lunar regolith and chondrite and achondrite regolith breccias are made up of fragmental material, including broken spherules and chondrules. In contrast, type 3 chondrites contain mostly unbroken chondrules. 4) Glass spherules in the lunar regolith are decorated with tiny hypervelocity impact craters; chondrules are not. In short, no more than a minuscule percentage of chondrules in chondrites could have formed by impact into a regolith.

Another demonstrably false idea is that chondrules formed during large impacts on chondrite parent bodies. Chondrites do not resemble lunar and terrestrial melt-bearing suevitic fragmental breccias. 1) Chondrites lack the clastic, unmelted debris present in suevitic breccias. 2) Very little of the melt clasts in suevitic breccias are spherical; most are irregular in shape. The melts also commonly show obvious signs of having been molten when the breccia was deposited; in contrast, chondrules were assembled into chondrites as solid objects. 3) Chondrules in a given meteorite have a broad range of compositions, yet melts produced in a single impact have a narrow range in composition.

Any model calling for the formation of chondrules from parent bodies (solid or liquid) must also account for their diversity of chemical and isotopic compositions and the presence of other components in chondrites. Even if a pile of chondrules could be produced in an impact on a parent body, it is not clear how the other components (metallic Fe,Ni; fine-grained, FeO-rich matrix and chondrule-rim materials; CAIs) in chondrites were incorporated into the hypothetical pile of chondrules. The origin of chondrules is related to the origins of the other primitive chondritic components. Although impact on parent bodies was clearly not a significant chondrule-forming process, collisions between cm-sized objects prior to accretion cannot be ruled out by the arguments outlined above. However, we think it more probable that the transient heating events resulted from release of chemical energy or compression in shock fronts.

A NEW MODEL FOR CHONDRULE ORIGIN.

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The origin of chondrules is one of the most fascinating and intractable meteorite problems. Recent studies of chondrules in highly unequilibrated ordinary chondrites have tightened the constraints on chondrule formation models, and have increased our understanding of the kinds of processes that are inherent to an evolving nebula.

A key new petrographic observation is that many chondrules contain relict grains. This reinforces earlier evidence (e.g., the presence of low-temperature components) indicating that chondrules are not formed by condensation. The presence of large relict grains (>0.2 mm across) is also inconsistent with models involving interstellar dust as the precursor since the fraction of the dust having such large sizes is believed to be very small. The melting of interstellar grains by infall into the nebula would also lead to a high-temperature period of several seconds, inconsistent with volatile retention.

Recent research indicates that the mean nebula temperature was 600 K when the chondrules formed from several well-defined precursor components that can be understood in terms of common nebular processes. However, the energy source for a melting evnet brief enough to prevent volatile loss remains uncertain. The recently popular submeter-body impact model fails since the minimum interbody velocity required to produce melting is $\sim$3 km s^{-1}, whereas the maximum allowed for planetesimal formation is 10X smaller. Interbody velocities increase with time, and chondrule formation precedes planetesimal formation.

The production of chondrules by lightning discharges in a cool ($\sim$400 K) nebula can account for the known properties of chondrules. Cameron proposed that the energy released in the discharge was extracted from the turbulence of the nebula. His model called for chondrule production throughout the nebula, but this appears to lead to a shortfall in the amount of energy available to heat solid particles.

We propose a new scenario in which lightning occurs in a confined zone, the interface between the gaseous nebula and the dusty median plane. We suggest that charge separation is due to the shear between the dust plane, which rotates around the Sun at Keplerian speeds, and the (thicker) gaseous nebula, which rotates at sub-Keplerian speeds. Static charge builds up in cloudlets. Heating results either by the passage of electric currents through solid particles or by ion-electron recombination on particle surfaces. A nebula model by Weidenshilling suggests that the shear energy available at the interface is >1.5X greater than that required to melt all metal and silicate particles. After the chondrules are formed, their increased density causes them to settle out of the production zone in a time scale of $\sim$10^3 a. As a result chondrule precursors mainly consist of the low-density particles present near the surface of the dusty disk.

CLASSIFICATION, MINERAL CHEMISTRY, AND MODAL ANALYSIS OF CHONDRULES IN THE MOKOIA C3(V) CARBONACEOUS CHONDRITE

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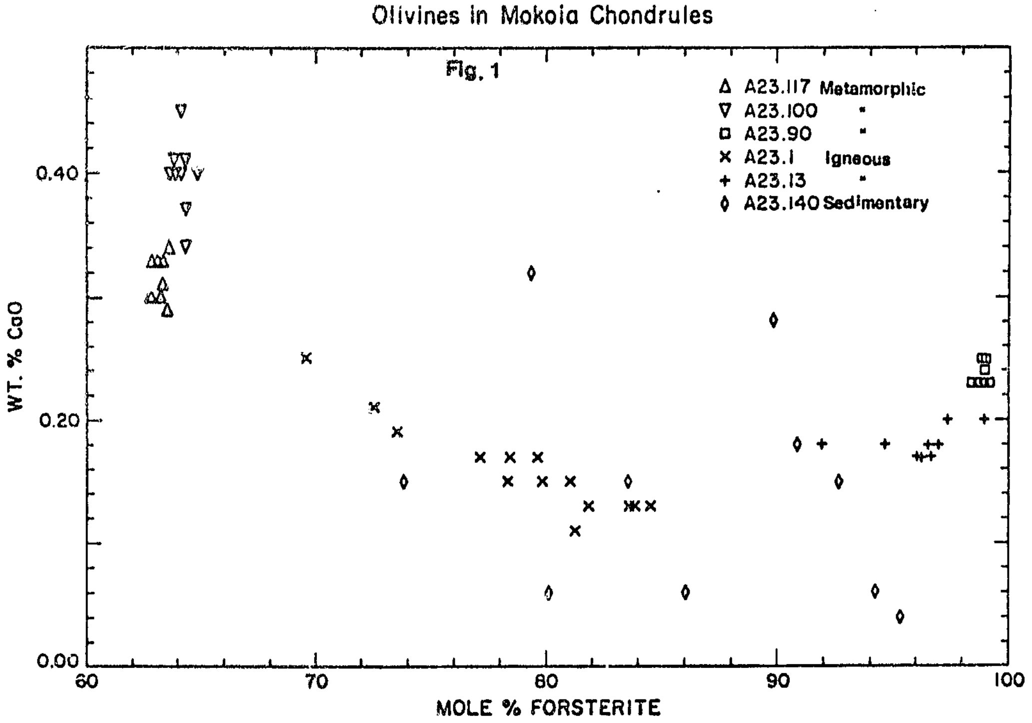
A modal survey of chondrules and inclusions in 5 polished thin sections (2.64 cm^2) of Mokoia has been completed. Igneous, 'metamorphic', and 'sedimentary' textured chondrules (898 objects) were observed. (Chondrule is used in a broad sense to include all objects >100μm which are not Ca,Al-rich inclusions or amoeboid olivine aggregates.) This classification is based on optical microscopy and electron microprobe analysis.

Olivine and/or pyroxene grains are zoned in igneous textured chondrules. 'Metamorphic' textured chondrules (.68±.70 vol. % of Mokoia) are recrystallized. They have granulitic textures and homogeneous mineral compositions. Fe-poor (ol>Fo_{90}) and Fe-rich (ol<Fo_{90}) varieties occur in both igneous and 'metamorphic' textured chondrules. 'Sedimentary' textured chondrules (5.2±1.5%) are inhomogeneous aggregates of mineral fragments cemented by a magnetite-rich groundmass.

Igneous textured chondrules were subdivided into several groups: opaque-rich (13±3.7%), pyroxene-rich (2.3±1.4%), barred olivine (.63±.90%) and others (8.4±4.4%). Magnetite-sulphide complexes (1.3±.78%), microgranular chondrules (.54±.32%) and isolated mineral grains (.16±.13%) were also observed. (The standard deviations show the variability among the 5 sections).

A plot of Ca content vs. % Fo (Fig. 1) in olivine grains in 6 chondrules shows the different types of composition distributions found in igneous, 'metamorphic', and 'sedimentary' textured chondrules. Mineral chemistry and petrographic observations are consistent with a model of planetary origin of these types of chondrules.



NEPHELENE AND SODALITE IN ALLENDE CHONDRULES AND MATRIX.

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As part of a scanning electron microscope (SEM) study of Allende, we are using cathodoluminescense to determine the distribution and associations of sodalite. Sodalite is a widespread minor component in matrix, chondrules, and mafic inclusions.

We have previously reported strong SEM evidence that matrix olivine in Allende formed from preexisting enstatite by a reaction which was initiated by the subsolidus reduction of Fe_3O_4 to FeO (1). The main reaction is then

$$MgSiO_3 + FeO \rightarrow (Mg,Fe)_2SiO_4 \quad .$$

However the enstatite contains several minor elements including Al, Ca, and Cr in larger amounts than can be incorporated in the forming olivine. Thus during the reaction numerous small pods of Al rich glass are formed as a byproduct.

Nephelene and sodalite are generally associated with reaction regions and appear to have formed by the addition of alkalies and chlorine to these pods and Al rich glass. The formation of nephelene and sodalite in other occurances in Allende has been discussed by Lumpkin (2) and Grossman and Steele (3).

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I-XE STUDIES OF INDIVIDUAL ALLENDE CHONDRULES, Caffee M.W., Hohenberg C.M., Lindstrom M.M. and Swindle T.D., McDonnell Center for the Space Sciences, Washington University, St. Louis, MO, and Hudson B., Lawrence Livermore National Laboratory, Livermore, CA.

Nine chondrules from the CV3 meteorite Allende have been individually analyzed using I-Xe methods to study early chondrule chronometry and initial iodine isotopic structures. The chondrules, ranging in size from 6.1mg to 100mg, were sealed in a single quartz vial and neutron irradiated. Following the irradiation, xenon was analyzed using stepwise heating and mass spectrometry techniques previously described (1). Elemental abundances were also determined from INAA for seven elements: Fe, Ni, Co, Cr, Sc, Ir and Eu.

When ^{128}Xe/^{129}Xe is plotted against ^{130}Xe/^{129}Xe for the temperature fractions released from each of the individual chondrules, only one graph, that of chondrule 6, displays a well-defined linear array ("isochron") characteristic of two-component mixing between a trapped Xe component and a single radiogenic component. If the initial iodine ratio is interpreted as a chronometer, controlled by the 17 m.y. halflife decay of ^{129}I, this would give a formation age of .53±.15 m.y. later than whole rock Bjurbole (1). This chondrule was also unique in chemical composition: it was the only one for which iridium and nickel could not be detected, and was also low in Co, Fe and Cr. A second chondrule produced a linear array consistent with an isochron, but there much less trapped Xe present, and the line is not nearly as well-defined. The radiogenic component, however, is the same as for chondrule 6, within the estimated errors.

Most of the other chondrules are depleted in trapped Xe relative to their radiogenic components (^{130}Xe/^{129}Xe often less than .001). Thus, for these chondrules, essentially all ^{128}Xe and ^{129}Xe is iodine-derived. However, the ^{128}Xe/^{129}Xe ratios vary, often by more than 10 percent, indicating that these chondrules did not have uniform iodine isotopic compositions at the time of isotopic closure. Some of these chondrules have isotopic structures difficult to interpret in terms of known processes or familiar isotopic patterns for either iodine or xenon.

Three chondrules, however, have iodine isotopic records in the release patterns suggestive of cooling sequences. The best example of this is chondrule 3, for which there is clearly a trend of decreasing ^{129}Xe/^{128}Xe (and consequently ^{129}I/^{127}I at xenon closure) with decreasing temperature. If this is due to the decay of 17m.y. ^{129}I, it corresponds to a cooling rate of roughly 200°K/m.y., which is within the range of published metallographic colling rates (2).

REFERENCES: 1) Caffee M.W., Hohenberg C.M., Hudson B. and Swindle T.D. (1982) Proc. Lunar Planet. Sci. Conf. 13th, to be published. 2) Wood J.A. (1979) In Asteroids, ed. T. Gehrels (Tucson: University of Arizona Press), pp. 849-891.

Microscopic Properties and Bulk Chemistry of Individual Chondrules of the Indarch Enstatite Chondrite

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About 100 individual chondrules were isolated by acid dissolution of metal and sulfide. Optical microscopy revealed two broad categories based on surface morphology. Two-thirds are sub-rounded and rough, and contain large crystals jutting out from the body of the chondrule. One-third are nearly spherical (including one compound chondrule) and smooth. Diameters of the two groups overlap, but most rough ones (~1 mm) are larger than the smooth ones.

SEM examination confirmed the dichotomy. Study of broken chondrules revealed radiating, barred and fine-grained textures in all the smooth ones, thus indicating crystallization from a liquid droplet. Rough chondrules are coarse aggregates of euhedral to subhedral (clino)-enstatite crystals with minor amounts of albite and silica mineral. These coarse aggregates correspond to the so-called "porphyritic" type of chondrule, origin is debatable. Cathodoluminescence and electron probe studies are underway to allow determination of the morphologies and spatial relations of red- and blue-luminescing crystals discovered earlier (1).

Short rabbit INAA yielded the following geometric mean and ranges for 12 individual chondrules of each type:

Element	Wt. Fraction and Range (rough)		Wt. Fraction and Range (smooth)		A*	B*
Al%	1.28	0.94-1.79	1.04	0.58-2.01	same	same
Mg%	19.8	18.6-20.9	19.3	16.5-25.7	same	same
Ca%	0.27	0.14-0.59	0.19	0.11-0.31	no data	6 x lower
Na%	0.84	0.57-1.37	0.68	0.33-1.59	9 x higher	same
Mn%	0.090	0.063-0.153	0.090	0.035-0.175	1.6 x lower	3 x lower
Cl ppm	880	340-2990	800	420-1650	no data	no data
V ppm	33	17-56	32	16-47	no data	2.5 x lower

*Comparison of geometric mean for all Indarch chondrules with those for chondrules from carbonaceous (A) and ordinary (B) chondrites.

The positive correlation between Na and Al for the Indarch chondrules correspond to a 2-fold range of albite content, while the small range of Mg corresponds to slight variation in enstatite. Calcium, Mn and V are lower in Indarch chondrules than for chondrules from ordinary chondrites. Sodium is higher and Mn lower for Indarch chondrules than for chondrules from C3 chondrites. Calcium and Mn are chalcophile in enstatite chondrites, and the lower levels in Indarch chondrules than in chondrules from ordinary chondrites suggests fractionation between silicate and sulfide phases.

Further neutron-activation analyses together with oxygen-isotopic analyses (R.N. Clayton) are planned.

NASA 14-001-171 (J.V. Smith); NGL-38-002-039 (R.A. Schmitt).

(1) C.A. Leitch and J.V. Smith (1982) Geochimica Cosmochimica Acta, accepted.

LITHOPHILE COMPONENTS OF CHONDRULES FROM THE SEMARKONA CHONDRITE

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Our studies of individual chondrules from the highly unequilibrated ordinary chondrites, Chainpur (LL3.4) and Semarkona (LL3.0) have resulted in the identification of the important precursor components which were mixed and melted together to form chondrules (1,2). Two metal/sulfide and two lithophile (refractory and 'common') components were resolved. The concentrations of trace volatiles and the minor elements Na and K seem to have been controlled both by minor precursor components, and also by volatilization during chondrule melting. Most of a chondrule's mass is derived from the two lithophile components which contain most of the major elements. The characterization of these two major nebular components offers important clues to the conditions in the nebula up to the time of chondrule formation.

The compositions of the chondrule lithophile components were determined from interelement trends. Mg, Fe, Ca, Al, Cr, and the trace elements V, Sc, Hf, and REE were measured by instrumental neutron activation analysis; Si and Fe as FeO were estimated from other parameters. Errors in Si and FeO are believed to be small, and the data are consistent with literature microprobe analyses (3). All of these elements are linearly intercorrelated.

The refractory component probably contains all of the elements with condensation temperatures above that of V (50% at 10^{-4} atm ~1450K), as well as most of the Mg, V, and part of the Si and Cr. The nonrefractory component seems to contain all of the FeO. The refractory component has a Mg/Si ratio of about 1.65 g/g; this is equal to the maximum value attainable through equilibrium condensation (4), reached just before the onset of pyroxene formation. The nonrefractory component clearly represents a lower-temperature epoch since it is rich in FeO, and lacks refractories.

The nonrefractory component probably formed as coatings on pre-existing refractory grains. The formation of pyroxene is the first major reaction in the condensing nebula in which solids must react with the gas (forsterite + gas $\rightleftharpoons$ enstatite). It is reasonable that the interiors of the refractory component grains ceased to equilibrate with the nebula at these temperatures. Reaction of Fe-Ni at much lower temperatures produced FeO, which then formed pyroxene by diffusing from the metal into materials formed on the refractory grains.

This evidence suggests that the dominant nebular materials at the ordinary chondrite location during chondrule formation were not formed through equilibrium condensation. Two components coexisted: one was a relict from a high temperature epoch (forsterite + refractories), the other an oxidized, low-temperature material. The relative amounts of these materials in each chondrule depended on the mean grain size of its set of precursor components.

References: (1) Grossman and Wasson (1982) Geochim. Cosmochim. Acta **46**, 1081-1089, (2) Grossman and Wasson, in preparation, (3) Dodd (1978) Earth Planet. Sci. Lett. **39**, 52-66, (4) Kerridge (1979) Proc. Lunar Planet Conf. **10th**, 989-996.

SILICATE MATRIX MATERIAL IN TYPE 3 ORDINARY CHONDRITES: IMPLICATIONS FOR THE ORIGIN OF CHONDRULES

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Fine-grained opaque silicate matrix material ("Huss matrix"[1]) is an important primitive component that constitutes 10-15 vol.% of type 3.0-3.5 ordinary chondrites. Huss matrix has a similar composition to that of C3 matrix and bulk CI chondrites, and may be a precursor material for chondrules [2]. Huss matrix occurs as (a) rims around chondrules, metallic Fe,Ni-sulfide assemblages and silicate-sulfide assemblages, (b) lumps inside chondrules, (c) discrete Huss matrix clasts, and (d) discrete matrix-rich silicate clasts. Matrix material in C3 chondrites also forms rims and isolated clasts. Within each chondrite there is a large variation in FeO content of Huss matrix material; e.g., 20-60 wt.% FeO in Ngawi (determined with a 15 µm diameter electron probe beam). However, the compositional variability of Huss matrix in an individual rim or clast is much less than the large compositional variability of Huss matrix throughout each chondrite. Compositional variations of the matrix probably result from primary differences in the proportions of constituent minerals and not from secondary reactions. Huss matrix that is poorer in FeO tends to be richer in Na_2O, K_2O and Al_2O_3 and probably contains more feldspathic material.

Huss matrix occurs as lumps inside a few radial pyroxene chondrules and as groundmass between euhedral olivine phenocrysts inside some porphyritic olivine chondrules, but does not appear to have served as nucleation sites for crystal growth. In these porphyritic chondrules, feldspathic mesostasis is present along with Huss matrix. The Huss matrix material inside all of these chondrules probably represents relict projectiles that were incorporated at low relative velocities immediately prior to or during chondrule crystallization. Huss matrix material inside some chondrules has the same composition as the matrix material rimming the chondrules. Because of the large variation in Huss matrix composition throughout each chondrite, this indicates that at least some chondrules acquired rims in the solar nebula not long after chondrule formation (assuming chondrules themselves formed in the nebula). For other chondrules, compositional differences between internal lumps of Huss matrix and Huss matrix rims indicate that rims were acquired much later.

The occurrence of Huss matrix material inside chondrules indicates that Huss matrix was already present in the nebula at the time of chondrule formation. This is consistent with the idea that chondrules may have been formed from matrix material in the nebula by melting, reduction of FeO to Fe^o and loss of Fe as an immiscible liquid [2]. The large compositional variability of Huss matrix within each chondrite and the general compositional homogeneity of Huss matrix rims around individual chondrules suggest that there were distinct compositional reservoirs of Huss matrix material in the nebula prior to chondrule formation. Different chondrules and matrix-sulfide and silicate-sulfide assemblages must have acquired Huss matrix rims from the different reservoirs in the nebula prior to chondrite agglomeration. The Huss matrix reservoirs probably developed by mineralogical sorting of pre-existing dust grains before the dust aggregated into millimeter-sized Huss matrix dustballs. The compositional variability of different chondrules in type 3 chondrites could be due to melting of Huss matrix dustballs from these different compositional reservoirs.

[1] Huss et al. (1981), GCA 45, 33. [2] Scott et al. (1982), LPS XIII, 704.

SiO_2-RICH CHONDRULES IN ORDINARY CHONDRITES

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The solar system abundances of Mg, Fe, and Si dictate that chondritic meteorites are silica-deficient compared to most terrestrial or lunar igneous rocks; thus olivine-orthopyroxene assemblages are commonly observed in ordinary chondrites. However, in three unequilibrated H-chondrites (Dhajala, Sharps, and Bremervörde) we have observed three chondrules containing a silica polymorph or an essentially pure-SiO_2 glass. (The ambiguity arises because we have only polished sections of these samples). The coexisting phases are predominantly orthopyroxenes, as expected for a well-crystallized silica-saturated chondrule. Also, the morphologies of the grains are suggestive of crystalline SiO_2. In addition, these chondrules are striking in being conspicuously depleted in Ca and Al-rich phases and having low CaO content for the orthopyroxene. No feldspar was observed and only tiny grains of Ca-rich pyroxene and material of apparently glass composition have been found. However, the textures of the three chondrules are quite different.

The Bremervörde chondrule (spherical, 0.6mm) is about 40% SiO_2 (by area) with the SiO_2 concentrated towards one side, except for a few laths in the center and a discontinuous inner rim of SiO_2 grains around the orthopyroxene part of the chondrule. Some grains appear to be crystals which nucleated on the rim and grew inward. Based on fission track radiography [1], the U content of the SiO_2 phase is 33 ppb. The chondrule is completely surrounded by an outer orthopyroxene rim. There are apparently two populations of interior orthopyroxene: $En_{85}Wo_{0.1}$ and $En_{66}Wo_{0.4}$. The chondrule is very poor in metal and sulfide.

The Dhajala chondrule (spherical, 0.4mm) is approximately 86% pyroxene, 8% SiO_2 phase and 6% metal. The upper limit for the U content of this SiO_2 is ≤ 8 ppb. The SiO_2 occurs as angular laths, thin concentric arcs or lamaellae oriented parallel to linear chains of metal blebs. Some pyroxene regions show a lamaellar (exsolution?) texture. Two analyses give $En_{74}Wo_2$ and $En_{36}Wo_{19}$.

The Sharps chondrule (half-circle, 0.6mm radius) has small (~10 micron) SiO_2 grains (~43%, volume) surrounded by an interstitial layer of iron oxide although SEM spectra of the iron oxides are never Si free. The fragment is completely rimmed (i.e. rim appears to have formed after fracturing) by what may be fine-grained olivine. The pyroxene composition appears uniform ($En_{87}Wo_0$).

The bulk composition of these chondrules is probably similar to some reported by McSween [2] from unequilibrated ordinary chondrites and Kakangari, except that ours are probably more deficient in CaO and Al_2O_3. Presumably, the SiO_2-rich phase in the chondrules of McSween is typical chondrule glass; ours is probably more crystallized.

Either the chondrule formation process is capable of occasionally producing quartz-normative compositions or there are chondrule source materials of such compositions. If chondrules are formed by impact on planetary surfaces, then otherwise unsampled parent bodies are implied. If chondrules are formed by condensation then condensation paths to SiO_2-rich compositions are required, which are not obvious.

References: [1] Murrell M.T. and Burnett D.S. (1982) this meeting.
[2] McSween H.Y. (1977) Geochimica-Cosmochim. Acta 41, 1843-1860.

RARE-EARTH ELEMENT ABUNDANCES IN CHONDRULES FROM UNEQUILIBRATED CHONDRITES.

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Abundances of the rare-earth elements (REE) La, Sm, Eu, Yb, and Lu were determined by instrumental neutron activation analysis (INAA) for individual chondrules separated from 11 different moderately to highly unequilibrated ordinary chondrites. Each chondrule was subsequently characterized petrographically and by electron microprobe analysis. Average whole-chondrule results were as follows:

	Geometric Mean Abundance, Normalized to Cl Chondrites					
Chondrite	No.	La	Sm	Eu	Yb	Lu
Tieschitz (H3)	17	1.5	1.7	1.4	1.6	1.4
Dhajala (H3, 4)	15	1.6	1.7	1.3	1.7	1.7
Ochansk (H4)	8	0.67	0.93	1.1	1.4	1.1
Weston (H4)	11	1.2	1.5	1.3	1.8	1.8
Hallingeberg (L3)	24	2.0	2.3	1.6	2.0	2.3
Saratov (L4)	13	1.2	1.3	0.95	1.6	1.7
Tennaisilm (L4)	6	1.3	1.1	1.4	1.4	1.4
Chainpur (LL3)	14	1.5	1.6	1.4	1.7	1.1
Semarkona (LL3)	15	1.5	1.9	1.7	1.6	1.7
Hamlet (LL4)	8	1.6	1.9	2.1	2.1	1.8
Soko-Banja (LL4)	7	1.2	1.5	0.96	1.4	1.2

Within any one suite (chondrules from the same chondrite), a wide variety of chondrule REE patterns may exist, including both those with positive and those with negative Eu anomalies. However, geometric mean patterns are remarkably similar among the various suites and are either approximately flat or slightly enriched in heavy REE (i.e., Cl chondrite-normalized Yb/La $\geq$ 1). Two of the most highly equilibrated chondrule suites studied (Ochānsk, Tennasilm) have small positive Eu anomalies and pronounced relative enrichments in heavy REE, implying that the process of "equilibration" may involve redistribution of REE. However, the same type of pattern is exhibited by a suite of much less equilibrated chondrules from Hamlet, thereby clouding the explanation of the effect.

For highly unequilibrated chondrites (Tieschitz, Hallingeberg, Chainpur, Semarkona), subdivision of chondrules into porphyritic and nonporphyritic types produces two appreciably different average REE patterns with the geometric mean porphyritic group being more highly enriched in all REE and exhibiting a smaller negative Eu anomaly.

Among individual chondrules, total REE abundance is generally correlated with abundances of refractory lithophile elements (e.g., Ca, Al) and, among porphyritic types, total REE content is weakly to moderately correlated with the abundance of chondrule mesostasis. Thus, chondrule mesostasis may contain information about at least one of the components which was melted to form chondrules. The mesotasis portions of REE-rich porphyritic chondrules are enriched in Ca (up to $\simeq$14% CaO) but not P ($\leq$0.04% P_2O_5). Na and K are also concentrated in the mesostasis but do not appear strongly correlated either with REE or P abundances. Therefore, the REE-rich component in the chondrule precursor materials was probably neither a phosphate nor a differentiated igneous analog of lunar KREEP. Instead, the chondrule REE carrier was probably a Ca, Al-rich silicate or oxide which possessed or experienced fractional partitioning of Eu prior to or during chondrule formation.

ISOTOPE RATIOS IN CANYON DIABLO IRON; R. G. Downing* and O. K. Manuel, Dept. of Chemistry, Univ. of Missouri, Rolla, MO 65401 U.S.A.

Noble gases were extracted in five incrementally higher temperature fractions from a 150 g interior specimen of Canyon Diablo. The sample was heated by direct coupling with a R.F. coil, avoiding the need and complications of a crucible. This large sample size and crucible-free environment allowed a more reliable evaluation of the gas composition by nearly eliminating the need to deconvolute background from sample.

Gas abundances observed in meteoritic iron are typically low and this specimen yielded values lower than most; yet, not atypical for the Canyon Diablo meteorite. The isotopic composition of helium, neon and argon show no indication for a trapped component, but only that of spallation. On the other hand, in addition to spallation products, krypton and xenon can be shown to contain a type-Y "planetary" component which is in contrast to the oxidized carbon-rich residues of chondrites that have trapped the type-X "strange" component.

Spallation ratios of the five noble gases varied distinctly from one temperature fraction to the next. Extensive computations show that any single irradiation model for the sample's target chemistry and/or shielding artifacts would need to be elaborately complex. Spallation ratios of both krypton and xenon tended to vary with those of neon and not of argon which rules against fractionation as a viable explanation for the variance in the ratios for the light gases. It is therefore suggested that portions of the material may have additionally undergone an irradiation prior to assemblage.

Two further observations were made for the heavy gases. (i) The excess component of Xenon-129 and Xenon-131 fit a neutron capture pattern for tellurium at energies greater than 0.4 eV, rather than the pattern expected for an incorporation of primordial Iodine-129 or the presence of exotic interstellar dust. (ii) Calculations also indicate that the maximun excess of Xenon-136 in the sample that could have resulted from any super heavy element fission is 600 atoms/g if the trapped xenon component is taken as atmospheric-like, however the yield could be as high as 6,000 atoms/g if AVCC xenon is assumed for the trapped component.

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ISOTOPIC COMPOSITION OF Ag, Cd AND Pb AT ULTRALOW LEVELS IN IRON METEORITES, J. H. Chen and G. J. Wasserburg, The Lunatic Asylum of the Charles Arms Laboratory, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California, 91125.

We report on Pd, Ag, Cd, U and Pb in metal, sulfide, and phosphide phases of iron meteorites (III). Because of contamination, all samples were etched with aqua regia and the interior pieces analyzed (1). The results on (1.3-14) × 10^{12} atoms of ^{109}Ag from the Cape York metal show an increase in ^{107}Ag/^{109}Ag of 6.5±1.1°/oo (2σ) relative to normal Ag. The δ^{107}Ag values determined on a second piece of Cape York also show an 8.9 ± 1.5°/oo shift with higher Pd/Ag. A Cape York sulfide sample provided by V.Buchwald was etched in hot 12M HCl. The central piece of sulfide has a factor of ~20 higher Ag concentration than the metal, but 10^3 times lower Pd. The ^{107}Ag/^{109}Ag for the the sulfide is normal within ± 2°/oo. An isochron from the metal and sulfide data has a slope corresponding to $^{107}\mathrm{Ag}^{*}/^{108}\mathrm{Pd} = (1.7\pm0.5)\times10^{-5}$ and an initial δ^{107}Ag of 1.6±1.5°/oo with an $^{107}\mathrm{Ag}^{*}$ abundance which is similar to that found previously in group IV. The Ag isotope results from the Grant metal agree with those obtained by Kaiser and Wasserburg (2), however, the new data are of higher precision. The results show a 13.6±1.2°/oo increase in the δ^{107}Ag values. In addition, ~0.2 g of schreibersite was analyzed to find a higher Pd/Ag ratio than the metal (3). The Pd/Ag ratio in the schreibersite is close to that in the metal and the δ^{107}Ag value is slightly higher (18.3±2.7). The Pd-Ag results support the explanation that ^{107}Ag was derived from in situ decay of ^{107}Pd which was present in a wide variety of iron meteorites. The concentrations of Pb in the metal from Cape York and Grant are 8.5×10^{12} and 5.2×10^{12} Pb atoms/g and are 10^2–10^3 lower than previously reported (4). The Pb in Cape York and Grant are more radiogenic than in Canyon Diablo troilite. The Pb concentration in the surface material dissolved by etching of the Cape York sulfide is 10^2 higher than that in the center (~1.1×10^{13} atoms/g) and the ^{206}Pb/^{204}Pb ratios in the surface are close to terrestrial Pb (17.89) while that in the center is also rather radiogenic (14.64). Radiogenic Pb has been introduced into the meteorites sometime during their history. The U concentration in Cape York metal is ~ 7×10^9 atom/g. To determine the effect of thermal neutron irradiation, we measured the isotopic composition and concentration of Cd in the metal phases of Cape York and Grant. A tracer of ^{106}Cd was added to a piece of the Cape York prior to dissolution to determine the concentration. Cd is ~ 3×10^{11} atoms Cd/g in the Cape York metal and ~7.4×10^{11} atoms Cd/g in the Grant metal which are 10^2 times lower than the values given for iron meteorites in the literature (5). The isotopic composition of Cd determined on (2.5-8)× 10^{11} atoms of ^{114}Cd from Cape York and Grant is within (2-7)°/oo the same as normal Cd. The ^{116}Cd/^{112}Cd ratios are also close to normal after correcting for a 1-10% contribution of ^{116}Sn. If the Cd data were normalized to the shielded isotopes ^{108}Cd/^{110}Cd the results for ^{111}Cd/^{110}Cd and ^{113}Cd/^{110}Cd are within a maximum error of 14°/oo the same as normal. There is no evidence for shifts in the isotopic composition of Cd. The preliminary results indicate that for both the Grant and Cape York, the upper limits for contributions by fission from a siderophile SHE are 11×10^8 atoms/g at mass 111 and 21×10^8 atoms/g at mass 112. If we use the measured limits on the variations in abundance as an estimate of fission products using the more precise normalization to ^{110}Cd/^{114}Cd then the limit is ~6×10^8 atoms/g for the isobaric yield in the mass region 111 to 116. The maximum depletion of ^{113}Cd due to neutron capture for both meteorites is 3°/oo. This corresponds to neutron fluence of less than ~ 2 × 10^{17} n/cm which does not exclude some possible ^{109}Ag production proposed by Kaiser and Wasserburg (6).

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EXPERIMENTAL GEOCHEMICAL INVESTIGATIONS OF MAGMATIC IRON METEORITES: MODELING COMPLEXITIES. John H. Jones and Michael J. Drake, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721.

Systematic trends in trace element concentrations within several magmatic iron meteorite groups appear to be consistent with an origin by fractional crystallization of a parent body core [1]. In order to examine this hypothesis we have investigated the dependence of solid metal/liquid metal partition coefficients for a number of elements upon S-content of the metallic liquid [2]. Complementary investigations at Lehigh University have concentrated on the dependence of partition coefficients on P- and C-contents of the metallic liquid and solid phases [3,4]. Both groups have shown that increases in S-, P- and C- concentrations in metallic liquid profoundly affect the magnitude of a number of partition coefficients and, hence, trace element trends in the crystallized product.

Using our previously reported partition coefficients [2] in Fe-Ni-S-X systems (X = trace element) and partition coefficients from Fe-Ni-P-X systems [4] we have attempted to match observed log X versus log Ni trends for P, Ir, Au and Ge in groups IIAB, IIIAB and IVA, using a simple fractional crystallization model [5]. The model assumes diffusion in the solid to be negligible and explicitly accounts for variations in partition coefficients during crystallization. Adjustable variables are the initial concentrations of S, P, Ir, Au, Ge and Ni. Observed trends for P, Ir, and Au can be acceptably reproduced for each meteorite group, but Ge trends cannot be matched in an internally consistent manner (see also [4]). Resolution of this discrepancy within the framework of a fractional crystallization process requires a higher value for the Ge partition coefficient at low S- and P-concentrations than is observed experimentally. Simple addition of S and P cannot be invoked to explain precise log Ge versus log Ni trends for groups IIAB, IIIAB and IVA. Germanium and (probably) Ga join W and Cr as elements which cannot be readily modeled [2].

A feature common to Ge, Cr and W in magmatic iron meteorites is that experimentally determined partition coefficients are smaller than values inferred directly from the meteorites. A resolution of this discrepancy would be an affinity of Ge, Cr and W for an oxide or silicate phase. Preliminary experiments involving chromite and Fe-Ti oxides appear to rule out this proposal for Ge and W. It would appear that magmatic iron meteorites evolved in a more complicated manner than simple fractional crystallization. Germanium, Cr and W contain the code which remains to be deciphered.

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EXPERIMENTAL STUDY OF WIDMANSTÄTTEN PRECIPITATION IN Fe-Ni-P ALLOYS - IMPLICATIONS ON METEORITE COOLING RATES

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Theoretical models that simulate the growth of the Widmanstätten pattern have been the basis for the determination of cooling rates of meteoritic bodies. The predicted cooling rates for different bodies range from 1 to 100°C/Myr. Geophysical studies indicate that these cooling rates are probably too low. The purpose of this study was to grow Widmanstatten precipitates in the laboratory and develop a kamacite growth model based on experimental results.

Homogeneous Fe-base alloys containing 5-8 wt.%Ni and 0.1-0.8wt.%P were heated into the single phase (taenite) region and slow cooled through the two phase (kamacite & taenite) field to grow the Widmanstätten precipitates. Kamacite nucleated and grew within the taenite grains with a rod shaped morphology. The samples were examined in an analytical electron microscope and Ni concentration profiles were measured across precipitate-matrix interfaces. Figure 1 shows a typical Ni profile that was measured across a kamacite/taenite interface in an Fe-6.6wt.%Ni-0.3wt.%P alloy that was slow cooled from 790°C to 650°C at the rate of 5°C/day and then quenched to room temperature. The experimentally determined composition profiles were compared with profiles predicted by a ternary model that simulated the diffusional growth of kamacite. Results suggest that the diffusivity data for Ni are incorrect and underestimate the growth rate of kamacite. Using corrected diffusivity values in a model for Widmanstätten growth, one predicts cooling rates, of meteoritic bodies, 10 to 20 times higher than previously determined.

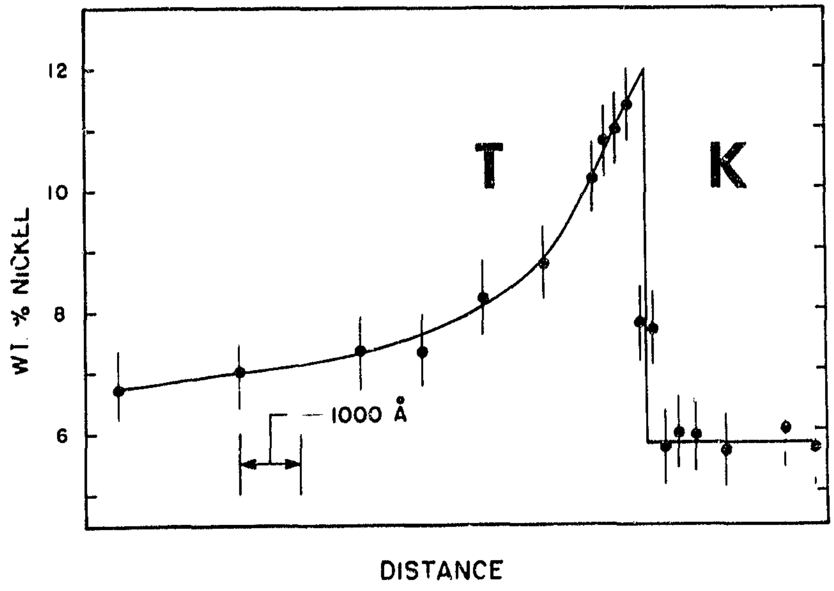

Figure 1

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A MULTIELEMENT STUDY OF UNGROUPED IRON METEORITES HAVING GE CONTENTS BETWEEN 20 AND 70 μG/G. D.J. Malvin and J.T. Wasson, Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024.

The compositional classification of iron meteorites is mainly based on the clustering observed on Ga-Ni and Ge-Ni diagrams; Ir is used to identify a meteorite's relationship to other group members. We used instrumental neutron activation analysis (INAA) to determine Cr, Co, Cu, As, W, Re, and Au in addition to redeterminations of Ni, Ga and Ir in a number of IIIAB irons and in others having similar Ge and Ni concentrations.

Copper shares many of the properties that make Ga and Ge such excellent taxonomic parameters, and we have increased our file of Cu data by a new reduction of INAA data published by E. Scott. Within magmatic groups low negative slopes are found on log Cu-log Ni diagrams; the range of Cu maximum values in the magmatic groups extends from 330 μg/g in IID and IIF to 2 μg/g in IVB. The Cu range in group IIIAB is from 180 to 115 μg/g. Literature Cu data >200 μg/g on the IIIAB irons Kenton County, Kyancutta, Loreto, and Tamarugal suggested these to be anomalous, but our new investigations show all to have normal IIIAB compositions in terms of all elements in our data set.

Two anomalous members of group IIIAB, Delegate and Treysa, have concentrations of Ir, Re, and W much higher than other IIIAB irons with greater than 90 mg/g Ni, but their contents of other elements are within the element-Ni fields for normal group members. During fractional crystallization Ir, Re, and W strongly favor the solid phase, thus these meteorites may be mixtures of early formed native metal debased by intimate contact with a more mature liquid.

We have investigated IIE irons and potentially related ungrouped irons. Group IIE is a collection of very different meteorites in terms of mineralogy and structure. We find that Barranca Blanca and Arlington should be redesignated IIE-anomalous on the basis of their Cu contents >400 μg/g, 2X higher than the typical IIE ranges. Eight ungrouped meteorites, Chebankol, Glenormiston, Gun Creek, Hammond, Kingston, Leshan, Reed City, and Techado, ahve Ni, Ga, and Ge near the IIE range. For each meteorite about 80% of the elements in our data set fall within accepted IIE element-Ni fields. The most closely related, Glenormiston, deviates chiefly in terms of Ir 2X low, and is reclassified an anomalous member of IIE. In the remaining irons some elements disgress sufficiently that we prefer to leave them ungrouped rather than IIE-An.

New Baltimore (64 mg/g Ni, 36 μg/g Ge) is a structurally unique meteorite composed of large kamacite grains adjacent to areas of mm-wide kamacite lamellae. Its trace element data show similarities to IIIAB irons, but there are too many differences to justify reclassification. The Victoria West (31 μg/g Ge) fine octahedrite we now find should be reassigned to group IIICD although its Ir content is low by a factor of ∿3.

THE KENDALL CO. IRON WITH SILICATE INCLUSIONS: A UREILITE CONNECTION?

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Previous surveys of irons with silicate inclusions have found Kendall Co. to be unique. This study focuses on Kendall Co. specifically and relates it to other meteorites, prior to gathering trace element and isotopic data. Slices of the meteorite reveal a complex mixture of metal, graphite and silicates. Metal is kamacite (no taenite), has low Ni (5.4%), unusually high C (1.3%) and is ungrouped, near IA. Masses of fine graphite are often at the cores of silicate-troilite-kamacite aggregates. Silicates are fine grained (10-200 microns), equigranular and irregular. Modally they are: 15.5% olivine (Fo98-99), 15.4% orthopyroxene (En96-99), 42.9% clinopyroxene (Wo43-47, En53-56), 0.8% plagioclase (An9-49), 22.5% tridymite, and 2.9% chromite. Some unusual features are high MnO (0.8%) and Cr_2O_3 (0.1%) in olivine, high MnO in orthopyroxene (0.2-1.2%), clinopyroxene (0.1-0.8%) and chromite (3.5%), very high Mg/Fe in chromite, plagioclase range from albite to andesine, coexisting olivine and tridymite, and dominance of clinopyroxene.

Coexistence of olivine and tridymite indicates disequilibrium and is probably the result of high temperature redox reactions between a precursor more Fe-rich silicate assemblage (cpx + ol$\pm$ opx) with metal in the presence of carbon. The reaction of the C with the FeO components in the olivine and pyroxene may have formed Fe^0+SiO_2+CO. SiO_2 and forsterite are unstable and reacted to form enstatite when in contact; olivine-rich areas are enriched in orthopyroxene but have little tridymite. The high abundance of tridymite indicates extensive reactions.

The precursor and present silicate assemblages are not chondritic; they are dominated by clinopyroxene, have plagioclase which is too calcic, and the present assemblage is rich in tridymite. Rough mass balance calculations using the above reactions indicate a precursor silicate assemblage with Mg/Fe about 80, and predominantly clinopyroxene-olivine-carbon-iron. The recalculated assemblage clinopyroxene + olivine+ graphite is most plausibly considered to be a cumulate, and similar to a late cumulate that may have formed from the magma body from which the ureilites were early cumulates. Ureilites differ slightly as they usually contain pigeonite instead of augite and diamond as well as graphite, and are dominated by olivine (but a later stage can be dominated by clinopyroxene). Ureilites also have Ca-Cr-rich olivine and essentially no chromite; however, ureilite olivine may have formed early from a Cr-saturated melt, whereas the precursor Kendall Co. assemblage may have formed at a later stage after chromite began crystallizing with clinopyroxene and plagioclase. Kendall Co. may provide a fuller insight into the nature of the melt from which ureilites formed. Silicate inclusions in IAB irons and winonaites are predominantly olivine-orthopyroxene-carbon-iron assemblages. Originally they may also have been more Fe-rich silicates which reacted at high temperatures with the metal under reducing conditions. However, there is presently no evidence for or against this hypothesis, perhaps because the reactions have reached completion. It is intriguing to speculate that the oxygen isotopes of ureilites, winonaites (including Tierra Blanca), and IAB silicates lie on a line which may be a mass fractionation line below the Earth-Moon line, possibly indicating derivation from the same nebular source region and perhaps the same carbon-rich planet. Further data on Kendall Co. should help clarify its origin and relationships to other meteorites.

METALLOGRAPHIC OBSERVATIONS OF THE ELTON AND WIMBERLY OCTAHEDRITES;

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ABSTRACT: Metallographic examinations of the Elton and Wimberly iron meteorites indicate that they are medium octahedrites. The presence of a number of troilite-schriebersite inclusions, which appear to be Fe-Ni-S-P, coarse-grained eutectics, suggest that Elton is related to Group II B, as is confirmed by its trace element chemistry. The fusion crust and α_2 zone are well-preserved. Elton is characterized by a bulk Ni content of 6.9 wt. %, a kamacite bandwidth of 1.0 ± 0.15 mm, and a kamacite Vickers microhardness of 210 ± 15.

Wimberly is recrystallized and contains graftonite. Schriebersite islands are observable near all taenite-kamacite phase interfaces. These minerals and their structural relationships strongly indicate that this meteorite is a member of Group III B. No evidence of a fusion crust, α_2 zone, or heat affected zone is observable on the examined section. Wimberly is characterized by a bulk Ni content of 9.8 wt. %, a kamacite bandwidth of 0.9 ± 0.15 mm, and a kamacite Vickers microhardness of 185 ± 8.

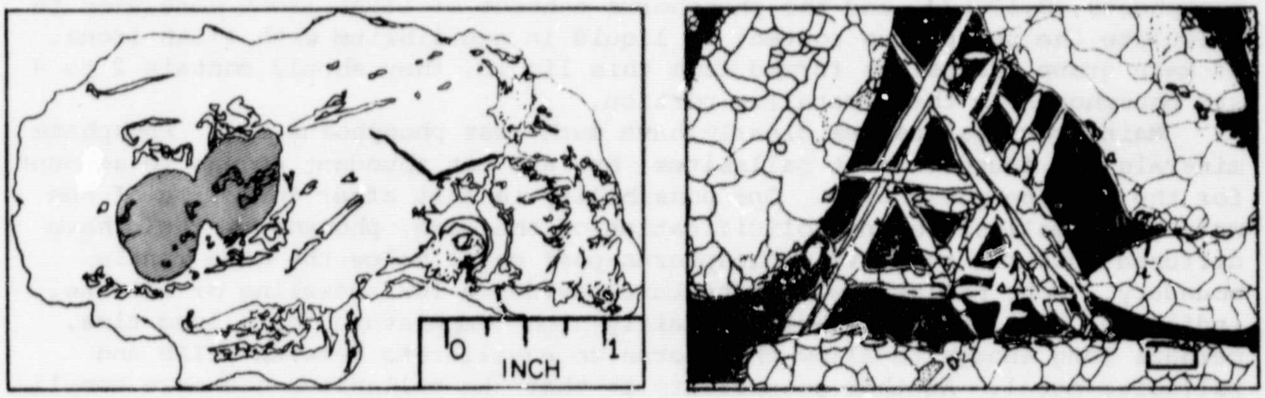

Figure 1. (Left) Elton. The polished and etched face of the main mass. A double trolite-schriebersite rosette is plainly visible in the left side of the section. Octahedral fractures, Brezina lamallae, and oriented skeleton schriebersite crystals stand out in high contrast throughout the section (deep etched). Figure 2. (Right) Wimberly. A triangular acicular and pearlitic plessite field which formed parallel to major Widmänstatten directions. All kamacite is recrystallized. There are numerous phosphides precipitated along the taenite-kamacite boundaries. Scale bar = 200 μ, etched.

PHOSPHORUS IN MAIN GROUP PALLASITES. Andrew M. Davis, James Franck Institute, The University of Chicago, Chicago, Illinois 60637.

Textures in many pallasites suggest that a mass of crystalline olivine was invaded by molten metal. In addition to metal and olivine, important minor phases found in pallasites are schreibersite and troilite. At temperatures high enough to melt metal, these minor phases would not have been stable and sulfur and phosphorus would have been dissolved in the melt. Point counts of nearly all known pallasites [1] were used to calculate the bulk composition of the metallic melt for each pallasite. The metallic portions of main group pallasites contain 0.3 ± .1 to 0.6 ± .1 wt% phosphorus, depending on how much phosphorus is assumed to be in solid solution in metal and in fine grained schreibersite and rhabdites not included in the point counts.

Group IIIAB iron meteorites are widely believed to have formed by fractional crystallization of an initially molten mass of metal, probably at the core of a planetesimal. The main group pallasites seem to be closely related to the IIIAB irons on the basis of trace element chemistry and Scott [2] has suggested that pallasite metal represents the liquid from which the IIIAB irons crystallized. He found a good match between pallasitic metal and the liquid left after 80% of the IIIAB metal had crystallized.

The recently measured ternary solid/liquid distribution coefficient for phosphorus, 0.12 [3], and the phosphorus content of IIIAB irons were used to calculate the phosphorus content of liquid in equilibrium with IIIAB irons. If main group pallasites formed from this liquid, they should contain 2 to 4 wt% phosphorus in their metallic portion.

Main group pallasites clearly have much less phosphorus now. Phosphate minerals are found in most pallasites, but are not abundant enough to account for the missing phosphorus. One possibility is that after formation of the main group pallasites and solidification of the core, phosphorus could have diffused into the relatively phosphorus-poor metal below the core mantle boundary. Most pallasites show textural evidence for annealing of olivine, indicating that they were held at fairly high temperature for a long time, perhaps long enough to allow phosphorus to equilibrate between IIIAB and pallasite metal. Another possibility is that the pallasites had more complicated history, in which IIIAB irons and olivine formed in a planetesimal, but there was little initial mixing. A later heating event remelted the metal and mixed it with olivine. This model would explain the similarity in the abundances of phosphorus and many trace elements between main group pallasite metal and IIIAB irons , but it calls for an unusual thermal history for the parent body.

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THE FORMATION OF PALLASITIC CHONDRULES:EVIDENCE FOR RAPID SOLIDIFICATION UNDER MICROGRAVITY CONDITIONS

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The microstructural features of pallasitic chondrules are clues to conditions in effect during solidification. We employ surface energy theory,analytical welding metallurgy,the findings of solidification experiments done under microgravity conditions, and past works on meteoritics to reexamine the formation of pallasite chondrules.

Previous investigators have overlooked the powerful influence of microgravity (or free fall) on chondrule formation. Springwater pallasite, a stony-iron meteorite whose microstructure has been characterized as remarkably smooth and undisturbed since crystallization occurred, is used as a model in this study. The similarities of morphologies between Springwater olivine chondrules and soap bubble aggregates suggest that chondrules solidified in an environment where surface energy forces dominated gravity forces, i.e., microgravity. This factor successfully explains the apparent contradiction of the co-existence of angular and rounded olivine features not only within the same sample, but also in one and the same olivine. Both rounded and angular morphologies can be generated within weightless molten olivine aggregates. These forms have been frozen in by rapid solidification.

Rapid solidification is the second important factor in pallasite formation. Non-equilibrium metal phases such as martensite in the pallasite microstructure attest to non-equilibrium formative conditions. This solidification was probably on a time scale of tens or hundreds of Centigrade degrees per minute or per day.

The picture of a pallasite melt solidifying rapidly in microgravity successfully answers "the pallasite problem."Under microgravity, density differences do not exist and the close association between olivine and metal phases is unremarkable.

The classic Kokscharow paper on the Pallas Iron chondrules includes a detailed description of the Pallas Iron by Pallas. This description closely matches that of Springwater. However, a careful reading indicates that Kokscharow's familiarity with goniometry influenced his interpretation of his observations. It can be shown that what Kokscharow characterized as crystal faces are olivine-to-olivine contact planes (or bubble-to-bubble interfaces).

Possible scenarios for pallasite formation consistent with rapid solidification under microgravity conditions include the breakup of a molten body or the spalling off of molten pieces from a body which is at least partially molten.

Rapid solidification under microgravity conditions is a simple, consistent, successful hypothesis for pallasite formation.

THE ZAISHO PALLASITE, A BEARER OF PYROXENE AND PHOSPHORAN OLIVINE

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The Zaisho meteorite, one of only four pallasite falls, has recently been made available for study; it turns out to have several interesting and unusual characteristics. Zaisho is exceptional in that it contains pyroxene, which is rare in pallasites, and it is only the fourth meteorite known to have phosphoran olivine. To date, such olivine is limited to pallasites, and seems to be restricted to those that contain the rare magnesium phosphate, farringtonite. Zaisho also contains stanfieldite and a phosphate having a composition intermediate to that of stanfieldite and farringtonite.

As in the seven other pallasites known to contain pyroxene, the Zaisho pyroxenes occur in symplectic intergrowths around some of the olivines; lacy troilite is a prominent feature. Zaisho also belongs to the small group of pallasites (Springwater and Phillips Co.) with both olivine and pyroxene having Fe/(Fe + Mg) ratios overlapping those of the H-group chondrites. As in the case of pyroxene from the other pallasites, the Zaisho pyroxene contains a lower Ca content than that of chondritic pyroxenes.

The phosphoran olivines of Zaisho appear similar to those in the other pallasites. However, occurrence and crystallographic location of the phosphorous in phosphoran olivine remains a problem. Charge balance could be provided by lithium, but an ion microprobe search produced negative results. A full anisotropic least squares single crystal structure refinement was performed (46 parameters and 713 reflections), but did not establish the presence or location of phosphorus or of compensating vacancies in the structure. Microprobe analyses of the phosphoran olivine suggest a mechanism like that in isostructural terrestrial phosphates such as heterosite $[\square(Fe^{3+},Mn)PO_4]$ and sarcopside $[\square FeFe_2(PO_4)_2]$ that achieve charge balance by having vacant octahedral sites. Atomic proportions of the octahedral cations in the phosphorus-free olivines total 2.02±.02, whereas those in phosphoran olivine total 1.95±.03. The atomic proportions of phosphorus in these olivines range from 0.06 to 0.10 and so, for charge balance by vacancies, we would predict a cationic deficit of 0.03 to 0.05 in the octahedral sites. These predicted values are close to the observed value of 0.05±.03. It thus appears as if charge balance may be achieved by octahedral site vacancies.

Zaisho exhibits several relatively unusual features, and Springwater shares them. The two meteorites landed on opposite sides of Earth; nonetheless, the unusual features the two pallasites have in common suggest that they have a related origin and source.

IGNEOUS PHOSPHORUS REDOX REACTIONS IN MESOSIDERITE SILICATES.

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The total exclusion by Harlow et al. (1) of igneous in favor of metamorphic P-silicate reactions in the mesosiderite parent body as a source of phosphate (merrilite) and silica enrichment of mesosiderites is not justified. Conversely, igneous P-silicate reactions do not exclude the metamorphic type after whole or partial solidification and brecciation of these rocks. However, igneous reactions have the advantage of explaining decreasing Fe/Mn trends with increasing FeO in mesosiderite orthopyroxenes as well as FeO depletion and phosphate and silica enrichment of mesosiderite bulk silicates compared with howardites.

Agosto et al. (2) incorporated all the above mesosiderite trends in their proposed igneous reaction

$$3CaMgSi_2O_6 + 5FeSiO_3 + 2[P]^{Fe} = Ca_3(PO_4)_2 + 3MgSiO_3 + 8SiO_2 + 5Fe \quad (a)$$

where $[P]^{Fe}$ refers to elemental P derived from metal. Harlow et al. (1) have proposed (a) as one of a suite of 4 metamorphic reactions (their model 2) to explain phosphate and silica enrichment. However, (a) is the only reaction of the suite that associates FeO reduction with phosphate formation, and two of the remaining reactions require Fe^o oxidation for phosphate formation. Accordingly, FeO enrichment rather than depletion of mesosiderite bulk silicates is more likely in the Harlow metamorphic scenario. In that respect, it is inconsistent with mesosiderite chemistry.

By assuming that dissociation of ferrosilite controlled fO_2 of mesosiderite parent melts according to the reaction $2FeSiO_3 = 2Fe^o + O_2 + 2SiO_2$ (b) Agosto (3) estimated the fO_2 of formation of 14 mesosiderites based on the data of Nash and Hausel (4) and Fs and Si activities derived from mesosiderite bulk silicate chemistries in combination with modal abundances of these phases determined by Prinz et al. (5). The fO_2 estimates correlate negatively with the P_2O_5 contents of the 14 rocks to a 95% confidence level, consistent with the idea that phosphate formation accompanies FeO reduction and silica enrichment. Reactions (a) and (b) can be combined as

$$45(Ca_{.09}Mg_{.56}Fe_{.35})SiO_{3cpx} + 2[P]^{Fe} =$$

$$Ca_3(PO_4)_2 + 35(Ca_{.03}Mg_{.72}Fe_{.25})SiO_{3opx} + 10SiO_2 + 7Fe + O_2 \quad (c)$$

where cpx and opx are typical mesosiderite pyroxenes. If reaction (c) to the left is applied to bulk mesosiderite silicate analyses of Simpson and Ahrens (6), Floran et al. (7), and Jarosewich, the averages of each researcher move from the mesosiderite to the howardite field in the Ol-An-Si pseudoternary diagram adapted from Stolper by Mittlefehldt et al.(8). Thus, in addition to the above mesosiderite trends, reaction (c) genetically links howardites and mesosiderites in an igneous process and is consistent with crustal foundering through liquid mantle to a planetesimal metal core proposed by Chapman and Greenberg (9) as a mechanism of mesosiderite formation.

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SUPERNOVAE, OB ASSOCIATIONS, AND THE ORIGIN OF THE SOLAR SYSTEM

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The continuation of the work of Olive and Schramm, following the work of Reeves on the evolution of OB Associations and the role that they would play in the origin of the solar system, and meteoritic abundance anomalies is presented. It is shown that three independent arguments all argue in the favor of the solar system having been significantly enriched in the heavy elements by factors of the order of 2 to 3, relative to the average heavy element composition of the interstellar medium, and the primordial molecular cloud out of which the OB association initially formed. These arguments are (1) mass of heavy elements ejected from supernovae when normalized to ^{26}Al and ^{107}Pd yields, (2) amount of processing through stars that the average interstellar medium has encountered and thus implying enrichment in associations, and (3) present observations of heavy element abundances in star-forming regions around the galaxy. In addition, new hydrodynamic arguments following the work of Cox (1981), show that supernovae ejecta will not mix with the entire 10^5 solar mass molecular cloud, but only with approximately $1000_{\odot}$ which go to form stars, thus yielding the enrichments quoted by Olive and Schramm, rather than the greater dilution used in the models of Reeves. Comparisons with cosmic ray and interstellar medium isotopic ratios are presented as is a discussion of the implications on variable C/O ratios, which will be a natural consequence of this enrichment. It will also be argued that the supernovae enriching the solar system did not enrich it in ultra-heavy r-process elements. This is argued from both observational (^{244}Pu timescale) and theoretical grounds that the r-process does not occur in the typical supernovae which produces heavy elements and ^{26}Al and ^{107}Pd in particular. Thus, the site for the actinide-producing r-process is not a typical supernovae, although some r-process-like enrichments will occur in a typical supernovae. Discussion of alternative r-process sites will be presented in separate work by Symbalisty.

VII-2

DUST-GAS FRACTIONATION IN THE EARLY SOLAR SYSTEM

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Both the elemental and isotopic compositions of chondritic meteorites are suggestive of extensive gas-dust fractionation in the nebula prior to accretion. With few exceptions (1,2), in most previous work a small fraction of the dust was assumed to be lost from the system at various stages during cooling and condensation. Such a process has little or no affect on the normal condensation sequence (3). But the discovery of isotopic anomalies seemingly implies that some dust was present originally and persisted through nebular processing. This raises the possibility of gas-dust fractionation prior to or during evaporation and recondensation. Dust enrichments in some regions and depletions in others will affect the stability fields of minerals in a predictable manner.

Consistent with the observed distribution in interstellar clouds, we have assumed the dust to consist of the more refractory cations (Al, Ca, Fe, Mg, Si, Ti, etc.) plus their associated oxygen. All the more volatile elements are assumed to be in the gas phase. Chemical equilibrium calculations were performed over a range of fractionation factors and P-T conditions. For illustrative purposes, the stability fields of the minerals are compared to their stabilities in a system with solar composition. Dust enrichments expand the stability fields of all condensates to higher temperatures and vice versa. Oxides and silicates become progressively more stable than metals at high dust concentrations. At dust enrichment factors of about 20 to 25 ($@P_T = 10^{-3}$ atm), a large liquid field is encountered. The activity of FeO in such liquids would be about 0.01, or higher at larger enrichments factors. If hibonite condenses shortly after Al_2O_3 in a solar gas (4) it almost certainly condenses before Al_2O_3 in a dust enriched system. On the other hand, in dust depleted regions the stability fields shrink, the system is somewhat more reducing and ultimately the condensates become more enriched in volatiles.

If the dust carries a unique isotopic signature, as generally assumed, then gas-dust fractionation will render the system both elementally and isotopically fractionated. Obviously such a process may provide some comparatively simple explanations for a variety of observations.

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SOLAR-SYSTEM ABUNDANCES OF THE ELEMENTS: A NEW TABLE

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We have compiled a new abundance table, based on a critical review of all C1 chondrite analyses up to mid-1982. Where C1 data were inaccurate or lacking, we have used data for other meteorite classes, but with allowance for fractionation among classes (*1-4*). In a number of cases, interelement ratios from lunar and terrestrial rocks (*5*) as well as solar wind (*6*) were used to check and constrain abundances.

For most elements, the new abundances differ by less than 20% from those of Cameron (7), but the improved agreement with known interelement ratios shows that the changes were in the right direction, and have reduced the "noise" in the data. In 13 cases, the change is between 20 and 50% (Be, P, Br, Nb, Te, I, Xe, La, Gd, Tb, Hg, and Pb), and in 3 others, it exceeds 50% (B, Mo, W). Some important interelement ratios (Na/K, Se/Te, Rb/Sr, Ne/Ar, Kr/Xe, La/W, Th/U, Pb/U, etc.) are significantly affected.

On the basis of the new data, we shall reexamine certain perennial questions, e.g.:

1. Difference between solar and C1 chondrite abundances
2. Is abundance of odd-A nuclides a smooth function of mass number?
3. Hydrothermal activity in the C1 chondrite parent body: chemical consequences
4. Fractionation of C2's and C3's relative to C1's.

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AS THE WORLD TURNS: ANGULAR MOMENTUM AND THE SOLAR NEBULA. John A. Wood, Harvard-Smithsonian Center for Astrophysics, Cambridge MA 02138

The current nebula model of Cameron (1) does not envisage the simultaneous collapse of a volume of interstellar gas, as his earlier models (e.g., 2) did, but the infall and accretion of interstellar matter over a period of 10^4-10^5 years. The nebula is heated not by adiabatic compression, but by continuing viscous shear in the gases.

Cameron develops the properties of two submodels, which assume different initial values for the specific angular momentum (J/M). Model A, which Cameron favors, has $J/M = 2.1 \times 10^{20}$ cm^2/sec, a value thought typical of interstellar cloud material. This is 1300 times the solar system's present J/M. With such high J/M, model A has a large disk/protosun mass ratio, is gravitationally unstable, and breaks into giant gaseous protoplanets. Model B assumes only 1/10 as much J/M, has a smaller disk/protosun ratio, and is only marginally unstable against breakup into protoplanets.

I will argue that the properties of chondritic meteorites are more compatible with model B than model A. It may be inappropriate to assume a typical interstellar value of J/M for the cloud fragment that was to become the solar system, since the sun is not a typical star. Most stars of the sun's spectral class are members of binary or multiple systems, which possess much larger J/M than the solar system does. I suggest that the solar system formed from a cloud fragment with atypically low J/M, and nebula models qualitatively similar to model B of (1) are more likely to rationalize the properties of chondrites than model A is.

Cameron's models provide no rigorous basis for predicting the juxtapositions of pressure with temperature in the nebula. The observation that molten chondrules were stable against vaporization for protracted periods of time sets a lower limit of ~1 atm on pressure in the zone of the nebula where T ~ 1700°K. This is the case regardless of what model of chondrule formation is adopted.

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GEOCHEMICAL ARGUMENTS AGAINST AN ORIGIN OF THE MOON BY FISSION FROM THE EARTH.

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The supposed similarity between siderophile element abundances in the upper mantles of the Earth and Moon, coupled with the small size of the lunar core, has been cited as evidence for an origin of the Moon by fission from the Earth following terrestrial core formation [e.g.,1]. In fact, siderophile element abundances are poorly constrained. Much better known are ratios of incompatible siderophile to incompatible lithophile elements. For example, accessible rocks on the Earth and Moon have W/La ratios of ≃0.019 and 0.019 ± 0.007 respectively, corresponding to depletion factors relative to Cl chondrites of ≃19 and 19 ± 7 respectively. We have recently shown [2] that the lunar depletion factor may be explained by extraction of W into a geophysically plausible (2 wt.%) lunar core and, hence, may not be used in support of the fission hypothesis.

This conclusion may be further supported by examination of P/La ratios. Accessible rocks on the Earth and Moon have P/La ratios of ≃ 100 and 36 ± 8 respectively, corresponding to depletion factors relative to Cl chondrites of ≃40 and 115 ± 25 respectively. We have determined the partitioning of P between solid metal and silicate melt experimentally (see below). The lunar depletion factor for P may be explained by extraction of P into a geophysically plausible lunar core under conditions which are consistent with the lunar depletion factor for W.

The similarity in W/La ratios for the Earth and the Moon precludes rejection of the fission hypothesis. In contrast, the substantial differences in P/La ratios (and FeO-content) of Earth and Moon are difficult to reconcile with the fission hypothesis. An independent origin of the Moon separate from the Earth remains a viable hypothesis.

Experimental Results [3]: $\log D(P) = -1.21 \log fO_2 - 15.95$ at 1190°C
$\log D(P) = -1.53 \log fO_2 - 17.73$ at 1300°C

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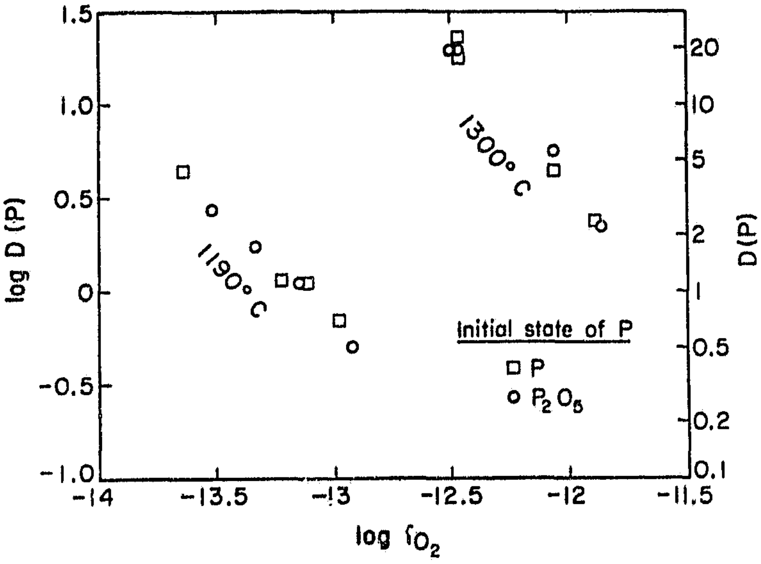

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VII-6

COMPARISON OF SIDEROPHILE ELEMENT FRACTIONATION IN TERRESTRIAL AND LUNAR ROCKS.

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The highly siderophile elements (i.e. six platinum-group elements, Re, and Au) in the undepleted upper mantle of the Earth have CI chondrite-like compositions (1,2,3). The abundances of these elements in the upper mantle can be accounted for by addition of a late accreting component (0.74 percent of the upper mantle) to the Earth after the core formation (2). The siderophile element pattern of the oceanic basalts is highly fractionated as a result of various distribution ratios of these elements between the liquid and solid phases during partial melting of the upper mantle. The CI-normalized Os/Ir, Pd/Ir, Au/Ir, and Re/Ir ratios are 0.5, 15, 110, and 220, respectively.

The siderophile element compositions of lunar mare basalts and pristine highlands rocks were reviewed for the purpose of comparison with terrestrial patterns. In contrast to oceanic basalts the siderophile element ratios in low-Ti mare basalts are considerably less variable. For example, the Au/Ir, Re/Ir and Os/Ir ratios are 7.6, 3.0, and $\sim$1, respectively, relative to the CI chondrites. Since Au and Re are perhaps the most mobile elements among the eight highly siderophiles, the contrasting siderophile patterns of terrestrial and lunar basalts are more likely to be resulted from different geochemical behavior of these elements during partial melting on the Earth and Moon rather than different elemental ratios in their source regions. It is proposed that under hydrous condition in the Earth's upper mantle Au and Re could form mobile complexes and partition significantly into the liquid. But under extremely dry and reducing conditions on the Moon the siderophile elements are probably reduced to the metal state and fractionated mainly by the metal phases.

The pristine highlands rocks have chondritic Os/Ir and Ru/Ir ratios. The Pd/Ir, Re/Ir, and Au/Ir ratios are within 6-18 times CI chondrite values. The fractionation of Ru/Os/Ir from other highly siderophile elements maybe indicates that they could have formed metallic alloys and were separated more efficiently than other elements from pristine rocks in the magma ocean. The observation that Re/Ir ratios in pristine highlands rocks and low-Ti mare basalts are higher than that in CI chondrites suggests that Re had not been depleted in the Moon by volatilization, contrary to that suggested by Delano and Ringwood (4).

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PARENT BODY OF THE SNC-METEORITES: CHEMISTRY, SIZE AND FORMATION.

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The low crystallization ages of shergottites, nakhlites and chassignites of about 1.3 b.y. and their oxygen isotopes make them distinct from all other meteorites. They seem to come from a parent body larger than asteroids because: 1. their young crystallization ages require late melting episodes; 2. their REE patterns require fractionation processes more complicated than those for other meteorites; 3. the strong shock features of many of them indicate a violent ejection process. It was because of these points that Mars was suggested as parent body repeatedly. However, point 1. may not be so strong. If impact brecciated and dusty surface layers of a smaller object provide an effective thermal blanket, such an object could stay hot for several b.y. (1).

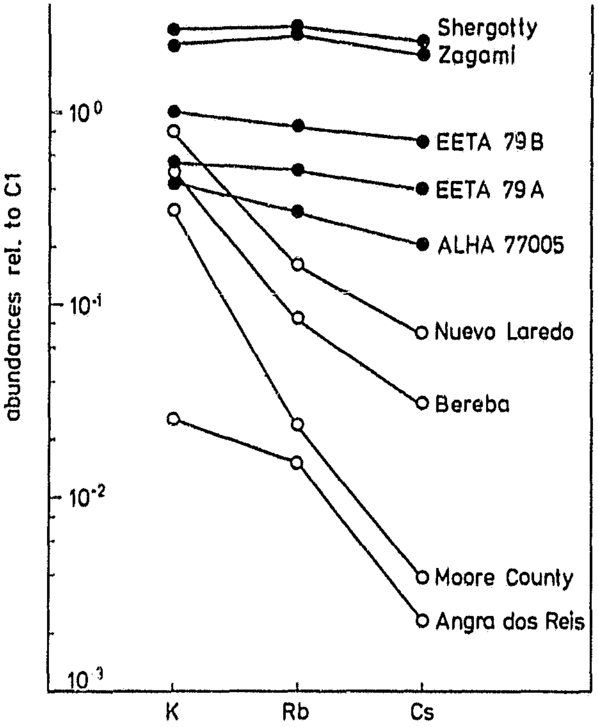

Fig. 1: Data: Lipschutz priv. com.; (4) and Mainz lab. Full circles: SNC; open circles: eucrites and angrite.

Chemical studies on SNC-meteorites yielded further indications for a large parent body. For all other basaltic achondrites the ratios K/Rb and Rb/Cs lie considerably above the primordial value (C 1). This can be explained by a preferential loss of the more volatile heavier alkaline elements in heating episodes on objects with low gravity. To the contrary: SNC-meteorites have K/Rb and Rb/Cs ratios close to the primordial value (Fig. 1).

However independent whatever object the SNC-meteorite parent body (SPB) might be, our estimates for its bulk composition yield similar abundances of moderately volatile and moderately siderophile elements (Fig.2) which indicates a formation of this object from two components. Following Ringwood (2) we previously proposed an origin of the Earth from two components (3), a highly reduced volatile free component A (85 weight%) and a fully oxidized volatiles containing component B (15%). For the SPB we calculate about 65 % component A and 35% component B and a chemistry close to the estimates of Mars.

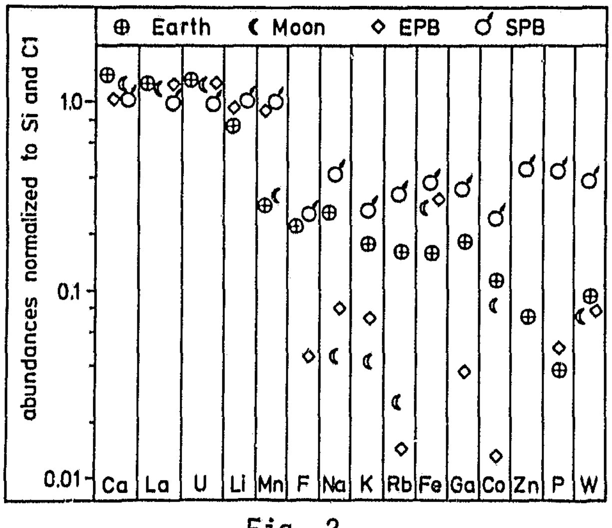

Fig. 2

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SHERGOTTITE PARENT BODY CONTROVERSY: THE GRAVITY OF THE SITUATION.

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Young crystallization ages and the presence of garnet in inferred source region compositions suggest that shergottites may have formed on a large planet, possibly Mars. Cumulus clinopyroxenes with preferred orientations apparently indicate that shergottite magmas cooled slowly enough to permit crystal fractionation. Using a cooling model developed by Walker et al. (1978) to constrain the size of the eucrite parent body, we have estimated the gravitational acceleration required to produce the observed concentrations of cumulus minerals in Shergotty and Zagami by crystal setting. Applicability of the model to a large planet was confirmed using the Palisades diabase sill as a test case. Limiting calculations for the shergottites were performed using large (zoned) and small (unzoned) phenocrysts. The surface acceleration of gravity and crystal settling zone width were varied as free parameters, and several values for initial phenocryst concentrations in the parental magma were adopted. Crystal settling calculations for both shergottites suggest that clinopyroxene phenocrysts can segregate only under extreme conditions of cooling time or gravitational field strength. The fine grain sizes of shergottites preclude excessive cooling times; thus the model may require a planetary parent body if crystal setting was the primary fractionation mechanism. Flow differentiation, another possible mechanism to effect crystal fractionation, would produce mineral lineations which are not observed. The model is consistent with the formation of shergottites in relatively thin, tabular bodies (less than $\sim$500 meters thick) of quiescent magma on a planetary object. However, calculated Raleigh numbers for shergottite sills greater than a few tens of meters thick indicate convection is probable, and settling of cumulus crystals in shergottite magma does not appear to be possible in an actively convecting environment. Nevertheless, conditions of the model may be satisfied in the case of a convecting magma chamber with a bottom stagnant zone of crystallization and accumulation.

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Rb-Sr isotopic and REE abundances in the Chassigny meteorite

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Origin of the SNC meteorites has been debated as to whether meteorites were derived from small planetary bodies or from large planetary bodies. In a recent study, we present the Sm-Nd, U-Pb isotopic and elemental data which were considered to be consistent with planetary origin of the Nakhla meteorite. As results of our extending effort to exploration of the unique meteorite group, we report here on a new Rb-Sr age and REE mineral data for the Chassigny meteorite.

Nine Rb-Sr data (Feldspar, Clinopyroxene, Olivine, Strongly-magnetic fraction, whole-rocks and others) form a linear array perfectly within experimental errors in a isochron diagram. The slope of the regression line corresponds to an age of 1226 + 12 (2σ) M.Y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70253 + 4(2σ). The age is in agreement with the previously reported $^{39}Ar/^{40}Ar$ and K-Ar ages (Bogard & Nyquist, 1979; Lancet & Lancet, 1971). It is remarkable that the Rb-Sr age and the Sr initial ratio obtained here are just in accordance with those of Nakhla (Papanastassiou & Wasserburg, 1974; Gale et al., 1975). Lack of Rb-Sr isotopic disturbance and age agreement with that from K-Ar system, and analogy with Nakhla suggest that the age of 1.23 b.y. obtained for Chassigny probably represent the time of igneous crystallization rather than impact event. This interpretation will be re-examined with the Sm-Nd isotopic data which will be presented at the meeting.

REE mineral data allow us to estimate a possible REE pattern for the Chassigny parent melt using solid/liquid partition coefficients. Calculated REE pattern of the parent melt is 7-15xchonditic for La, 10-20x for Ce and -2x for Lu, and quite similar to but higher in absolute abundance than that of Nakhla (Nakamura et al., 1982).

Rb-Sr whole-rock model age assuming BABI initial ratio was calculated to be 2.1 + 0.3 B.Y. As is the case of Nakhla (Gale et al., 1975), this age may not have rigorous meaning but suggest that Chassigny evolved by at least two stages. Two-stage model calculation assuming initial differentiation at 4.55 B.Y. and 1.23 B.Y. magmatic differentiation suggest that the Rb/Sr ratio of the Chassigny source was 0.025. The inferred Rb/Sr ratio of the Chassigny source is resemble to Earth's upper mantle and is consistent with the light-REE-depleted source characterised from REE model calculation.

Rb-Sr and REE data obtained in this work again suggest close genetic relation of Chassigny to Nakhla. Claimed difficulty by oxygen isotopic data in genetic relation of these two meteorite group should be re-evaluated with additional analyses, because it is difficult to know if the quoted oxygen data by Wood et al. (1981) are really critical or not.

We thank Prof. H. Honma and Dr. M. Tatsumoto for support and encouragement, and Dr. P. Pellas for providing the meteorite sample used in this work.

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C-2

REE AND Rb-Sr SYSTEMATICS OF YAMATO DIOGENITE 74013

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Mineralogical, REE, Rb-Sr, and Sm-Nd studies of the Yamato diogenites have been previously reported (1,2,3). We report REE and Rb-Sr analyses of a single chip of Y74013. Additional Rb-Sr analyses are planned.

Chondrite normalized REE abundances range from 0.056X (Sm) to 0.37X (Yb). Chondrite normalized Eu = 0.136X producing a pronounced Eu anomaly and La = 0.10X reflecting an enrichment of LREE in comparison to Sm. An analysis of a bulk sample of Y74013 by Masuda et al. (2) yielded somewhat greater REE abundances and a flatter abundance pattern. REE abundances in a pyroxene separate (2) show general agreement of the HREE with those in our chip, a small negative Eu anomaly, and depleted LREE abundances.

The abundances of HREE and Eu in the three samples of 74013 can be successfully modeled with the following assumptions: (i) diogenites are cumulates from a parent magma with chondritic relative REE at least from Eu to Lu; (ii) bulk mineral/liquid distribution coefficients are dominated by opx from Gd to Yb; (iii) some cumulus plagioclase must be present to account for positive Eu anomalies. It was found that variations in the Gd/Yb ratio could be explained as due to the presence of, respectively, 0.2%, 1.6%, and 4.5% intercumulus trapped liquid in our chip, the pyroxene separate, and the bulk sample of Masuda et al. (2). The Eu anomalies could be explained by, respectively, 4.3%, 0%, and 2.6% of cumulus plagioclase. The LREE abundance patterns were not well matched by these models, suggesting the presence of an additional carrier phase for LREE. However, the models yielded self-consistent values of 1.8-1.9X for the Yb concentration in the parent magma as calculated from all three samples. Thus, we suggest that REE abundances in the parent magma were about twice chondritic. The formation of cumulates with only small amounts of trapped intercumulus liquid may have implications for the depth of origin of the diogenites and the size of the parent body.

Unlike previous Rb-Sr analyses of diogenites by Birck and Allegre (4) and Nakamura et al. (3) our analysis of 74013 showed no evidence of disturbance of the Rb-Sr systematics. On an Rb-Sr isochron diagram the 74013 datum lies within error limits of a regression line fit to a subset of eucrite data from our laboratory. The apparent age corresponding to this regression line is 4.57 ± 0.17 AE [$\lambda(Rb) = 0.0142 AE^{-1}$] for an initial $^{87}Sr/^{86}Sr = 0.69895 \pm 0.00003$. The regression line is defined by 22 whole rock and mineral analyses. Subsamples of Allan Hills eucrites 76005 and 78132 lie below the regression line. The Rb-Sr datum for 74013 is consistent with a genetic relationship between diogenites and eucrites. A similar conclusion was reached by Birck and Allegre (4) from a more extensive study of the Rb-Sr systematics of non-Antarctic diogenites.

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U-Pb SYSTEMATICS IN ACHONDRITES : CHRONOLOGY AND INFERENCES ON THE BOMBARDMENT HISTORY OF THEIR PARENT BODY(IES).

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Lead isotopic composition measured in fragments of achondrites (published data and data presented here : Juvinas, Bouvante, Bereba, Serra de Mage) define in the lead-lead diagram a line : when this line is interpreted as an isochron it defines an age of 4.545 ± 0.034 Ga and shows the possibility of a common initial lead similar to the primordial lead. However , the accuracy of 35 x 10^6 years reflects the significant scatter of the data and some eucrites (Stannern, Bereba, Serra de Mage) show lead-lead model ages distinctly lower than 4.50 Ga.

We have performed internal U-Th-Pb analyses of some of these eucrites in order to understand these lead isotopic characteristics and to define more precise chronometric data.

Juvinas shows a non perturbed Rb/Sr system. U-Pb system is slighty perturbed and points out a radiogenic lead component which has been formed in situ since 4.54 Ga and a non radiogenic lead component Nr: (^{206}Pb/^{204}Pb = 13.0 ; ^{207}Pb/^{204}Pb = 13.5). This latter component can be looked neither as the initial lead of this eucrite (it corresponds to an evolution in a source between 4.54 Ga and 1.9 Ga) nor as the product of internal reequilibration. We propose the following interpretation : material of the Juvinas eucrite has crystallized at 4.539 ± 0.004 Ga, including no lead (and then no ^{204}Pb) ; most of the ^{204}Pb measured today in this meteorite has been added as "exotic lead", identified to the Nr component. This exotic lead would be formed and made labile by the bombardment at 1.9 Ga of the surface of the parent body (or a fragment of this body) of Juvinas. The term "exotic" is used to indicate that part of this lead component comes from a source which is distinct from the eucritic material : the projectile probably constituted by undepleted chondritic material.

Bereba has been completely reequilibrated at 4.2 ± 0.26 Ga in Rb-Sr. U-Pb systematics has been analyzed with the general treatment for the U-Pb open systems (Manhes et al., 1981). It shows a reequilibration at 4.13 ± 0.20 Ga = 2.1) interpreted as an addition of exotic lead at 2.4 ± 0.15 Ga.

Stannern is perturbed in Rb-Sr (Birck et Allègre, 1978). U-Pb systematics shows a reequilibration at 4.0 ± 0.15 Ga and an unradiogenic lead component (^{206}Pb/^{204}Pb = 25) which has been added at 3.1 ± 0.2 Ga.

The U-Pb system in Serra de Mage has been reequilibrated at 4.0 ± 0.2 Ga and shows unradiogenic lead (^{206}Pb/^{204}Pb = 15-16) which could have been added at 1.8 ± 0.2 Ga.

As whole, internal U-Pb systematics in eucrites is in agreement with the informations from Rb-Sr and K-Ar chronometers and allows to define the events which have affected this material at the surface of their parent body(ies). This material crystallized at around 4.55 Ga (Juvinas at 4.539 ± 0.004 Ga) without incorporating any lead. Bombardment activity has then affected this material in two ways : it has directly perturbed some of this material during event(s) at around 4 Ga (to be compared with the lunar record). It has induced in all the analyzed material addition of non radiogenic lead (a mixture from the eucrite target and the undepleted chondritic projectile) during posterior events (recorded here between 1.8 and 3.1 Ga).

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SURFACE MATERIALS HETEROGENEITY ON (4) VESTA AND IMPLICATIONS FOR THE ORIGIN OF THE BASALTIC ACHONDRITES; M.J. Gaffey, Planetary Geosciences Div., Hawaii Inst. of Geophysics, Univ. of Hawaii, 2525 Correa Rd., Honolulu, HI 96822

Vesta is one of the very few asteroids for which exists specific meteorite analogues, the basaltic achondrites. McCord et al. (1970) discovered the spectral similarity of this body to these meteorites. Subsequent investigators have strengthened this spectral identification in the area of mineral chemistry. This has lead a number of researchers to suggest that Vesta is indeed the parent body of the basaltic achondritic meteorites (e.g., Drake, 1979). The major argument raised against this linkage involves dynamical difficulties in delivering fragments from Vesta to the Earth (e.g., Wetherill, 1978). It has also been noted that the variety of basaltic achondrite assemblages imply sampling from some significant range of depths within the parent body (e.g., Takeda, 1979). It has therefore been suggested that the actual parent body may have been disrupted by impact or have had its crust collisionally removed so that it no longer spectrally resembles these meteorites.

Vesta can only be plausible as the basaltic achondrite parent body if units of all these meteorite types are present on its surface, even if the deeper layers are present only as ejecta blankets around larger craters. This can be tested observationally. A positive result improves Vesta as a viable candidate, a negative one means that either (a) the variety of materials is not present on the surface and Vesta is not the parent body, (b) the units are buried by a mineralogically uniform ejecta from the last large impact, or (c) the types are well mixed on a scale much smaller than a hemisphere.

Observations over the last thirty years have shown indications of color variations on the surface of Vesta (Stephenson, 1951; Groenveld and Kuiper, 1954; Gehrels, 1967; McCord et al., 1970; Blanco and Catalano, 1979; Gradie, 1981). Our own visible and near-IR observations in late 1980 and early 1981 clearly establish these variations and provide the data base to define their mineralogical implications. Two reported failures to detect variations (Larson and Fink, 1975; Feierberg et al., 1980) cannot be explained in terms of unfavorable viewing geometries and must be attributed to flaws in either instrumentation, observing procedure, or data analysis.

On a hemispheric scale, Vesta exhibits a variation in pyroxene chemistry of $\sim$22 mole % in iron and $\sim$5 mole % in calcium and a variation in the plagioclase/pyroxene abundance ratio from $\sim$0.2 to $\sim$0.8. Olivine may be present as $\sim$5% of the surface assemblage in at least one region. These variations have a rotational scale and relationship which indicates the presence of large, but subhemispheric, regions of basaltic material consisting of two pyroxenes (high and low calcium) and feldspar. These must represent surface units of relatively pure assemblages from the full range of the basaltic achondritic assemblages. Based on the range of mineral assemblages present on the surface of Vesta, we would conclude that this asteroid is definitely a viable candidate for the actual basaltic achondrite parent body.

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APOLLO ASTEROIDS: RELATIONSHIPS TO MAIN-BELT ASTEROIDS AND METEORITES.

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The Apollo asteroids have often been evaluated as sources for meteorites, especially since Wetherill and Williams' comprehensive discussion (1). Although some difficulties have been identified in the association, Wetherill (2) believes "a large fraction" of meteorites--possibly nearly all of them--are Apollo fragments or cratering ejecta. The Apollos, however, are in short-lived orbits so the ultimate origin of meteorites and Apollos must be some other reservoir/s, such as the Oort cloud of comets or the main asteroid belt. Most Apollo-sized objects in the asteroid belt are probably products of collisional disruption of larger objects. Depending on the origin of comets, those Apollo objects that are dead comet cores may also be the product of collisions.

New ideas about collisional processes affect earlier models for the origin of meteorites and Apollos. We suspect that very few meteorites come from observable Apollos (>1 km diameter). Most of the mass of Apollos processed by disruptive collisions remains in large pieces which impact the Earth rarely and are not counted among meteorite falls. Perhaps only 0.1% of the mass of disrupted Apollos is dispersed into meteorite-sized fragments. Occasional supercatastrophic collisions are more efficient at producing meteorite-sized pieces, but the net contribution is still small compared with the several times 10^8 gm/yr that fall to Earth. Greenberg and Chapman (3) estimate that most falls can be derived as cratering ejecta directly from main-belt asteroids.

Apollo objects may be extremely weak bodies, unlike the rocky fragments usually envisioned. Davis et al. (4) have argued that dozens of repeated collisional impacts may have converted most of the larger, original main-belt asteroids into gravitationally-bound rubble piles prior to the supercatastrophic disruptive event that finally disperses the material. Little of the mass of such precursor bodies would be expected to survive such collisional processing as coherent bodies the size of Apollos. Yet Hirayama families exist, consisting of still larger asteroids, suggesting that--somehow--dispersed rubble piles do yield sizable bodies.

One possibility is that as a large asteroid is dispersed, some gravitational clumping of its ejected fragments occurs to accumlate bodies of km to tens-of-km sizes. Any resulting reaccumulated pieces would likely themselves have a "rubble pile" character and be inherently weak. Those entering resonances or commensurabilities might become Apollos. We calculate that for such weak Apollos to survive, there must be fewer tiny main-belt asteroids than previously thought. Using our best estimates of parameters, we calculate that about 20 S-type Apollos and 8 C-types have undergone a disruptive collision (usually only marginally disruptive) over the duration corresponding to exposure-ages of ordinary chondrites and carbonaceous chondrites, respectively. As above, most of the mass remains in large pieces, so even such weak Apollos contribute only 1 to 2% of observed meteorite falls.

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THE MINERALOGICAL RELATIONSHIP OF METEORITE TYPES TO NEAR-EARTH ASTEROIDS AS DETERMINED FROM REFLECTANCE SPECTROSCOPY; L.A. McFadden, Planetary Geosciences, Div , HIG, Univ. of Hawaii, Honolulu, HI 96822.

A search for mineralogical analogues to the meteorites in the near-earth asteroid population has been carried out using ground-based telescopic reflectance measurements. There are presently 17 near-earth asteroids with spectra measured between 0.33-1.0 μm. Of these 17, seven have surface compositions mineralogically analogous to some meteorite types, four have spectral characteristics analogous to some asteroid types in the main belt which are not represented in the terrestrial meteorite collection (1580 Betulia, 1979VA, 1865 Cerberus, 1627 Ivar), two have a combination of spectral characteristics which are not seen in any meteorite type (whether or not these particular spectral features are controlled by physical or chemical and mineralogical properties has not yet been determined), and four have not been measured with sufficient wavelength coverage to determine their surface composition. The following meteorite analogues have been identified in the near-earth asteroid population based on distinguishing reflectance characteristics: LL6 (1862 Apollo), black H chondrite (1980AA), E6 (1943 Anteros), C3 (887 Alinda), mesosiderite (2100 Ra-Shalom, 1981 QA) and diogenite (1915 Quetzalcoatl). It is possible that some of these analogues are genetically related to corresponding meteorite types. However, a dynamical relationship between specific asteroid-meteorite types is necessary for an argument which intends to prove a genetic relationship between the two. From these results come the following conclusions: 1) No rare or unusual transition-bearing minerals have been found to date. 2) Given that the observations are biased for high albedo objects, we would expect to have found more bright meteorite analogues if they still exist. Conspicuously absent from this population as it is known to date, are most, but not all of the ordinary chondrites, and all of the basaltic achondrites except diogenites. It is possible that kilometer-sized fragments of these meteorite types have not survived to be detected. The diogenite analogue, 1915 Quetzalcoatl, is the second known basaltic achondrite asteroid. Its small size (0.5 km), and early-stage differentiated composition indicate that it is a fragment of a larger parent body which is probably not intact. The orbital elements of 1980AA and those determined for the Farmington meteorite, a black chondrite, are different. This precludes any genetic association between these two objects based on composition and present or recent (prior to earth impact) location alone.

PARTIAL MELT GENESIS FOR GLASSY CLASTS IN BASALTIC ACHONDRITES.

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Glassy clasts in howardites and polymict eucrites have been interpreted as impact melts of the regolith on the basaltic achondrite parent body (1-5). An origin involving internal igneous activity has not been discussed. Variation of the ratio Na/(Na+K) in bulk basaltic achondrites, and in lithic and glassy clasts from them, constrains the origin of the glassy clasts. Glassy clasts from the alkali poor howardites often show high K_2O (1,2,6) and similar clasts from the polymict eucrites (ALHA78040; EETA79004; 79011 and howardite EETA79005) have high K_2O (up to 0.27%). The ranges of Na/(Na+K) in basaltic achondrites are: (a) bulk howardites and eucrites (7) have almost constant Na/(Na+K) (0.94-0.96) with a few as low as 0.9; (b) the bulk polymict eucrites (8) range is 0.87-0.96; (c) lithic clasts in howardites and polymict eucrites (6,9-12) range from 0.80-0.96; (d) glassy clasts in howardites and polymict eucrites have Na/(Na+K) 0.5-0.96. Glass in Malvern has the lowest ratios (1,2). Variation of Na/(Na+K) is not clearly related to variation of Mg/(Mg+Fe). The range for the glassy clasts is, therefore, more like that of the lithic clasts from the polymict achondrites (4-6,11) than the range of the bulk achondrites.

Three possible origins for the glassy clasts may be considered. (1) Impact related total melting: this requires a K-rich regolith that has not yet been identified in any known basaltic achondrite. (2)Impact related partial melting: If this can occur then these clasts may have been produced by melting of an achondritic regolith similar to the howardite-polymict eucrite continuum. (3) Volcanism related to internal igneous activity on the basaltic achondrite parent body; the glassy clasts should show chemical resemblance to mafic rocks such as those sampled by polymict eucrites and especially the howardites (4-7,9-11).

The low Na/(Na+K) ratios of many clasts suggest that, if they are related to the basaltic achondrite mafic clasts, they represent either very small degrees of partial melting or small melt fractions remaining after extensive fractional crystallization that led to greater K enrichment in the melt relative to Na. These crystal-liquid separation processes are more likely to be the result of internal igneous processes rather than impact processes on the basaltic achondrite parent body. The detailed relationship of the glassy clasts to the mafic clasts is unclear, however, because of the lack of a clear correlation of Na/(Na+K) with Mg/(Mg+Fe). The difficulty of producing partial melting as a result of impact processes leaves volcanic eruption of a late stage liquid as a more likely mechanism for the formation of glassy clasts. However, evidence from polymict eucrites (4) suggests that impact processes may be important in the formation of many mafic clasts so that some of the less K-rich glass clasts of similar composition may be of impact origin. Both impact and volcanic events have, therefore, contributed to the formation of the glass clasts in the polymict achondrites.

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CUMULATE EUCRITE CLASTS IN YAMATO POLYMICT EUCRITES.

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Inverted pigeonites from Mg-rich cumulate eucrites are characterized by blebby augite inclusions and Mg-rich host compositions(1). Binda $Ca_{2.1}Mg_{63.2}Fe_{34.7}$ and Moama $Ca_{3.0}Mg_{56.7}Fe_{40.2}$ are two typical examples. Fragments of such Binda(BD)-type pyroxene have been identified in Yamato polymict eucrites, Y75011 and Y75015. The fact that no Binda-type pyroxene has been found in Y74159 and Y74450 was interpreted as they are rich in surface eucrite components. In the course of Polymict Eucrite Consortium study (2), the BD-type pyroxenes have been found in thin sections of the different portions of Y74450. In addition, the first occurrence of crystalline clasts composed of the BD-type pyroxene has been reported by the Preliminary Examination Team of the Yamato-79 collection (3). We report the mineralogy of these pyroxenes and discuss a possibility that they represent pieces of a single fall.

Several grains of pyroxene with blebby inclusions of augite have been found in a matrix of Y74450 attached to a clast, which consists of large Mg-rich skeletal pigeonite(SP) phenocrysts and variolitic matrix of plagioclase and pigeonite $Ca_{13}Mg_{47}Fe_{40}$. The host composition of the BD-type pyroxene $Ca_{3}Mg_{63}Fe_{34}$ is identical to that of Binda. The core of the SP crystals $Ca_{5}Mg_{68}Fe_{27}$ is more Mg-rich than the BD-type, and is zoned to rim of $Ca_{24}Mg_{25}Fe_{50}$. A new thin section of Y74159 at NIPR also contains the BD-type. However, these pyroxenes are all crystal fragments, and no lithic clast has been found.

Y790007 contains many fragments of the BD-type pyroxene, but one lithic clast 1mm in diameter is composed of plagioclase and inverted pigeonite with blebby augite inclusions (3). The chemical compositions of the host pyroxene $Ca_{3}Mg_{64}Fe_{33}$ and plagioclase $Ab_{6.1}An_{93.8}Or_{0.2}$ are close to those of Binda. Y790020 contains partly inverted pigeonites with coarse (001) augite lamellae similar to the Moore County(MC)-type, but the host composition $Ca_{2}Mg_{60}Fe_{38}$ is not as Fe-rich as that of MC. There may be local variation for the cumulates.

The presence of the BD-type pyroxenes in all Yamato-74, Yamato-75 and some of the Yamato-79 polymict eucrites and similarity in other components will not give us any evidence that they are not pieces of a single fall. However, there are subtle differences in their compositions of the cumulate eucrite pyroxenes and quickly cooled basalt types. Some of the Antarctic polymict eucrites in the U. S. collection (4) show textures and compositions different from the Yamato eucrites. An occurrence of a gabbroic clast 1.5x2.0x 0.3cm in size with the BD-type pyroxene $Ca_{2}Mg_{59}Fe_{39}$ and plagioclase up to 3mm long in Y791200(3), which is a diogenite of the Y75032-type, supports an idea that the Binda-like cumulate eucrite has close genetic link with some diogenites. The Binda-like pyroxene may be used as a signature to identify meteorites of the same fall. The presence of pyroxene as Mg-rich as a diogenite in Y74450 implies that diogenitic pyroxene may be produced from such melt.

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THE DIVERSITY OF IGNEOUS ROCKS OF THE EUCRITE PARENT BODY, AS EXPLORED VIA CLASTS FROM KAPOETA.

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Howardites are polymict impact breccias, and a much more comprehensive sampling of the eucrite parent body (EPB) is provided by pristine (unmixed, compositionally endogenous) clasts found in howardites, than by the components (i.e., eucrites and diogenites) known from discrete meteorites. To assess the diversity of the igneous processes which took place on the EPB, we are collaborating with M.R. Smith and R.A. Schmitt (of Oregon State), who are providing comprehensive chemical analyses of the same clasts from the regolith breccia Kapoeta that we are describing petrologically (the source for all bulk chemistry data referred to below is a personal communication from M.R. Smith). This report covers only a few of these clasts.

Clast CF4 may be the most evolved lithology ever described from the EPB. It has light REE at ∿20 x chondrites. The area of our thin section is 8 sq. mm. This clast has an exquisitely preserved (unbrecciated, unannealed) subophitic-intersertal texture. This, the low contents of siderophile elements, and the unchondritic compositions of the metal grains (avg. Ni = 0.27%), indicate that the clast is pristine. The approximate mode is 45% pyroxene, 35% plagioclase, 20% patches of glassy mesostasis (these appear almost opaque, becuase of abundant opaque microlites; microlites of silica, ferrohedenbergite, and plag. are also abundant), and 1% troilite. The plag. crystals are almost all lath-shaped, and are up to 2.4 mm long. The troilite occurs as anhedral grains associated with the mesostasis, up to 0.15 mm across. The pyroxenes are generally zoned, and their compositions are remarkably diverse, ranging fron En65Wo5 to various Fe-rich compositions, e.g., En9Wo17, En7Wo29 (ferrohedenbergite), En17Wo40. The average, En31.7Wo19.8, is exceptionally En-poor, for a sample from the EPB. In comparison to the pyroxene, the plag. is remarkably equilibrated, ranging from An87 to An79. The average, An82.4, is exceptionally An-poor, for a sample from the EPB. Another clast, BF7, is similar to CF4, although its pyroxenes are not so extraordinary. Both these clasts are probably related to the normal eucritic basalts, except they evidently formed by exceptionally low-degree partial melting. The separation of such minor proportions of liquid from the surrounding crystals may have been aided by filter pressing, perhaps driven by large impacts.

Another interesting clast, CB15, is apparently a cumulate. It has a Eu anomaly greater than that of the cumulate eucrite Serra de Mage and nearly as great as that of Moama. Unfortunately, the area of our thin section is only 1.4 sq. mm, and the clast has been severely brecciated, and also slightly annealed, so that the original igneous texture has been almost completely obscured. We infer from the distribution of the crystal fragments into monomineralic crush zones that the original crystals were probably equant and medium-grained (1 mm or more across), as is the case for the cumulate eucrites. The approximate mode is 60% plag., 40% pyroxene, plus traces of chromite and troilite. The clast is clearly not an unrepresentative piece from a normal eucritic basalt, because its plag. is very uniform and averages An94.4, and its pyroxenes cluster at En51Wo4 and En38Wo40. CB15 is probably a close relative of Serra de Mage and Moama.

Detailed study of these and other extraordinary clasts from large howardites like Kapoeta can fill important gaps in our information base concerning the igneous evolution of the eucrite parent body.

RARE EARTH AND SIDEROPHILE ELEMENTS IN COMPONENTS OF THE ALH-765 AND -77302 POLYMICT EUCRITES.

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A block sample of the ALH-765 meteorite and sliced samples (about 6-7 mm thickness) of the ALH-77302 meteorite were provided from National Institute of Polar Research of Japan. After mapping of the locations of the igneous clasts and phenocrysts on the surface of the specimen, the igneous clasts, phenocrysts, matrices etc. were extracted from the sample specimens. The abundances of 27 major, minor, and trace elements (Ti, Al, Fe, Mg, Ca, Na, Mn, Cr, V, Co, Ni, Ir, Au, Sr, Ba, Sc, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Hf, Th, and Ta) in 3 matrices, 9 igneous clasts, and 13 phenocrysts etc. of the ALH-765 meteorite and in 5 matrices, 18 igneous clasts, 14 phenocrysts etc. of the ALH-77302 meteorite have been determined by instrumental neutron activation analysis (INAA).

The chondritic normalized rare earth elements (REE) patterns of the matrices and igneous clasts of both meteorites except for a igneous clast of ALH-765 show the monotonically enriched flat patterns with some negative and/or positive Eu anomalies compared to the chondritic pattern. These features are similar to those of known non-cumulative eucrites. The La abundances in the clasts range from the lowest La abundance in the previously reported non-cumulative eucrites to the highest one (1). An igneous clast from ALH-765 has similar REE pattern to cumulate eucrite Moor County (2) and to clast #4 from ALH-765 (3). However, REE pattern for cumulative eucrite could not be observed in the igneous clasts from ALH-77302, although (4) found the such clast in ALH-77302.

A metallic grain which had high cocentrations of siderophile elements (Fe, Ni, Co, Ir, and Au), was found in the ALH-765. Two pyroxene phenocrysts extracted from the ALH-765 have anomalously high Co, Ni, Ir, and Au contents. Co contents in matrices from ALH-765 show scattered values, although other chemical compositions in the matrices do not show such scattered values. This indicate presence of extra Co which is not contained in major mineral phase of ALH-765 as seen in howardites (5). These anomalous siderophile elements in the ALH-765 meteorite might be introduced to surface of the parent body of this meteorite by impact of meteorite which is rich in siderophile elements, such as chondrite and/or iron meteorite. This impact might produce polymict breccia on the surface of the parent body. Anomalies of siderophile elements are not observed in components of ALH-77302, so far.

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FOURIER GRAIN SHAPE ANALYSIS OF CLASTS IN ACHONDRITES.

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Shapes and sizes of particles in clastic materials, indurated or otherwise, are responses to the processes generating such material. Unfortunately, there is no satisfactory model available to relate shape and size of clasts to specific processes. Comparative studies of particle shape and size can still be made for taxonomic purposes with the hope that the taxonomy would be genetic. Fourier grain shape analysis of two dimensional projections of particles is a rigorous and quantitative method to determine particle morphometry (1). The method has been applied to shapes of quartz grains in terrestrial sands and to shapes of organisms and their colonies (2,3). We are applying the technique (4) for a comparative characterization of the shapes and sizes of fragmentary particles in achondrites, lunar soil breccias, and in impregnated lunar soils. We are encouraged by the results of preliminary visual estimates of sphericity and roundness of these materials (5). Here we briefly describe our method of Fourier grain shape and size analysis and hope that others in the community will also be encouraged to use this relatively simple but fairly rigorous method.

Photomicrographs of thin sections of the samples in both transmitted and reflected light are used. These are projected onto the magnetic screen of a digitizer. Forty-eight equiangular intercepts around the periphery of each clast are plotted and their coordinates are automatically recorded. From these points the centroid of the clast may be calculated. The points are then converted into polar coordinates and from these two Fourier coefficients, harmonic amplitude and phase angle, are calculated. Each term of the series is a harmonic which describes the contribution to the series of superimposed senusoidal waves. The "zeroth" harmonic is the mean radius of the shape and provides a measurement of size. Other harmonics are normalized by the mean radius; therefore, they are size independent. The normalized roughness coefficient, which is calculated as one-half the square root of the sum of the squared normalized harmonic amplitudes, measures the deviation from a centered circle. The Fourier method is limited to expansion of single valued function. Thus a radius drawn through the center of gravity must intersect only one point on the periphery of the clast. It follows that grains with large indentations are excluded from our measurements.

We shall be happy to provide all assistance to anyone interested in Fourier grain shape analysis.

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POLYMICT CHONDRITES AS INFERRED FROM A POLYMICT EUCRITE GENESIS.

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Because impacts are important processes to the evolution of the surface of planetary bodies, the products of brecciation(e.g. polymict chondrite) imply a close genetic relationship among the clasts contained and give us an important information on the genesis of parent bodies. Polymict or dimict chondrites studied to date include Yamato-75028, Weston and Romero etc.[e.g. 1,2,3].

Y-75028 contains equilibrated H-type clasts in the matrix of unequilibrated texture[3,4]. Its bulk chemistry has been reported to be between those of H and L group, but this deviation from the H composition may be due to oxidation of metal. Ohta and Takeda[4] studied macroscopic textures and concluded it to be a genomict breccia of H3 chondrite with H5 clasts. We studied detailed textural and compositional variations within representative chondrule types to elucidate the components of the polymict chondrites and to obtain better understanding of brecciation process and reassemble mechanism after fragmentation[5].

Typical chondrule types within the matrix are: (1) One very ideally spherical chondrule(Ch1) has a porphiritic texture with a dozen of olivine crystals and interstician glass; These olivines have dominant composition Fa_{4-8}, but are chemically zoned up to Fa_{20} at the rim; The average CaO content in these olivines is ~0.23%; Thus, the petrologic type is 3; (2) Ellipsoidal chondrule(Ch2) is composed of three large crystals of skeletal olivine joining at the center with nearly 120° triple point juncture; Core composition of each olivine is Fa_{19} and average CaO is 0.07%; The composition is fairly uniform and strongly zoned only at the rim up to ~Fa_{40}; (3) The chondrule(Ch3) adjacent to the porphiritic chondrule(Ch1) contains olivines of uniform composition with prominent peak at Fa_{19}; Their average CaO is 0.026%; (4) A H5-like poorely-defined chondrule(Ch4) exists; The olivines have the prominent peak at ~Fa_{20} with a range Fa_{18-30}, and average CaO 0.018%. The range of the composition and average CaO of the olivines within these chondrules are different and chemically zoned olivines contain high CaO content. Ch2 has uniform core of equilibrated H composition but is zoned at the rim. Ch3 and 4 may have a possibility that they are abrasion chondrules of the equilibrated type.

The largest clast observed within the thin section examined is 5.5x2.9 mm in size. The clast has very sharp boundary with the matrix. It consists of olivine and orthopyroxene of uniform composition comparable to the equilibrated H chondrites. No chondrule was observed in the clast. The largest such clast found in other portion of this meteorite is 6x2 cm in size[4].

If a H-chondrite parent body has a type 6 core and type 3 crust and types 4 and 5 intermediate layers between them as was proposed for the onion-shell model[6,7], one might expect brecciated regolith chondrites of mixture of various petrologic types, by analogy of howardite parent body[8]. There may be a polymict chondrite with abundant H3 components and with little H4 which is comparable to polymict eucrites rich in surface eucrites. However, if the excavation is deep enough to mix deep seated H6, polymict chondrite with fragments of all petrologic types may be produced. This breccia can not be distinguished from a breccia produced by fragmentation and reassemble. It is, therefore, important to identify chondrules of different petrologic types by certain criterion different from those of Van Schmus and Wood[9].

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LEOVILLE (CV3) - AN "ACCRETIONARY BRECCIA"? Alfred Kracher, Klaus Keil, and E.R.D. Scott. Institute of Meteoritics and Department of Geology, University of New Mexico, Albuquerque, NM 87131.

Leoville is a CV3 chondrite containing a variety of dark-colored, clast-like objects petrologically distinct from the host, three of which have been studied in detail: LV-1 appears to have been derived from a CV-like precursor by extensive hydrous alteration and subsequent dehydration. Outlines of chondrules and lithic fragments are preserved, but they now consist of fine-grained, yellowish material of low birefringence and nearly uniform composition, probably a dehydrated layer silicate. Objects apparently derived from CAI's additionally have cores of andradite. The matrix of the clast appears to be water-poor, but has clearly taken part in the chemical reactions which formed the phase(s) now present in the chondrules and fragments. LV-2: texturally similar to host Leoville, with droplet chondrules, mineral fragments, etc., but on a much smaller (5-10X) grain size scale. Their compositions appear to be similar to the host chondrite, except that the mineral fragments contain a somewhat more Fe-rich olivine population. Some chondrules contain alteration products (layer silicates?). Unlike the host, LV-2 contains much more magnetite than metal. The matrix:chondrule ratio in LV-2 appears to be similar to the host chondrite. The matrix is higher in Na and K, but lower in Ca than that of the host. LV-2R: Clast LV-2 is surrounded by a rim of opaque, fine-grained matrix material similar to LV-3 below, but in addition containing some mineral fragments and microchondrules (≤ 30 μm dia.) low in FeO and high in CaO. LV-3 is an inclusion of dark, aphanitic, matrix-like material with a sharp boundary to the host, containing a vein-like metal particle rich in Ni and Co.

Discussion: Most meteoritic breccias are composed of angular, broken fragments (clasts) in a finer-grained clastic matrix, formed by impact on a parent body surface. Leoville, in spite of its "brecciated" appearance, may not have formed by impact crushing on the parent body. Instead it may be a rock whose constituents (clast-like objects, CAI's, chondrules, matrix) were assembled during accretion of the CV parent body. We term such rocks accretionary breccias. Leoville preserves many accretionary features: (1) Clast-like objects like LV-2, CAI's, and most chondrules are surrounded by rims of opaque, matrix-like material, which we believe is primitive dust that rimmed these objects while they were in the solar nebula and not on some planetary surface. (2) Chondrules and CAI's (some of the latter with delicate, amoeboid shapes) are very well-preserved, and fragments, which are common in most breccias, are rare.

Some of the matrix-like rims and clasts may have been slightly altered in situ, but they are generally well preserved because Leoville itself shows only minor effects of shock and reheating. The complex history inferred for LV-1 implies that this clast experienced alteration on a planetesimal prior to incorporation into Leoville. This argues that the Leoville breccia did not form in the very earliest stages of accretion. The existence of type 3 chondrite breccias like Ngawi (LL) with metal grains with diverse cooling rates and well preserved rimmed chondrules in their matrices means that we cannot exclude the possibility that the Leoville breccia, like Ngawi, was consolidated after accretion of their respective parent bodies. Allende, which also contains rimmed clasts, may be an accretionary breccia, too, but solar-wind-implanted CV3s like Vigarano probably formed after accretion of the CV parent body.

XENOLITHIC CLAST IN MURCHISON: A NEW TYPE OF CARBONACEOUS CHONDRITE

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Fuchs etal (1) reported finding 10 clasts of what appeared to be a C3 chondrite within the Murchison C2 chondrite. From their preliminary study the C3 could not be assigned unequivocally to a Vigarano (V) or Ornans (O) subtype. We have done additional work on the largest clast (13mm) and report these observations:

1. In hand specimen it looks like an O-subtype.
2. In thin-section it looks like a V-subtype.
3. In a plot of bulk Mg against Fe (wt.pcts.) it plots by itself between the C3V and C2 groupings.
4. Its trace element pattern matches the C2 chondrites better than either the C3V or C30 chondrites. The most significant mismatch with the V's and O's are for the volatile lithophile elements Cr, Mn, Na, K, for which it is enriched by factors from 1.1 to 2.3, and for the siderophile, Se, for which it is enriched by a factor of 2.
5. The matrix consists of submicron grains of fayalitic olivine (around Fa50) and some aluminous phase that cannot be resolved, but may be an aluminous low Ca pyroxene. No metal is present; troilite and pentlandite occur abundantly in the matrix. In addition, there are numerous rounded, subrounded, and fragmental objects that are polycrystalline and olivine-bearing; these range from 20-1000 micrometers. Some of them are clearly melt-droplet chondrules; it is not clear what others are. Within the matrix are occasional grains of a high FeO (25%) Mg-Al spinel and patches of (probable) nepheline and Ca-phosphate.
6. Larger inclusions consist of single, subhedral, concentrically zoned olivines and olivine fragments, porphyritic melt droplet chondrules, an aggregate of Fe-rich olivine with overgrowths of enstatite (Fs=0), and an irregular aggregate made of FeO-free poikilitic hibonite within FeO-rich spinel; this aggregate is surrounded by micron-size pyroxenes that range from diopside to fassaite.
7. X-ray diffraction of bulk clast indicates the presence of a minor amount of hydrated phyllosilicate ($\leq$10 wt.%), probably in the matrix.
8. Oxygen isotope measurements of the bulk give: $\delta^{18}O=4.03$, $\delta^{17}O=-1.46$. On the three-isotope oxygen diagram it plots between bulk Murchison and the cluster of C3V-C30 points, with the exception of Mokoia (C3V), which plots very close to the clast.

From our observations we conclude this clast is of a type of carbonaceous chondrite intermediate between the C3 and C2 types.

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STRUCTURE OF THE ABEE E-CHONDRITE BRECCIA AND IMPLICATIONS FOR ITS ORIGIN

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The Abee E-4 chondrite is a highly brecciated member of an otherwise unbrecciated group of meteorites. The structure of Abee is unusual among stony meteorites. For example:

a)no veins or fractures are present; the stone is quite indurated
b)typical clast interior textures and matrix textures are similar
c)no clasts within clasts
d)many clasts have metal enriched peripheral zones
e)evidence exists for pre-compaction metamorphism(1)
f)a few clasts are highly metamorphosed
g)Abee is not gas-rich (2) and has not been subjected to pre-irradiation(3)
h)mineral chemistries show little variation from clast to clast; relative mineral abundances vary significantly from clast to clast or matrix

Keil(4) has described Abee as being a fragmental breccia. From the original description of Abee (5), along with our own observations, it can be better described as a macrobreccia of a microbreccia. This description comes from b) above; typical Abee clasts and matrix appear to be composed of the same kind of fine-grained material. The clasts were derived by compaction from fine-grained material which contained chondrules but no metal-rich or dark inclusions, whereas, the matrix does not appear to be simply derived from the breakage of clasts. Metal-rich and dark inclusions were either formed after the clasts or were formed at a different location from the clasts. The different mineral abundances for the various clasts appear to be due to incomplete mechanical mixing. The origin of the metal rims surrounding the clasts is an open question but it is possible that they were formed by the preferrential adhesion of metal grains to the clasts during a late stage of formation.

The above discussion implies that the Abee breccia may have been produced in a regolith. Nevertheless, it is clear that Abee is not a surfical regolith breccia, at least in the sense of the gas-rich breccias. Abee has been metamorphosed (1) and lacks fine-grained (Huss) matrix (6), features which are incompatible with type-3 ordinary chondritic, primitive breccias. Abee does not contain fragments of other classes of E-chondrites (1,7) indicating that it may not be an accumulation breccia. An accumulation breccia, formed by the disruption and reassembly of an asteriod, would probably contain a variety of metamorphic grades. A good candidate for an accumulation breccia is the Kelly LL-4 chondrite, which is also classified as a fragmental breccia (4). Kelly does contain types LL-4,5,6 clasts as well as having a texture distinct from Abee's (8). Recent regolith models (9,10) have described the formation of gas-rich or regolith breccias, but these models cannot be directly applied to Abee using present-day asteroidal input parameters.

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CONSOLIDATION OF CHONDRITE REGOLITH BRECCIAS BY GRAIN BOUNDARY AND LOCALIZED SHOCK-MELTING. A. Bischoff[1], K. Keil[2], and D. Stoffler[1], [1]Institut fur Mineralogie, Univ. Munster, F.R. Germany; [2] Dept. of Geology and Institute of Meteoritics, Univ. of New Mexico, Albuquerque, New Mexico, 87131, U.S.A.

Ordinary chondrite regolith breccias are rich in solar wind-implanted rare gases and consist of a variety of mineral and lithic clasts embedded in a fine-grained matrix. They formed by lithification of unconsolidated, impact-produced fragmental debris on parent body surfaces; shock-induced grain boundary melting has previously been suggested to convert the unconsolidated regolith material into tough breccias (e.g., Ashworth and Barber, 1976; Kieffer, 1975; Keil and Fodor, 1980). However, details of this process are not understood. We present evidence that variable degrees of grain boundary and localized shock-melting of the finest-grained matrix material $\leq$15 µm in size are responsible for the lithification of gas-rich chondrite regolith breccias.

The matrix textures of different breccias vary considerably. SEM studies show that the finest-grained material in the matrices of Fayetteville (H) , Weston (H), Breitscheid (H), and Rio Negro (L) consists of angular clasts as small as a few microns in size which are partially surrounded by an accessory feldspathic, shock-melted material. The matrices of Dimmitt (H), Nulles (H), Cangas de Onis (H), Plainview (H), Abbott (H), and Grassland (L), on the other hand, consist of small, rounded (partially resorbed) clasts, completely surrounded by interconnected glassy to microcrystalline, shock-melted, feldspathic material. The matrices of Ipiranga (H), Tysnes Island (H), Pantar (H), and St. Mesmin (LL) are texturally intermediate between these two extremes and consist of angular to subrounded clasts with moderate amounts of interstitial, shock-melted feldspathic material.

Our observations indicate that there is a continuous gradation in matrix textures of the finest-grained fractions of gas-rich chondrite regolith breccias from nearly completely clastic breccias to highly cemented breccias in which the remaining clasts are completely surrounded by interstitial, shock-melted material. In general, the abundance of solar-wind-implanted ^{4}He and ^{20}Ne (Schultz and Kruse, 1978) in these breccias is anticorrelated with the abundance of interstitial, shock-melted feldspathic material (Fig. 1). We conclude that this interstitial material formed by shock-melting in a porous medium. Chondrites with the highest abundance of interstitial, melted material most likely experienced the highest shock pressures and temperatures and suffered the most extensive degassing. It is this interstitial, feldspathic melt that lithifies and cements the breccias together; those breccias with very little interstitial melt are more poorly consolidated.

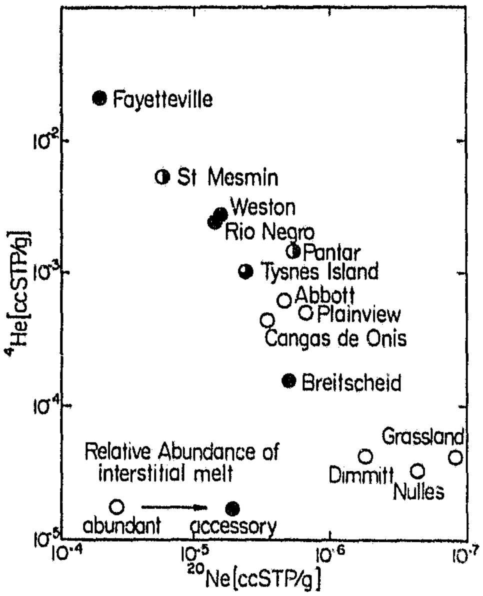

Fig. 1

BRECCIATED TYPE 3 CHONDRITES AND THEIR PARENT BODIES.

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We have studied clasts and hosts in several type 3 chondrites to elucidate the origin of these breccias and the structure and history of their parent bodies. All of these chondrites lack clastic material in their hosts and have been described as typical type 3 chondrites. However, rare cm-sized clasts and, in some cases, taenite grains which record diverse thermal histories show that these chondrites are breccias. Ngawi (LL3.6), for example, has type 4-6 clasts and host taenites which record cooling rates of 1-200 K/Myr indicating that its host components (chondrules, matrix etc.) were metamorphosed in diverse environments in the LL parent body. Thus Ngawi itself was never metamorphosed to temperatures appropriate to type 3.6, just as the Weston regolith breccia was never heated to type 4 levels.

Breccias among type 3 chondrites

Meteorite	Host	Clasts	Cooling rates in host, K/Myr
Sharps	H3.4	C,H3	
Bremervörde*	H3.7	H3,H4,H5	$10-10^3$
Mezö-Madaras	L3.7	L4,CM,Me	1
Quinyambie	L/LL3.4	type 3	
Krymka	LL3.0	C	1
Ngawi	LL3.6	LL4-6,f.b.	1-200
Parnallee	LL3.6	Me	
ALHA77278	LL3.6		$10-10^3$
Kakangari*	type 3	type 3	~50
Vigarano*	CV3	CV3	0.3-20
Mokoia*	CV3		

* Solar-wind irradiated. Includes literature data.
Me - melted clast; f.b.- fragmental breccia clast.

From the presence of type 4 clasts in type 3 hosts, earlier workers inferred that chondrules were still forming after metamorphism. But, since chondrules are now recognized to be primitive objects that formed before accretion, we infer that type 3 components were loosely consolidated in chondrite parent bodies prior to breccia formation. The first sub-km chondritic planetesimals must have consisted of loosely consolidated materials as impact velocities were too low to cause effective shock welding. Material which preserved type 3 levels of mild metamorphism in larger bodies generally experienced insufficient grain growth to consolidate chondrules. The distribution of type 3 material throughout chondrite parent bodies, which we infer from the wide range of metallographic cooling rates (see table), suggests that type 3-6 chondrites experienced maximum metamorphic temperatures in planetesimals prior to accretion of their parent bodies. Alternatively, 'onion shell' parent bodies were fragmented and reassembled prior to slow cooling through 500°C. Mezö-Madaras and Krymka breccias, which have uniform cooling rates of 1 K/Myr, must have been consolidated before slow cooling either during accretion --'accretionary breccias'-- or in a fragmentation and reassembly event during slow cooling.

These type 3 chondritic breccias differ from fragmental chondritic breccias (both regolith and those lacking solar-wind gas) in having much higher abundances of well-defined chondrules and opaque matrix in their hosts and little clastic material. We call the former, 'primitive-component breccias' to emphasize these differences. The apparent lack of intermediate types of H-L-LL breccias is curious, as examples of both types exist that contain solar-wind gas and formed on planetary surfaces. This may be because most type 3 breccias formed instead during accretion or fragmentation and reassembly of their parent bodies. If type 3 materials were abundant on the parent body surfaces, they must have been quickly diluted with clastic debris forming a Weston-like regolith. Like most fragmental breccias, many primitive-component breccias were probably consolidated by shock. The general lack of type 3 clasts in chondritic breccias suggests that unconsolidated type 3 material was, and still may be, abundant in chondritic parent bodies, significantly affecting their physical properties.

GEOCHEMICAL AND PETROGRAPHIC STUDY OF INDIVIDUAL 1-2 MM PARTICLES FROM TWO APOLLO 16 SOILS;

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Individual 1-8 mg particles from the 1-2 mm grain size fraction of two Apollo 16 soils were analyzed by instrumental neutron activation analysis. Twenty particles from 65502 and twenty-one particles from 67712 were analyzed for concentrations of 23-27 elements.

67712. Samples from 67712 were analyzed to discover and characterize the source of the anomalously high concentrations of Na, Sr, and Eu present in the <1 mm fraction of this soil (Korotev, 1981). The anomaly is intriguing because bulk fines samples do not usually show extreme compositions, yet no rock type has been identified with high enough concentrations of these elements to be the source of the excess in 67711. The sodic ferrogabbro (e.g., Taylor et al., 1980) cannot alone account for the anomaly since 67711 has a higher Mg/Fe ratio and lower REE concentrations (6-9 times chondritic) than other Apollo 16 soils. The component carrying the high concentrations of Na, Sr, and Eu in the soils may be important as several other Apollo 16 soils show the anomaly to a lesser extent and none can be modeled as mixtures of observed rock types and account for the high concentrations of the elements (Korotev, 1982). Nine of the 1-2 mm particles show the anomaly, but only one is more extreme in this regard than the <1 mm bulk soil.

65502. This soil was identified by Korotev (1981) as one of the Apollo 16 surface soils most enriched in the "Cayley component," i.e., high Fe and Mg, low Ca and Al, and high LIL element concentrations. The 1-2 mm particles were examined primarily to characterize the nature of the component(s) carrying the bulk of the Fe, Mg, and LIL elements. One KREEP particle was found (La: 350 times chondritic concentration). Two particles appear compositionally to be 75-25 mixtures of chondritic meteorite-VHA type melt rock (25% FeO, 3000 and 5900 ppm Ni, 1.0% Na_2O, 4.8 ppm La, and 0.37 ppm Eu).

Thin sections of all particles will be examined.

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COLLECTIONS AND CURATION OF YAMATO METEORITES

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On December 24, 1969, the Japanese Antarctic Research Expedition (JARE) collected nine meteorites on the bare ice, in a very limited area, adjacent to the Yamato mountains which are located at about 300 km south-southwest from the Japanese Syowa Station in East Antarctica. Most of the specimens have been identified petrologically and chemically to be of the five chondritic types after examination , therefore most of them fell as individual specimens. In December 1973, a JARE team also found twelve meteorites, including one howardite specimen.

As the result of the above discoveries, an exhaustive search for Antarctic meteorites by JARE was conducted in both the seasons of November to December 1974 and the 1975-76 austral summer. About 1000 meteorites including many unique meteorites were collected by systematic search in both seasons. From this the present authors conjectured the existence of accumulations and concentrational processes of Antarctic meteorites on the surface of bare ice in the Antarctic continent. However it was not yet recognized as a common phenomenon in all the bare ice fields in Antarctica.

The authors expect that there will be many more meteorites on the Yamato bare ice areas which are about 4000 square km from which in excess of 8000 meteorite pieces might be collected. This estimation is based on the result that 200 pieces were collected from a 10 x 10 km grid by detailed search at the southern end of the Yamato Mountains. In the 1979-80 summer, JARE teams again visited the Yamato Mountains, and collected 3,676 individual pieces, about 300 kg in total weight, including many unique specimens. In the 1980-81 and 1981-82 summer, 13 and 133 specimens were collected, respectively.

Present Yamato meteorite collections are 4813 pieces in total including 6 irons, 2 or more stony-irons (including one lodranite), 40 carbonaceous chondrites (including some of large mass, over 1 kg), 4 ureilites, 2 or more types of diogenite (including over 60 pieces), 4 or more howardites, several types of eucrites (including over 50 pieces), 2 or more enstatite chondrites, many ordinary chondrites and many pieces of rare or new meteorites. However, there are many specimens that have not been processed initially and examined in detail in the National Institute of Polar Research, Tokyo.

CURATION OF THE U.S. ANTARCTIC METEORITE COLLECTION; D. D. Bogard, NASA/Johnson Space Center, Houston, TX 77058

The U.S. Antarctic meteorite program is an interactive one among three governmental agencies--NASA, NSF, and the Smithsonian Institution--and the meteoritic scientific community. The program has drawn on NASA curatorial experience derived from the lunar program to: (1) develop specific collection and preliminary examination protocols; (2) provide documented samples for scientific investigations in response to specific requests; and (3) aid cooperative research by scientific consortia.

Meteorites are shipped frozen from Antarctica via Port Hueneme, California, to the Meteorite Curatorial Facility at Johnson Space Center (JSC). Here they are kept frozen until they can be dried in a gaseous nitrogen cabinet. The meteorites are then weighed, photographed, and described by a combination of macroscopic and microscopic techniques. Each meteorite is chipped or sawed to expose the interior surfaces and to obtain a small chip from which petrologic thin sections are made for classification. All tools and equipment used in processing have been cleaned to avoid contamination. Only those emade of acceptable materials, including teflon, polyurethane aluminum, and stainless steel, may come in contact with the meteorite samples. Two complete thin section libraries are available for examination, one at the Smithsonian Institution and the other at JSC. After processing, the specimens are stored in a low contamination,gaseous nitrogen environment and a complete inventory is maintained on all subsamples.

Pertinent information on each specimen is compiled in the Antarctic Meteorite Newsletter, which is distributed to about 600 scientists worldwide. Samples are allocated to individual investigators generally twice a year as a result of specific requests to the Meteorite Working Group, a scientific committee set up to evaluate the proposed research. Meteorite allocations are prepared according to the requestor's directions, whenever possible, with particular emphasis on maintaining low contamination levels and full sample documentation. To date, over 1600 meteorite specimens have been provided to approximately 100 scientific groups in 13 nations for study. Several broad consortia are now actively studying a number of complex meteorites. Included in these are the polymict eucrites and a shergottite.

EVIDENCE FOR TWO OR MORE DISTINCT SOLAR-TYPE NOBLE GAS COMPONENTS IN ENSTATITE ACHONDRITES.

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There is no evidence for the long-term temporal variation in the isotopic compositions of Pesyanoe and solar wind Xe on the lunar surface. Pepin and Phinney (1979) argue against a solar source for the fractionation observed in lunar xenon. On the other hand, the Kr isotopic systematics in the Pesyanoe meteorite, as observed in stepwise release data (Marti, 1980), are puzzling. Trapped ^{36}Ar shows a bimodal release with a dip in the intermediate temperature step, while the Ne isotopic composition in a three isotope plot is not consistent with a mixing line of trapped and spallation components. Interestingly, the intermediate and high temperature data plot close to the line defined by etched plagioclase separates of lunar soil 61501 (Etique et al., 1981). We obtain an upper limit of 12.2 for trapped $^{20}Ne/^{22}Ne$ which is lower than that observed for solar wind Ne in lunar fines, but consistent with ratios observed in etched lunar plagioclases, in the top 0.5 mm layer of lunar rock 68815 (Yaniv and Marti, 1981), and in the atmosphere of Venus (Moroz, 1982). Similar ratios are calculated for other gas-rich enstatite achondrites. Recent studies in enstatite chondrites revealed the presence of two distinct trapped gas components, The ^{36}Ar-rich component is characterized, as in the case of Venus, by a very low ratio $^{20}Ne/^{36}Ar$. What do the above listed reservoirs have in common in addition to similar $^{20}Ne/^{22}Ne$ ratios, and do they relate to a common source?

Relationships of this type provide clues to their origins and need to be assessed in more detail. The presence of two solar-type components in Pesyanoe, one of which lost He and much of its Ne, may account for the lower $^{20}Ne/^{36}Ar$ ratio and for distinct isotopic signatures. The origin of the latter is not obvious.

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D/H RATIOS OF SOME ORDINARY AND CARBONACEOUS CHONDRITES

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The total hydrogen released from bulk meteorite samples has been reported to be enriched in deuterium relative to SMOW for both types C1 and C2 carbonaceous chondrites (1) and type 3 ordinary chondrites (2). The data set comprises a small number of samples which are extremely D rich (Renazzo, Bishunpur and Semarkona) together with a greater selection of specimens having more modest isotopic abnormalities. Intermediate samples are uncommon which makes trends difficult to distinquish, hence an overall rationale for the occurrence and survival of D rich phases has not yet been established. In an attempt to examine the extent of deuterium enrichments in primitive meteorites we have extended our study to include other carbonaceous and ordinary chondrites.

Two type 2 carbonaceous chondrites, Banten (CM) and Al Rais (CR?) have been studied. The samples yielded a total of 3.1 and 6.0% water on combustion at 1050°C. δD values were +45°/oo and +520°/oo respectively. The latter is the most significant result since it indicates that Renazzo is not unique as a carbonaceous chondrite in affording a very high bulk δD and may confirm previously postulated affinities between Renazzo and Al Rais (3). The discovery of a sample similar to Renazzo will allow a more critical examination of suggested trends in δD vs yield and δD (acid residues) vs δD (phyllosilicates).

Three new ordinary chondrites have been analysed. Khohar, a type L3.6 (on the TL scale) released 0.24% water at δD -9.6°/oo. Other type 3.6 meteorites have given both higher and lower δD values. Higher petrologic type, but nevertheless unequilibrated specimens, Hamlet (LL4) and Castalia (H5) both liberate small amounts of water, 0.09 and 0.14% respectively, but with δD's of +78 and +105°/oo. Castalia also has a high total carbon and an unusual ^{13}C for a type 5 meteorite which could be significant. We are now able to confirm that the very unequilibrated sample, Krymka, unlike Bishunpur and Semarkona from the same category, is not appreciably deuterium enriched. Stepwise pyrolysis liberates a number of water fractions but none has a δD >92°/oo (450-600°C). Therefore the low bulk values previously found for Krymka are a true representation of its hydrogen isotope composition and not an artifact of terrestrial contamination.

Studies of ALHA 77003 (CO3) have revealed that Ornans type meteorites should be included amongst those known to have deuterium contents in excess of SMOW. Bulk measurements have afforded ca 0.15% water with δD values of +60 and +147°/oo whilst stepwise extraction demonstrates that the deuterium content increases systematically up to 450°C, a maximum δD of +216°/oo (300-450°C step) being obtained. The amount of water released at higher temperatures was too small to analyse.

The new data, however, do not yet permit a consistent model of meteorite deuterium/hydrogen systematics to be defined.

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We thank R. Hutchison, R. Clarke, M. Lipschutz, G. Kurat and the Antartic Meteorite Committee for samples.

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ON THE ORIGIN AND COMPOSITION OF HYDROGEN AND CARBON IN METEORITES

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As a continuation of our previous studies (1, 2), 19 bulk meteorites and 40 acid treated meteorites of all types were analyzed for their concentration and isotopic composition of hydrogen and carbon. Bulk samples show low δD values (~0 ‰) with some exceptions. There is no relationship between δD and hydrogen or carbon content, $\delta^{13}C$, class, etc. However, we find that there are positive relationships between δD in acid residues and hydrogen or carbon content. These correlations seem to be independent of meteoritic class or petrologic types.

The acid residues are more resistant to oxidizing reagents than was found by Robert and Epstein (2) and residues resemble those which contain anomalous noble gases (3). The suggested intersteller origin of these residues whose hydrogen has high D/H finds further support in: 1) the positive relationships between δD and hydrogen or carbon content, 2) the high δD values of hydrogen in residues from both carbonacious and noncarbonacious meteorites, 3) the presence of anomalous noble gases in these residues (4).

Good relationships exist between δD and $\delta^{13}C$ in acid residues. Primitive meteorites have a strong inverse relationship between δD (between -500 and +2000 ‰) and $\delta^{13}C$ (between -22 and -12 ‰). Residues from meteorites which suffered metamorphism show a larger variation in $\delta^{13}C$ (-31 to -15 ‰).

We attempted to isolate phases containing hydrogen of high D/H ratio by several techniques: 1) Magnetic separation of bulk Carraweena and Abee. 2) Density and magnetic separation of Orgueil HCl-HF residue. 3) Treatment with organic solvents (CCl_4, C_6H_{14}, Acetone, C_6H_6, CH_3OH) on Semarkona acid residue. 4) 3 size separations of Semarkona acid residues. Only experiment 4 produced an effect. Fine grains show higher δD values and higher hydrogen concentrations (1065 ‰; 2200 μmoles/g) as compared to coarse grains (156 ‰; 890 μmoles/g). Also the fine grains showed a higher $\delta^{13}C$ and carbon concentration (-19 ‰; 8.0% carbon/g) than did the coarse grains (-31 ‰; 2.8% carbon/g).

An HCl-HF residue of Murchison was treated by H_2O_2 for one aliquot and by HNO_3 for the other aliquot. The δD for the former residue was 1800 ‰ and for the latter 940 ‰. The H_2O_2 oxidation reduced the hydrogen and carbon content by 60 to 80%. The Allende acid residues showed similar results.

In our extraction procedure where we pyrolize our samples, we found that the δD values became generally more positive with higher temperatures. When both H_2O and H_2 are produced, δD values of H_2O are higher than δD values of H_2 gas. Semarkona bulk however, showed very different release patterns. For example, 54 μmoles/g of H_2 gas gave a δD value of 3600 ‰ , whereas, 156 μmoles/g of H_2O extracted at the same temperature range gave a δD value of 2150 ‰. Moreover one bulk sample released H_2 gas with a δD value of 5300‰ . This H_2 gas may contain spallation deuterium.

A very low δD value of -500 ‰ was obtained from a yield of 3600 μmoles/g of hydrogen from HCl-HF residue of Abee (E4). Organic polymer formed at ~300°K would produce such a δD value.

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CARBON ISOTOPES IN GRAPHITE FROM GRAPHITE-MAGNETITE MATRIX

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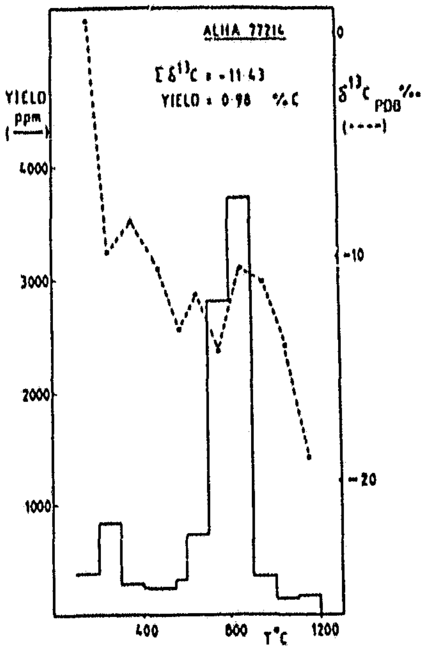
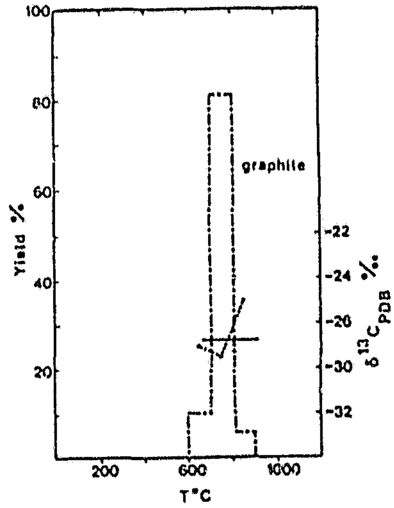
Our survey of the bulk carbon abundance and isotopic composition of type 3 unequilibrated ordinary chondrites (1) has revealed considerable variability within this group. The range of $\delta^{13}C$ values might be ascribed to mixing of two or more carbon phases in different proportions. Candidate phases are graphite-magnetite matrix (G-M) (2) and terrestrial weathering products. Stepwise combustion provides a method of differentiating between carbon phases in bulk samples (3). We have applied this technique to two meteorites (one a "find" and the other a "fall") known to contain appreciable amounts of G-M in order to determine the isotopic composition of the graphite involved. The study should provide information about the formation of G-M and the role of terrestrial weathering.

ALHA 77214 is a badly weathered (category C) L3 chondrite from Antarctica which McKinley et al (4) paired with eighteen other samples on the basis of the abundance of G-M. Shown below is the temperature release profile of carbon extracted from ALHA 77214 by stepwise combustion, together with that of standard graphite. A minor carbon phase released at low temperatures is possibly terrestrial contamination or a weathering product, but the bulk of the ALHA 77214 carbon combusts in the same temperature range, 700-900^{0}C, as the standard. A similar release profile was obtained for the Sharps H3 chondrite (a meteorite "fall"), thus, weathering does not appear to have affected one sample more than the other. The bulk carbon isotopic compositions of the two meteorites are distinct, that of ALHA 77214 at -11^o/oo being some 13^o/oo heavier than Sharps at -24^o/oo. Stepwise combustion unambiguously reveals that this is due, not to the presence of secondary phases produced by terrestrial weathering, but is a result of the graphite present as G-M having fundamentally different values in the two samples: -11^o/oo in ALHA 77214 vs -20^o/oo in Sharps.





Assuming that the graphite in ALHA 77214 has not isotopically equilibrated with atmospheric CO_2 the range of $\delta^{13}C$ for G-M argues strongly against the phases being a primitive condensate. The reaction $4CO + 3Fe \rightleftharpoons Fe_3O_4 + 4C$ could be more important in the formation of G-M; variable $\delta^{13}C$ values may reflect conditions on the H/L parent bodies. Other type 3 samples are under study to allow further insight into the origin of G-M.

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NOBLE GASES IN GRAPHITE-MAGNETITE INCLUSIONS. M.W. Caffee, C.M. Hohenberg, and T.D. Swindle, McDonnell Center for Space Sciences, Washington University, St. Louis, MO 63130, and B. Hudson, Lawrence Livermore National Laboratory, Livermore, CA 94550.

Noble gases from graphite-magnetite inclusions in Dimmitt, Plainview and Allan Hills 77011 have been studied, both in unirradiated samples and neutron-irradiated samples.

Ne-E (pure ^{22}Ne) has been previously found to be enriched in a graphite-rich, acid-resistant residue from Dimmitt (1). When aggregates consisting largely of graphite and magnetite were found in Dimmitt (2), it was suggested that these might be the carriers of Ne-E, and hence presolar in origin. But studies of unirradiated samples of inclusions from Dimmitt and the clast PV1 of Plainview showed that the Ne was dominated by spallation, with no trapped ^{20}Ne or excess ^{22}Ne observed.

The noble gases from the two unirradiated samples were also quite similar in other respects, showing much adsorbed air, abundant planetary ^{36}Ar and trapped Kr and Xe which were largely planetary in composition.

In addition, large amounts of excess ^{129}Xe were observed in both samples, attributable to decay of the extinct radionuclide ^{129}I. Samples of PV1 and of ALHA 77011 were then irradiated at the University of Missouri Research Reactor and studied using I-Xe dating techniques.

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UNPAIRED ELECTRONS: KEY TO THE TRAPPING OF PRIMORDIAL GASES BY METEORITIC CARBON?

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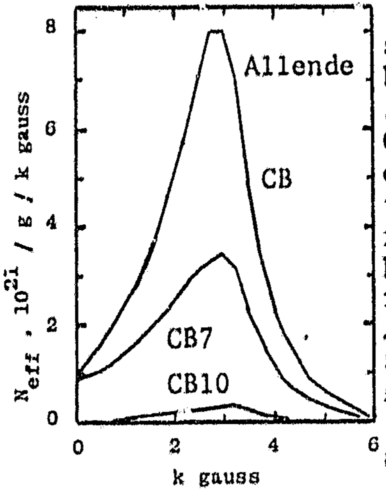
We have used electron spin resonance (ESR) to look for unpaired electrons in Allende carbon samples. The original motive was to see whether the structure consisted mainly of graphitic (*1*) or carbyne (*2*) units; the latter, having two unpaired electrons at the ends of the chain: $\cdot C{\equiv}C\{C{\equiv}C\}_n C{\equiv}C\cdot$, should be readily recognizable by ESR. We indeed found huge concentrations of unpaired electrons, but these electrons seem to be associated with "Phase Q", and vanish, along with the planetary gases contained in Q, when the sample is etched with HNO_3.

We ran 4 carbon-rich samples (Table 1) alongside a dilute solution of DPPH as a sensitivity standard. The effective number of free e^-, N_{eff}, was determined by double integration of the recorded second derivative (*3*). All samples show very high N_{eff} with a very broad distribution in g values (Fig. 1). Sample CB contains ≈20% ferrichromite, and so the unpaired d-electrons of Fe^{2+}, Fe^{3+}, and Cr^{3+} might account for up to ≈25% of the N_{eff}. But the next 3 samples were treated with H_3PO_4, which is known to deplete chromite by $\approx 10^2$x, yet N_{eff} of CB7 dropped by only 2x. The traces of Fe and Cr that survived the H_3PO_4 treatment can at most account for ≈3.5% of N_{eff} in BY (and presumably CB7). Thus, although the width of the feature resembles that of ferrichromite, there simply isn't enough Fe^{2+} and Cr^{3+} in these samples to account for the observed N_{eff}. Apparently most of the free electrons are associated with carbon. The N_{eff} value for CB corresponds to one unpaired e^- for every 7 C atoms -- an astonishingly high ratio!



We are not aware of any known type of C that shows such a high concentration or broad signal: graphite, lampblack, chars from PVC or PVDC [which Smith [illegible] Buseck (*1*) likened to Allende carbon], as well as tars [illegible]es, or Orgueil polymer (*4*). N_{eff} in these materia[illegible]s by orders of magnitude, depending on the method [illegible]ration, but only rarely approaches, let alone exceeds, 1×10^{21}/g. The distributions also are very much sharper, having FWHM of less than ≈50 gauss. Though we cannot yet rule out radiation damage as the cause, it appears that Allende carbon is a very special material, different from all common types of C. Perhaps carbynes are involved somehow.

Upon etching with HNO_3 (sample CB10), N_{eff} drops by an order of magnitude, and so does the content of planetary Xe (Table 1, Fig. 1). Such gas loss usually is attributed to dissolution of a hypothetical "phase Q", which thus far has resisted all attempts at characterization. Indeed, Yang et al. (*5*) have suggested that Q is not a phase at all, but merely an adsorbed gas layer that is held in place by active adsorption sites on the surface. The simultaneous loss of gas and unpaired electrons may imply a causal connection; the unpaired electrons may provide strongly bonding, active sites on the surface, which are deactivated by oxidizing agents such as HNO_3.

Allende HF,HCl - residues, Colloidal Fractions*

Sample	Xe^{132} 10^{-8} cc/g	Free e^- 10^{21}/g	Treatment	Weight %	
				Fe	Cr
CB	*60*	19	none	*9*	*4*
CB7	*60*	9	H_3PO_4 @ 230°C	*<0.1*	*<0.3*
BY	80	7	H_3PO_4 @ 200°C	0.12	0.51
CB10	*4*	0.7	H_3PO_4 @ 230°C & HNO_3 @ 80°C	*<0.1*	*<0.3*

*Values in italics are not directly measured, but are inferred from analogous, identically treated samples.

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STRUCTURE AND NOBLE GAS CONTENTS OF POLYVINYLIDENE CHLORIDE

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Increasing evidence suggests that carbon is an important host phase for noble gases in meteorites (e.g. 1, 2, 3). The microstructure of carbon in acid insoluble Allende residues observed by TEM has been likened to the structure of carbonized polyvinylidene chloride (PVDC) (4). This prompted us to synthesize PVDC in the presence of noble gases to determine its gas retention properties.

The samples were prepared by a method similar to that described in (5). Liquid vinylidene chloride was first polymerized in sunlight and then carbonized by heating in a furnace. During each step one had the option of exposing the material to a noble gas mixture (10 ppm Xe, 0.01% Kr, 0.1% Ar, 1.1% Ne, bal He; atmos. isotopic composition). Portions of some samples were examined by x-ray diffraction, SEM/EDS, and ^{13}C NMR (in progress). As the carbonization temperature increases, the structure begins to transform from predominantly chains (a single band at ∿4Å in XRD pattern) to an early stage in the formation of "turbostratic" structure with cross-bonding between chains (peak at 2.1Å).

Noble gases were analyzed via mass spectrometry in two runs. All single extractions were performed at 1600°C (±25°C). The measured ^{132}Xe concentrations and $^{132}Xe/^{84}Kr$ ratios are shown below. The first six samples did not have He, Ne, or Ar concentrations detectable above blank. Samples 7-7 and 7-8, measured in the second run with lower blanks ($^{22}Ne = 0.05$, $^{36}Ar = 0.01$ in 10^{-8} cm^3-STP), contained ^{22}Ne and ^{36}Ar in amounts approximately three times blank.

A stepwise heating experiment (500, 800, 1000, 1600°C) was conducted on additional aliquots of 7-6 and 7-8. In both samples the bulk of the gas was released in the 800°C step. Combining the gas evolved at 500°C and 800°C accounts for ≥98% of the Kr and Xe in both samples. Although the noble gas concentration increases with increasing carbonization temperature, stepwise heating data indicate that the outgassing temperature is independent of the carbonization temperature. There was no evidence for isotopic fractionation in the noble gases.

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Sample	(a)	(b)	Structure	Cl (wt %)	[^{132}Xe] ($10^{-8}cm^3$-STP-g^{-1})	$^{132}Xe/^{84}Kr$
3-1	n	400	Chain	10-20	0.13 ± 0.05	1.1 ± 1.0
3-3	n	800	Chain	2-7	1.25	4.7 ± 1.7
5-1	v	400	Chain	5-15	0.04 ± 0.01	-
5-3	v	800	Chain	1-2	0.87	6.2 ± 3.1
7-2	v	400n	Chain	5-15	0	-
7-6	v	800n	Cross-bonding	<0.1	27.5	7.3 ± 1.1
7-7	n	1000n	Cross-bonding	<0.2	285	8.4 ± 1.8
7-8	v	1000n	Cross-bonding	2-5	69.1	10.0 ± 1.5

(a) Polymerized in presence of pure vapor (v) or noble gases (n). (b) Carbonization temperature in °C; n indicates noble gases present. Unless otherwise stated, errors in ^{132}Xe are ±15%. Where no $^{132}Xe/^{84}Kr$ ratio is given [^{84}Kr] = 0.

^{13}C NMR SPECTROSCOPY OF THE INSOLUBLE CARBON OF CARBONACEOUS CHONDRITES.

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Between 70 and essentially 100 percent of the carbon of carbonaceous chondrites is present as an acid and solvent-insoluble macromolecular material. This carbon as found in the Allende CV3 chondrite has been alternatively suggested to be largely in the form of carbynes (1) or to occur as a poorly crystalline graphite (2). We have attempted to distinguish between these alternate structures by ^{13}C NMR spectroscopy, an instrumental method that is sensitive to the electronic environment of carbon atoms, in particular, to differences in carbon hybridization that exist between these alternative structures (sp, carbynes vs. sp^2, graphites).

Cross polarization magic-angle spinning ^{13}C NMR spectra (3) have been obtained of carbon residues resulting from HF-HCl digestion of the Allende, Orgueil (CI), and Murchison (CM2) meteorites. The Murchison and Orgueil residues give spectra similar to those of terrestrial coals and oil shales having two major features attributable, respectively, to carbon in various aliphatic and aromatic/olefinic structures. The spectrum of the Allende residue does not show these features. Without use of the cross polarization technique (carbon spectra not dependent on local hydrogen atoms) all three meteorite residues give spectra with a single feature at 150 ppm. Samples of carbonized polyvinylidene chloride give almost identical spectra. These results are consistent with a dehydrogenated polycyclic aromatic network as a major structural feature of the insoluble carbon of all three meteorites. The CI and CM2 meteorites have, in addition, structurally diverse, hydrogen-containing aliphatic and aromatic/olefinic structures.

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CORRELATED ISOTOPIC ANOMALIES OF C AND Xe IN ALLENDE

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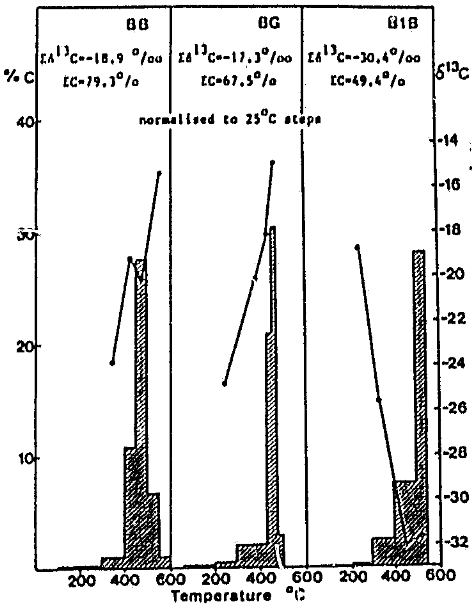
Anomalous noble gases in Allende are unevenly distributed, being contained mainly in a small (∿16%) subfraction of an acid residue resistant to oxidation (1). We have therefore performed coordinated measurements on a set of Allende carbon samples prepared by progressively harsher treatments. All consisted mainly of carbon, with lesser amounts of spinel, chromite and hibonite. Carbon abundance and isotopic measurements made on samples BB, BG & B1B were obtained using the stepwise combustion technique described earlier (2).

Sample	Description	% by wt	C %	$\delta^{13}C_{PDB}$ $^o/oo$	^{136}Xe 10^{-8} cc/g	$\frac{^{136}Xe}{^{132}Xe}$	$^{136}Xe^*$ % of total	^{20}Ne % of total
BB	Colloidal HF, HCl residue	≡100	79.3	-18.9	60.7	0.340	≡100	≡100
BG	BB + 16M HNO_3	95	67.5†	-17.3†	9.9	0.464	77	80
B1B	BG + acid dichromate	16	49.4	-30.4†	25.4	0.644	72	91

† replicate analyses; bulk Allende carbon value: C=0.23%; $\delta^{13}C$=-17.3^o/oo (2).

Stepwise combustion (fig) demonstrates that BB and BG have matching carbon release characteristics and reveals that only a small amount of carbon is destroyed during HNO3 treatment. The $\delta^{13}C$ patterns of the two samples are also similar, increasing in a trend from -25 to -15^o/oo with summed values of -18.9 and -17.3^o/oo respectively. Some heavy carbon is lost during preparation of BB from bulk whereas the opposite is true in isolating BG. B1B again shows a similar carbon release but in contrast the isotope pattern is substantially different with $\delta^{13}C$ decreasing with temperature of combustion; the $\Sigma\delta^{13}C$ value of B1B is -30.4 and that of the carbon lost is ca -15^o/oo. The chromic acid treatment which affords B1B destroys a large proportion of the carbon in BG but leaves, possibly in a fairly pure form, a phase whose existence was predicted by stepwise combustion of bulk undemineralised samples (2,3).

The most significant conclusion from the investigation is that at least some of the carbon in B1B (known to host 72% of CCFXe) has an isotopic composition which is unusual for a meteorite, possibly indicating some close association of two abnormal isotope compositions. If CCFXe is extrasolar and related to C in B1B it seems odd that the $\delta^{13}C$ is not even more exotic. However we do not yet exclude the possibility that B1B is unresolved gas-poor solar system carbon ($^{12}C/^{13}C$∿90) and a small amount of gas-rich extrasolar material ($^{12}C/^{13}C$ <<90). Alternatively the nearness of the $\delta^{13}C$ of B1B to 90 may suggest a local origin. Most of the Allende carbon has a $\delta^{13}C$ of ca -15^o/oo; it contains little or no CCFXe or Ne and probably formed under conditions not conducive to gas retention.



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NITROGEN ISOTOPE SYSTEMATICS IN METEORITES

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Within the paradigm of condensation from an essentially homogeneous solar nebula, the values of $^{15}N/^{14}N$ observed in meteoritic material defy reasonable explanation. The validity of this statement may be demonstrated by taking any of the variously postulated values for "primordial" $^{15}N/^{14}N$ and constructing scenarios wherein that value is modified, by fractionation, in an attempt to generate the gamut of observed values. This exercise is complicated by the lack of agreement concerning "primordial" $^{15}N/^{14}N$; values suggested to date span virtually the entire observed range [1]. However, it is readily apparent that fractionation invariably works to enrich protometeoritic material in the heavier isotope so that only relatively light N may serve as putative starting material in such a scenario. (A purely kinetic effect seems unlikely.)

The values of $^{15}N/^{14}N$ most commonly suggested as "primordial" [1] are 0.00291 and 0.00357, representing the lightest value observed in ancient lunar breccias [2] and the value characteristic of enstatite chondrites [3], respectively. If such materials are postulated to be ancestral to N in carbonaceous chondrites, enrichment of ^{15}N to the following levels is required: $^{15}N/^{14}N = 0.00384$, if the main body of bulk meteorite values is considered [3]; $\sim$0.004, if individual components within common carbonaceous chondrites are considered [4]; and 0.00431, if all bulk values are included [3]. Single-stage Rayleigh distillation can generate the lowest of these values from the higher primordial value, assuming loss of N as NH_3; however N_2 would have been the dominant stable nebular species at all temperatures above $\sim$300K (at 10^{-5} atm) and fractionation of N_2 would not have been adequately effective. The lower primordial value and/or the highest carbonaceous chondrite values are not compatible with any such scenario.

Equilibrium fractionation of all known neutral species reacting at all realistic temperatures is of the order of a few percent at most: inadequate to explain the observations, *including those of intrameteorite variability*.

Reaction between excited species at very low translational temperatures can produce isotopic fractionations of the magnitude implied by the meteoritic data [5]. Such reactions *may* enrich interstellar molecules in ^{15}N relative to the gas [6]. The most plausible locale where such reactions could have acted upon protosolar material would have been in the parental interstellar cloud prior to fragmentation and collapse.

Alternatively, perhaps we are seeing evidence for a significant component of nucleogenetic origin, i.e. alien N [7]. Effective decoupling of ^{14}N and ^{15}N nucleosynthesis makes this possibility astrophysically plausible [8].

Both viable interpretations for N isotope systematics in meteorites lead to the same conclusion: a significant proportion of meteoritic N was not isotopically homogenised in the nebula but apparently survived in solid form. This possibility has interesting implications for the thermal history of the protosolar system and the volatile inventory of the terrestrial planets.

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ANOMALOUS NOBLE GASES AND NITROGEN IN ALLENDE CARBONACEOUS MATTER.

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A previous analysis in this laboratory of noble gases released from an Allende acid residue by closed-system stepwise combustion(1,2) gave about the same enhancement level of anomalous Kr and Xe components as attained earlier by the Chicago and Berkeley groups using open-system chemical treatment by oxidizing reagents(3-5). We have now applied this combustion technique to a carbon-rich Allende residue previously oxidized in H_2O_2 to strip out AVCC-type components, and measured nitrogen as well as the noble gases released at each temperature by O_2 attack.

The H_2O_2 pretreatment resulted in significantly less masking of the anomalous gases by ordinary trapped gases than in the earlier experiment(1,2). Measured ^{78}Kr deficiencies of up to ∿ -200 permil relative to AVCC-Kr are consistent with previous results(6,7), as are correlations defined by mixing of the AVCC and anomalous DME (CCF) Xe components(5,8). Maximum 136/132 is ∿ 0.60.

Ne-E and s-process Xe are present in the Murchison(C2) and Orgueil(C1) carbonaceous chondrites(9,10). Neither of these components from stellar nuclear processing has been detected previously in the Allende C3 chondrite(1-4,11,12), but preliminary analysis of data from the present experiment suggests that Allende does contain minute traces of both. ^{20}Ne/^{22}Ne decreases from the value of 8.7 characteristic of Allende carbon(9,12) to a minimum of 3.5±0.4 in a high temperature fraction (550°C) containing <<1% of the total ^{22}Ne. Xe isotopes in the final steps of measurable Xe release break significantly away from the DME-AVCC correlation toward an end-point composition in which, if ^{136}Xe is assumed to vanish, ^{124}Xe, ^{126}Xe, and ^{134}Xe also vanish within error, and the ratios 128/130 and 132/130 are within ∿±50% of the s-Xe composition in Murchison and Orgueil(9). However, 129/130 and 131/130 are considerably higher, by factors of 3-4.

Nitrogen δ^{15}N associated with AVCC-type trapped noble gases in low temperature release is ∿+40 permil, characteristic of C1 and C2 chondrites(13). At higher temperatures δ^{15}N decreases relatively smoothly, associated with but not precisely correlated with release of anomalous noble gas components, and reaches an extreme meteoritic value of ∿-115 permil near the temperatures of prominant DME and s-Xe release.

Carbon combustion was essentially complete at 510°C; only ∿0.35% of the total CO_2 generated in the combustion appeared at higher temperatures (which extended to >1500°C). CO_2 and noble gas release were extremely well correlated. Splits of the evolved CO_2 were condensed in glass tubes and removed from the processing line for measurement of carbon isotopic composition in another laboratory. Results should be in hand by the time of the conference.

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NITROGEN ISOTOPES IN IRON METEORITES, R. O. Pepin and R. H. Becker, School of Physics and Astronomy, Univ. of Minnesota, Minneapolis, MN 55455.

We have extended an investigation of the nitrogen isotopic compositions of iron meteorites by the combustion technique (1) to six new samples, covering several different chemical groups. The procedure has been modified from that previously used for Piñon (1), in that it has been established that, for the samples sizes we are using (5-50 mg), two 3-hour steps at 1160°C are sufficient to release 95-100% of the gases present in the samples. These steps are in all cases preceded by a 700°C combustion for 1 hour to remove surface contaminants. The results for the new samples, plus a new analysis for Piñon with only 1 step at 1160°C, yielding 90% release of spallation noble gases, are shown in Table 1. Also shown is the value previously obtained for Piñon (1). The nitrogen obtained at 700°C is not included in the values in Table 1, since its isotopic uniformity from sample to sample indicates that it is probably a handling contaminant. Data work-up is incomplete at this time, so yields are uncertain to about 10% and δ^{15}N values to ± 3‰.

Table 1

Sample	Group	Wt (mg)	Yield (ppm)	δ^{15}N (‰)
Dayton	IIID	21.7	18	-56
Cape York	IIIA	6.7	20	-33
Toluca	IA	10.2	6	-12
Hoba	IVB	45.3	0.8	+ 7
Tlacotepec	IVB	48.0	2	+12
Washington Co.	Anom	14.9	3	+ 9
Piñon	Anom	22.4	3.5	+17
Piñon(1)	Anom	26.9	6.6	+15

Although there is still insufficient data available to allow one to make a convincing story about the nitrogen in iron meteorites, a couple of observations can be made. One is that the nitrogen variability, if it is the result of admixture of a very light nitrogen component into the solar system (2,3), appears to be decoupled from the source of the ^{107}Ag anomaly found in some iron meteorites (4,5). Cape York has the anomaly (5) and light nitrogen, Piñon and Hoba have the anomaly (4) and heavier nitrogen, while Tlacotepec has no anomaly and the same nitrogen as Piñon and Hoba. A second observation is that the isotopically heavier nitrogen, coupled with relatively low N contents, occurs in meteorites with ataxitic structure. It is observed in our experiments that nitrogen in these meteorites is sometimes released at a rate faster than the combustion rate, implying diffusive release is occurring in these samples. This suggests that perhaps all the meteorites at one time had higher N contents and lower δ^{15}N values, and that diffusive fractionation has played a role in establishing the present isotopic ratios. However, more data are needed before it can be decided whether the irons could have all been derived from a single, isotopically uniform nitrogen reservoir.

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THE IRRADIATION HISTORY OF LUNAR BRECCIA 79035.

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Several regolith breccias from the Apollo 11 and 17 sites contain trapped N extremely depleted in ^{15}N, and large amounts of spallation-produced ^{15}N(1). Exposure ages calculated from the near-surface ^{15}N production rate(2), combined with neutron fluence measurements, imply irradiation by galactic cosmic rays (GCR) at very shallow (<20g/cm^2) regolith depths for $\sim$2.5 b.y.(3). Taking this inferred residence time as a measure of how long ago the breccias' constituent soils were exposed to the solar wind, together with data from other soils, Clayton and Thiemens(1) derive a secular increase in solar wind δ^{15}N of $\sim$150‰ per b.y. for the past 2.5 b.y.

A problem with this model is that one would not expect, on the basis of regolith dynamics, a soil stratum in the upper 20g/cm^2 to escape disruption or burial for billions of years. The residence time *vs.* depth history and the epoch of surface exposure inferred for the breccias from fluence and spallation N are thus suspect. To address this problem, we have calculated spallation Kr and Xe abundances in 79035, a type example of this breccia class, from data obtained in a general study of noble gases and N(4), combined them with spallation N and fluence measurements(1,3), and assessed all four of these monitors of integrated cosmic ray exposure against production rate *vs.* depth profiles(5,6,7) in a search for self-consistent models of burial depth *vs.* time.

The relative magnitudes of the exposure signatures in 79035 are such that no single-stage (one depth) or multi-stage (different depths and times) irradiation by GCR alone is consistent with the data, within conservative estimates of uncertainty in production rates and analytic measurements (±15%, 25%, 25%, 50% for fluence/flux, Kr, Xe, and N respectively). One single-stage fit, for irradiation at $\sim$75g/cm^2 for $\sim$1.2 b.y., exists at the limits of error if Kr and Xe are stretched by $\sim$35% in opposite directions from their nominal values. The shallow neutron-nitrogen concordance at $\sim$2.5 b.y.(3) is drastically discordant with spallation Kr and Xe contents and production rates.

79035 is characterized by large abundances of spallogenic ^{15}N and ^{82}Kr. Both are produced copiously at shallow regolith depths by solar cosmic rays(5,7). If production by the present-day solar proton flux is included along with that by GCR in the production rate profiles, a two-stage model fit is obtained in which most of the spallogenic N, Kr and Xe is generated by $\sim$550 m.y. of exposure at very shallow depth (<1g/cm^2) and most of the neutron fluence during subsequent burial at $\sim$500g/cm^2 for $\sim$3200 m.y. This model is not unique, but the class to which it belongs is uniform in requiring long exposure at the extreme surface, and is in conflict with current estimates of surface strata lifetimes against burial, which are at least a factor 10 shorter(8). A $\sim$x10-20 higher solar proton flux circumvents this problem and leads to families of fits in which solar proton exposure at $\leq$10g/cm^2 for 10's-100's of m.y. is followed by burial at $\sim$100 g/cm^2 for $\sim$900 m.y. Very deep burial for indeterminant times prior to excavation can follow. Higher solar proton flux from the sun $\sim$4 b.y. ago has been suggested independently on astronomical evidence(9). 79035 could have acquired its solar wind nitrogen during surface exposure as long ago as this.

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NITROGEN ISOTOPES IN THE APOLLO 16 DEEP DRILL CORE. S. Fourcade and R. N. Clayton, Enrico Fermi Institute, University of Chicago, Chicago, IL 60637.

Five soil samples from various depths in the Apollo 16 deep drill core have been analyzed by stepwise heating for their nitrogen content and isotopic composition, in addition to one sample previously studied by Becker and Clayton (1977). Bulk nitrogen contents range from 42 to 79 ppm. The variations of $\delta^{15}N$ in stepwise heating experiments demonstrate that all the studied levels in the core have experienced at least two episodes of exposure to the solar wind, a conclusion which does not necessarily apply to each soil sample itself, but possibly to components of the soils with different exposure histories if these samples represent mixed soils. The total exposure time span contained within the core is at least 1 Gy, taking into account the isotopic variation of implanted nitrogen with time (Kerridge, 1975; Becker and Clayton, 1975; Thiemens and Clayton, 1980), as some released components have $\delta^{15}N$ as low as -105‰ (section 60002) or as high as +85‰ (section 60006). The isotopic composition of the trapped component, while generally increasing from the bottom to the top of the core, is not monotonically related either to depth, or to the total nitrogen content.

Spallogenic ^{15}N contents, measured from the high temperature release in stepwise heating (Becker et al., 1976), give apparent minimum cosmic ray exposure ages ranging from ∿5 to ∿9.5 × 10^8 y (shielding effect not considered). However, the variations of measured spallogenic ^{15}N contents with depth do not follow the drop observed in the upper 70 cm of the core (section 60006) for cosmogenic ^{21}Ne (Bogard et al., 1973). Such discrepancies between ^{15}N and ^{21}Ne irradiation ages have already been reported and could result from better retention of ^{15}N compared to inert gases during soil maturation (Thiemens and Clayton, 1980). The high plagioclase content of Apollo 16 soil samples compared to other sites can enhance this effect.

The nitrogen data lead to the following suggestions:

1) The upward increase of $\delta^{15}N$ from trapped component, while not monotonic, does not suggest an accumulation of the core from materials exposed elsewhere at the lunar surface, in a single depositional event. If such was the case, it would be a coincidence to find in the stratigraphic pile upward deposits corresponding to materials more and more recently exposed at the lunar surface (or containing an increasing amount of recently exposed soil component).
2) The depositional history of the core could possibly be related to several distinct episodes of rapid accretion. This is suggested in section 60003, for example, by the very similar exposure characteristics of two samples separated by 80 g/cm^2, themselves very similar to the sample of section 60004 (while this last soil possesses a considerably higher spallogenic ^{15}N component). Even if the homogeneity of the entire section 60003 is not proven for N isotopes, these data suggest rapid deposition of this part of the core at the expense of a material widespread at the Apollo 16 landing site, comparable to the trench soil 61241 (Becker et al., 1976), which is very similar to the 60003 samples in its nitrogen isotopes release pattern.

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ORGANIC COMPOUNDS IN THREE ANTARCTIC METEORITES

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Carbonaceous chondrites are the only natural source of prebiotic molecules available for analysis. Unambiguous evidence for extraterrestrial organic matter of abiotic origin was first obtained from the Murchison meteorite. Subsequently, Murray, Mighei and several others were shown to contain extraterrestrial organic compounds. But our understanding of the nature and origins of the organic matter is still at an introductory stage. One of the main reasons has been the paucity of clean, well documented specimens. Recent expeditions to the Antarctic have brought back more than 5,000 meteorites. Some of these are carbonaceous chondrites. The relatively cold, dry and sterile environment of Antarctica may have been an ideal storehouse for the fragile carbonaceous chondrites.

Allan Hills 77306 (C2), Allan Hills 77307 (C3), and Yamato 74662 (C2) have been analyzed for amino acids and hydrocarbons. The Murchison meteorite was also analyzed for comparison. Ion-exchange chromatography, gas chromatography and GC-MS were utilized for identification and quantitation as described in references 1 and 2.

Yamato 74662 contained about the same quantities of amino acids as the Murchison; Allan Hills 77306 contained 10-20% of these quantities and Allan Hills 77307 contained no extractable amino acids. The exterior and interior portions contained nearly equal amounts of amino acids. Both protein and non-protein amino acids were detected. D/L ratios for several amino acids from the interior and exterior were near unity. Preliminary evidence was obtained for lysine, phenylalanine and tyrosine, as well as for two precursors dipeptides. Single ion monitoring evidence indicates the presence of ala-ala and gly-val. Further attempts to identify peptides in meteorites are described in another paper in this volume (3).

Normal alkanes were the dominant hydrocarbons. Smaller amounts of aromatic hydrocarbons were detected also. For alkanes neither an odd over even preference nor a bimodal distribution was observed. Small quantities of pristane and no phytane were detected.

The results of this first study on three different Antarctic carbonaceous chondrites indicate that they have been preserved free of terrestrial contamination with no significant alteration after falling. Similar though less detailed studies have found the same results (4,5,6). Thus, the Antarctic meteorites may be ideal samples for studies on organic chemical evolution in the solar system. They also provide an opportunity to examine further a recent report that carbonaceous chondrites may contain indigenous non-racemic amino acids (7).

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ORGANIC CHEMISTRY, CARBON AND SULFUR ABUNDANCES OF ANTARCTIC METEORITES: IMPLICATIONS FOR POST-FALL HISTORY.

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Meteorites recovered from Antarctica offer the opportunity to study samples which have been stored for varying lengths of time in a relatively clean and cold environment. Previously reported total carbon and sulfur abundance data (1,2) noted that the majority of Antarctic meteorites studied do not exhibit total carbon and sulfur abundances outside the ranges previously observed for falls. In addition, the results of organic analyses (3-6) have shown that the Antarctic carbonaceous chondrites are uncontaminated by terrestrial organic matter. The long terrestrial ages reported by (7) along with the "clean" nature of the specimens, despite the obvious evidence of some form of chemical and physical weathering, represents a unique opportunity to study the potential effects of organogenic element alteration and modification since arrival of the specimens on earth. Lipschutz (8) in his recent review of weathering effects in Antarctic meteorites noted that, in general, interior samples of Antarctic specimens (both volatile-rich and volatile-poor) seem compositionally unaffected by weathering whereas exterior samples (i.e., 0-1 cm depth) indicate potential contamination by C and alkalis and, on occasion, other elements or loss (by leaching of still other elements-Ag, Bi, Cd, In, Sb, Se, Te and Tl). He noted some interior samples indicated redistribution, contamination and/or loss of cosmochronologic nuclides; other specimens seem unaffected by weathering.

From analysis of over 30 Antarctic specimens, more than two-thirds of the meteorites analyzed do not contain enriched carbon abundances resulting from weathering processes. The presence of trace amounts of secondary carbonates was noted during pyrolysis experiments, despite "normal" total carbon abundances. Secondary carbonates accounted for less than 5% of the total carbon. Variations in carbon abundances observed for specimens within the A and B classification fall within the ranges observed for non-Antarctic falls (1). One of the biggest surprises noted was the low carbon abundances observed for ALHA 77002, an L5 chondrite, which is reported by Nishiizumi and Arnold (7) to have a terrestrial age of 690 ± 170 x 10^3 years. We find the total carbon content of the interior to be 375 ± 25 ugC/g and the surface (0-1 cm depth) to be 655 ugC/g. With such an extended exposure to the Antarctic weathering environment, the ALHA 77002 carbon abundance "enrichment" is within the normal range for L5 chondrite falls. Total sulfur abundances are within the observed ranges for chondritic meteorites.

Extraterrestrial abiotic amino acids are present in two Antarctic C2 meteorites. Abundances of amino acids in the exterior and interior portions are nearly equal. The D/L ratio of a number of protein and non-protein amino acids in the exterior and interior is near one. Thus, these meteorites are uncontaminated by terrestrial organic matter. The abundances compare well with other C2 meteorites of similar total carbon content. The long stay in the Antarctic appears not to have altered the organic content detectably.

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^{40}Ar-^{39}Ar AGES OF ANTARCTIC METEORITES AND THE EFFECT OF WEATHERING ON THEIR AGES: I. Kaneoka, Geophys. Inst., Univ. Tokyo, Bunkyo-ku, Tokyo 113, Japan.

So far, we have dated more than twelve meteorites from Antarctica by the ^{40}Ar-^{39}Ar method, including ordinary chondrites (H, L, LL) and some achondrites, in order to get information on their age relationships (1-3). Because of the circumstances, however, Antarctic meteorites have been subject to the weathering effect. Even if we tried to remove weathered portions from them before using for ^{40}Ar-^{39}Ar analysis as much as possible, the results seem to show that some samples were affected by their weathering to some extent. Hence it is indispensable to examine the effect of weathering on the ^{40}Ar-^{39}Ar ages of Antarctic meteorites in more detail. For this purpose, two kinds of Antarctic meteorites were selected and their ^{40}Ar-^{39}Ar age results were compared between the outer and inner parts reflecting different degree of weathering. The sample ALH-761 (L6) is a relatively large block with a diameter of about 20 cm. From this block, the outermost part, the intermediate part and the innermost part were prepared. The outermost part includes the oxidized portions and fragile. The intermediate part also includes the oxidized portions with lesser amounts. The innermost part is relatively fresh. They were irradiated in JMTR with the fast neutron flux of about 10^{19} nvt together with the MMhb 1 as an age standard. All three portions show similar plateau-like ^{40}Ar-^{39}Ar ages of about 4400 Ma up to 900°C. In the 1000 ∿ 1100°C fractions, however, the samples from the outermost and the intermediate parts show high ^{40}Ar-^{39}Ar ages of more than 4600 Ma. In these fractions, the amount of released ^{36}Ar also increased. The sample from the innermost part does not show such high ages. Hence, the apparent high ^{40}Ar-^{39}Ar ages are probably attributed to the incorporation of terrestrial atmospheric Ar in some secondary minerals such as limonite (?). The outermost part contains much larger amounts of ^{36}Ar compared with that of the innermost part, reflecting the different degree of weathering effect. Similar results were obtained for the other sample ALH-77288 (H6), whose original size is about 10 cm in diameter. From this sample, the outermost and the innermost parts were prepared for ^{40}Ar-^{39}Ar analysis. The outermost part is seriously oxidized and the innermost part with lesser degree oxidized. No clear plateau ages were observed for these samples, but apparently high ^{40}Ar-^{39}Ar ages of more than 4600 Ma were observed in the 800 ∿ 900°C fractions in both samples, where the released fraction of ^{36}Ar also increased. These results suggest that the oxidized parts add the atmospheric components, which might cause the apparent increase in the ^{40}Ar-^{39}Ar age, in the intermediate temperature (around 800 ∿ 1000°C). These components might not be removed by preheating.

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CHEMICAL STUDIES OF EVAPORATION RESIDUES PRODUCED IN A SOLAR FURNACE

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King (1) used a solar furnace to produce evaporation residues from the Murchison and Allende meteorites in air and from a Columbia Plateau basalt in vacuum, in H_2 and in air. MacPherson *et al.* (2) described the petrography and mineralogy in detail and the chemistry in brief of some of the run products. More details of the chemical compositions are given here. A bulk sample of a basalt residue produced in H_2, CPB1-13, contains $CaAl_4O_7$, spinel, $CaAl_2O_4$, perovskite, metallic iron (8%Si) and Ca-Al-rich glass. Relative to the starting material, it is most enriched, and uniformly so, in Ca, Al, Ti, Sc, REE, Sr, Ba, Ta, Zr, Hf, Th and U, lithophile elements known to be refractory in a gas of solar composition. From the average enrichment factor for these elements, ∿74% of the starting material was volatilized. V is only enriched by 50%, but an Fe bead removed from the residue contains 3800 ppm V. Mg, Fe, Si, Co, Mn, Na and K are all depleted in the bulk residue relative to the starting material. The top of CPB1-4, a basalt residue produced in air, contains $CaAl_4O_7$, $CaAl_2O_4$ and spinel. Uniform enrichment in many refractory lithophiles indicates that ∿75% of the starting material was volatilized from it. Ce, U, Ba and V, predicted to be refractory under reducing conditions but volatile under oxidizing ones, are strongly depleted relative to Sm compared to CPB1-13. The top of CPB1-21, a basalt residue produced in vacuum (<1mm Hg), contains $CaAl_4O_7$ and $CaAl_2O_4$, while the bottom contains spinel, anorthite, melilite and glass in addition to these. From the uniform enrichments of refractory lithophiles in each, the top was more severely volatilized than the bottom, as expected: ∿84% *vs.* ∿71%. In both samples, Ce, U, Ba and V are strongly depleted relative to Sm, the top more so than the bottom. This suggests oxidizing conditions during volatilization, probably from air being present due to the relatively poor vacuum. The top sample is also depleted in Eu and Sr relative to Sm compared to the starting material, but the bottom is not. The top is much more strongly depleted in Na, Mg, Mn, Fe, Co and Si relative to the starting material than is the bottom. Relative to the starting material, the amorphous material that condensed from the vapor produced during volatilization of CPB1-21 is only enriched in Si, Ce, Ba and Ti. Relative to the starting material, the condensate tends to be higher in those elements depleted in the residue than in those which are enriched in the residue, although the enrichment patterns are not exactly complementary to one another.

The tops of two Murchison residues produced in air, CM2-6 and CM2-3, are composed of olivine+glass and olivine+glass+spinel+magnetite and represent volatilization loss of 71% and 66% of the starting material, resp. Both are depleted in V, Ce and Eu relative to Sm by factors ranging from 1.3 to 7.6 compared to the starting material because of oxidizing conditions. Ir and Os are much more strongly depleted relative to Sm, by factors of $>10^3$ and >35, resp. This is noteworthy because these two siderophiles are very refractory under reducing conditions. This effect is even more striking in the top and bottom of an Allende residue produced in air, All-1. Concentrations of refractory lithophiles compared to the starting material show that only 15% of the material in the top was volatilized and a negligible fraction of that in the bottom. Despite the relatively mild heating, >99.8% of the Ir and ≥91% of the Os were lost. It is unlikely that this is due to loss of a metal phase from the portions of the residue which were sampled, as the Ir/Co and Os/Co ratios are $<5.3\times10^{-3}$ and ≤.22 of their values in the starting material, resp. Ir and Os may form extremely volatile compounds during rapid heating of chondritic material.

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FINE-GRAINED SPINEL-RICH AND HIBONITE-RICH ALLENDE INCLUSIONS.

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The overall textures and structures of the many types of Allende fine-grained inclusions (FGI) indicate a complex history of condensation, aggregation, alteration and, finally, accretion into the Allende parent body. Spinel (*sp*)-rich FGI are distinguished by their pink to purple hue and concentric color zonation. Of the 7 "pink" FGI studied by us, no two are identical in detail, but all share many common features. One good example is a cm-sized object with 4 distinct color zones. Its pale-grey to pink core is a porous aggregate of *sp*, perovskite (*pv*), nepheline (*ne*), Al-diopside (*di*), anorthite (*an*) and grossular (*gr*) grains (all 1-20μm). These phases show few clear intergrowths with one another; mostly, the grains lie loosely next to each other with void space between them, suggesting that the grains formed separately and were randomly aggregated together. Surrounding this porous core, however, is a dense grey zone of *sp* crystals and crystal chains, *pv* and rare hibonite (*hib*), each mantled by a multilayered rim sequence of *ne+an*, and *di* or *gr*. Numerous cavities are lined with *di*, *gr*, sodalite (*so*), or rare hedenbergite (*hd*). The rimming of the *sp* and *hib* in this zone occurred after the FGI was formed, because the rim layers are continuous from one *sp* or *hib* crystal to the next. This dense zone grades outward to a red zone in which the mantled *sp* are more sparse, the *sp* is more Fe-rich than that nearer the inclusion center, and *hd* grains and interstitial *so* and *ne* are very abundant. The outermost white to pale-green zone of the inclusion is similar to the red one except that *sp* is nearly absent. The inclusion is partly mantled by a clastic rim sequence similar to those on coarse-grained inclusions (CGI) [1]. Melilite (*mel*) is absent from most FGI, making it difficult to relate them to the *mel*-rich CGI. We have found one pink FGI, however, with abundant *mel*. Its core consists of mantled *sp* grains in a matrix of *so*, *hd* and cavities, similar to the red zone of the inclusion noted above. Outside of this is a dense zone of *sp* patches mantled by *di*. The outermost parts of this dense zone contain *mel*, as highly embayed patches mantled by *gr*, *an* and *di*. Where *mel* contacts *sp*, it generally encloses the latter; only rarely are tiny patches of *mel* enclosed within *sp*. These relationships indicate that the *sp* in FGI is not equivalent to the *sp* in rim sequences on CGI as suggested by others [2]. Rather, it is equivalent to the primary *sp* in the interiors of the CGI. The loosely-packed and porous textures of FGI cores cannot easily be explained by origins involving melting [cf. 3,4] or metamorphism. The presence of *di* and *hd* grains sitting loosely-packed next to each other in the outer zones of FGI argues further against any wholesale melting or recrystallization of these objects. More likely, they are random aggregates of independently solidified grains. The zones of densely intergrown *sp* and *di* in some FGI do indicate that post-aggregation alteration has occurred. The pervasive interstitial filling by *so* and *ne* must also have occurred after aggregation, and at much lower T's than those at which the *sp* and *mel* formed. Both secondary processes must have predated incorporation into the parent body, however, since: a the secondary phases are rare or absent in the Allende matrix; and, b in places the inclusions are broken, exposing inner zones to direct contact with the matrix. Finally, we have found an entirely new type of FGI, noteworthy for the abundance of *hib*. One of our two specimens has a porous core consisting almost entirely of Ti-Mg-poor hibonite plates that are loosely packed next to one another with no intergrowths. This aggregate could not have formed from a liquid or by metamorphism; it must have resulted from aggregation of independently solidified crystals that probably condensed from the solar nebular gas.

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THE ORIGIN OF INCLUSION AND METEORITE MATRIX IN THE ALLENDE METEORITE

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The matrix of the Allende meteorite is a porous aggregate of fine-grained ferrous olivine (Fo_{55}) and lesser amounts of clinopyroxene, feldspathoids, sulfides, metal, and carbonaceous material (1). While the matrices of C1 and C2 chondrites were altered extensively by planetary aqueous activity (2-4), the properties of C3 meteorite matrix probably still reflect nebular processes (1,3,5).

"Inclusion matrix," a major constituent of amoeboid olivine aggregates (AOA's) and many fine-grained Ca,Al-rich inclusions (CAI's) in the Mokoia (6) and Allende (7) meteorites, is a similar fine-grained, mafic material in C3(V) chondrites. In Allende, the texture and mineralogy of inclusion matrix resemble those of opaque meteorite matrix, except that inclusion matrix is depleted in sulfides, metal, and carbonaceous material.

C3 meteorite matrix has been traditionally interpreted as an aggregate of low-temperature, crystalline nebular condensates (1,5). Ferrous olivine is the most abundant mineral in inclusion and meteorite matrix, but it is difficult to account for the formation of this mineral by equilibrium condensation. That model requires grains of enstatite and metallic iron (which condensed separately) to remain in intimate physical contact and react to form ferrous olivine at $T<1000$ K (5). Since residual low-Ca pyroxene does not occur in matrix materials, this reaction must have occurred with complete efficiency, but reaction and solid-state diffusion rates would have been low at these low temperatures. Notice that CAI minerals like hibonite, melilite, spinel, and perovskite did not react with complete efficiency at much higher temperatures where reaction and diffusion rates were much higher. Nebular gravitational and magnetic fields also ought to have supported metal/silicate fractionation, further reducing the likelihood that proto-enstatite could be completely converted to ferrous olivine. Finally, the preservation in meteorite matrix of extrasolar isotopic anomalies among volatile elements (8,9) and low-temperature minerals (10) demonstrates that some constituents of meteorite matrix were not completely vaporized in the solar nebula.

These difficulties are avoided if inclusion and meteorite matrix are interpreted as residues of partially-distilled interstellar dust, and/or nebular condensates from vapors produced by the more efficient distillation of proto-CAI aggregates (6,7). Distillation experiments provide supporting evidence for this interpretation. Ferrous olivine and sulfides form from C2 meteorite matrix at a temperature of ~1000 K (11). Amorphous Fe-Mg-silicates condense from vapors produced by efficient distillation of C2 material (12). Finally, many Allende AOA's show textural evidence of sintering during episodic thermal metamorphism: rims of massive zoned olivine surround cores of inclusion matrix (7).

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FRACTIONATION OF REFRACTORY METALS IN CA,AL-RICH INCLUSIONS FROM CARBONACEOUS CHONDRITES.

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Coarse grained refractory inclusions from C2 and C3 carbonaceous chondrites are commonly enriched in refractory lithophile elements (Ca, Al, Sc, REE, Th, etc.) as well as in refractory metals (W, Re, Os, Ir, Mo, Ru, Pt, Rh). Uniform enrichment factors relative to bulk chondrites are however rarely found. The relative abundances of Re, Os, and Ir are in all cases within a factor of two chondritic. Chondritic ratios among Re, Os, and Ir were also found in separated metal particles and in single mineral grains, containing small metal inclusions. The Os contents of the analyzed samples covers a range from 10^{-6} to 10^{-11} g Os. This finding suggests that Fremdlinge with non-cosmic proportions of noble metals (1) do not contribute significantly to the bulk chemistry of these inclusions, or that the grains of almost pure Os, Re or Pt described by El Goresy et al. (1) were formed by secondary processes from an initially cosmic reservoir.

The more volatile refractory metals Ru and Pt are often depleted relative to Re, Os, and Ir. Platinum is always more depleted than Ru. This sequence of depletion indicates that the refractory metal abundances in these inclusions are fractionated according to their vapor pressure and are not affected by their chemical properties.

Tungsten, having the lowest vapor pressure of all metals, and Mo (vapor pressure similar to Ir) do in many cases not fit into this sequence. Depletion of these two elements may indicate oxidizing conditions, since both elements readily form volatile oxides.

However there are several occurrencies of chondritic ratios among all refractory metals (2,3). These metals appear to be the best candidates for unaltered condensates from a cooling gas of solar composition. Evaporative residues presumably have lost W and Mo because of more oxidizing conditions during reheating.

We have also found cases where the fractionated pattern of refractory metals conforms to the fractionated pattern of refractory lithophile elements (REE, Hf, Sc, etc.) in such a sense that condensation temperatures calculated from the pattern of lithophiles and metals are in good agreement. It appears therefore that high temperatures are required to obtain the fractionated pattern of refractory metals found in the inclusions. The abundances of W and Mo further demonstrate that at least some of the metals were formed by condensation from a gas of solar composition.

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THE Mg ISOTOPIC COMPOSITION OF IGNEOUS-TEXTURED REFRACTORY INCLUSIONS FROM C3 METEORITES.

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Radiogenic ^{26}Mg excesses are a common feature of refractory inclusions in C3 meteorites, but the importance of ^{26}Al as a heat source for melting planetary bodies and the usefulness of the Al-Mg system as a chronometer remain unclear. Much of the uncertainty is due to the undetermined origin of refractory inclusions and the subsequent question over initial Al isotopic heterogeneity. We report Mg isotopic analyses of four refractory inclusions from Allende and Ornans whose igneous textures leave no doubt about their origin from a liquid and their consequent internal Al isotopic homogeneity.

Allende ABC [1] is an irregularly shaped, millimeter-size inclusion with diabasic texture comprised of large plagioclase laths (An 99-100) enclosing blocky interstitial Ti-Al-pyroxene. The interior of Allende inclusion TS-26, a Type I [2], is similar to ABC but contains abundant spinel framboids and is surrounded by a thick pyroxene mantle set off by a chain of sulphide. Allende 3510 is a ∿3 mm diameter circular inclusion comprised of intergrown laths of plagioclase (An 95-98) and olivine (Fo 88-92). Ornans RC-11 [3] has a subophitic texture comprised of plagioclase laths (∿An 70-80) intergrown with blocky enstatite and low-Fe augite. Aside from their distinctive textures, these inclusions share five other features which set them apart from most C3 refractory inclusions. Four features are mineralogic: melilite is absent, forsteritic olivine is present, no Wark-Lovering rim surrounds the inclusions, and alteration of plagioclase is minor.

The fifth feature common to the inclusions is isotopic: ^{26}Al was not abundant when these objects crystallized. The Mg isotopic composition of plagioclase and an Mg-rich phase (pyroxene or olivine) was measured in each inclusion with an ion microprobe. The Mg isotopic composition of the Mg-rich phases in all inclusions is normal with no indication of high ^{25}Mg/^{24}Mg ratios indicative of isotopic reequilibration. Plagioclase in ABC and 3510 contains small but clearly resolved ^{26}Mg excesses correlated with Al/Mg ratios which define an Al-Mg isochron with slope $(^{26}\mathrm{Al}/^{27}\mathrm{Al})_0 = 6 \times 10^{-6}$, nearly an order of magnitude less than the canonical Allende value [4]. Plagioclase in TS-26 and RC-11 has an Mg isotopic composition indistinguishable from terrestrial and $^{26}\mathrm{Al}/^{27}\mathrm{Al}$ was $< 2.5 \times 10^{-6}$ when these inclusions crystallized. The near absence of radiogenic ^{26}Mg from refractory inclusions with clearly molten origin [5] has important implications for the distribution of ^{26}Al in the solar nebula. If these inclusions formed contemporaneously with Allende B1 inclusions, ^{26}Al-decay was not the heat source which produced melting. If ^{26}Al initially was uniformly distributed, refractory inclusions were still crystallizing from a liquid at least 3 million years after the formation of Allende B1 inclusions. In this scenario, the normal ^{25}Mg/^{24}Mg ratios of the Mg-rich phases require that the parent liquid cannot have had as high an Al/Mg ratio as the bulk composition of ABC.

Sample		δ^{26}Mg(‰)	^{27}Al/^{24}Mg
ABC	Pg 1	16 ± 6	354
	Pg 3	17 ± 5	403
	Pg 4	10 ± 5	268
3510	Pg 1	5 ± 3	98
	Pg 2	7 ± 3	128
TS-26	Pg 1	-1 ± 4	157
	Pg 2	0 ± 4	208
RC-11	Pg 1	-3 ± 4	80

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NUCLEAR TRACKS IN REFRACTORY SILICATE AND OXIDE PHASES IN CM CHONDRITES.

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The CM chondrites contain a small percentage of refractory inclusions that occur both as irregular aggregates and compact spherules (1, 2). The dominant phases observed in these inclusions are refractory oxides like hibonites, spinels and perovskites. Al- and Ti-rich pyroxenes, free of Fe, have also been identified in some inclusions. Another refractory silicate, diopside, is present as the outermost boundary layer in most or all of the refractory inclusions in CM chondrites. It is suggested that this phase may perhaps be used as a time-marker in the condensation scenario for the formation of the refractory inclusions (2, 3).

Nuclear track records in separated refractory silicate and oxide phases from the CM chondrites Murchison and Murray have been studied to obtain information on the possible presence of plutonium and curium fission tracks in them, and to attempt a chronology of the events leading to the formation of these inclusions. Samples recovered from disaggregated material as well as picked directly from refractory inclusions, identified in small fragments of the meteorites, were included in our analysis. Nuclear tracks were found in several hibonites, diopsides, and fassaites. The track densities in the silicate phases are in the range of ~ 1 to 4×10^6 cm^{-2}. The maximum track density observed in hibonites is 1.5×10^7 cm^{-2}. Preliminary analysis of the track results indicate presence of ^{244}Pu fission tracks in all the three phases. Presence of ^{244}Pu tracks in Murchison hibonites has been reported recently (4). Precise measurement of U-content in the analysed phases and laboratory experiments on their track retention properties are currently in progress, and will be reported at the meeting.

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NASA COSMIC DUST PROGRAM: A SOURCE OF EXTRATERRESTRIAL MATERIAL FOR RESEARCH. U.S. Clanton, J.L. Gooding, and D.P. Blanchard, Code SN2, NASA Johnson Space Center, Houston, TX 77058.

The "cosmic dust" which populates interplanetary space has several different postulated origins, including disaggregation of comets, asteroid collisions, meteorite/planet impacts, and injection of material into the solar system from extrasolar sources. The possible cometary connection, in particular, has been emphasized by several different workers. Regardless of its origins, though, cosmic dust should be sampled and studied for the information it may contain regarding the origin and evolution of solar system materials. Attempts to collect cosmic dust met with decades of failure until suitable techniques for collecting dust from Earth's stratosphere were applied to the problem by D.E. Brownlee. Since 1974, Brownlee and collaborators have collected demonstrably extraterrestrial particles using impactors mounted on NASA U-2 aircraft. Despite these pioneering efforts, the small size of the collection program has seriously limited the amount of cosmic dust available for study. Consequently, the Johnson Space Center (JSC) initiated a program for the systematic collection and curation of cosmic dust samples and their distribution to scientific researchers.

In May 1981, JSC began its collection program using silicone oil-coated impactor "flags" mounted in wing pylons of NASA jet aircraft. Under typical collection conditions (Mach 0.8 at 20-km altitude), each flag of 30 cm^2 surface area sweeps a volume of ≈2500 m^3 per hour. A set of 8 flags is flown on a typical WB57F aircraft mission and a set of 2 flags is flown on each U-2 mission. Collector positions on both aircraft are shared with other experiments and several different flights are required to accumulate the desired exposure time (≈30-60 hours) for each set of collectors. Ultimately, the introduction into service of large-area (457 cm^2) collectors will provide a greater supply of large (≥50-μm) particles which should facilitate analyses by techniques not currently applicable to the commonly occurring ≈10-20-μm particles. An ultra-clean (Class-100) facility at JSC is used for pre- and post-flight handling of the collectors and for the curation of collected particles. Individual particles (≥4-μm) are removed from the flags and, after washing, examined by optical and scanning electron microscopy (including qualitative elemental analysis by energy-dispersive x-ray analysis). Preliminary examination data are published as loose-leaf catalogs which are distributed to the scientific community.

As of June 1982, the JSC cosmic dust sample inventory includes 24 flags from WB57F missions and 4 flags from U-2 missions. Two complete catalogs have been issued with descriptions for approximately 250 individual particles, about 40% of which appear to be extraterrestrial. Samples have been allocated to six different research groups and additional sample requests have been received. Thus, in only one year of operation, the NASA/JSC program has contributed significantly to the positive growth of cosmic dust science. Scientists interested in requesting samples or further information should write to "Curator/Cosmic Dust" at the address given above.

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AL-PRIME PARTICLES IN THE COSMIC DUST COLLECTION: DEBRIS OR NOT DEBRIS?

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The presence of aluminum-rich particles in cosmic dust collected from the stratosphere has led to some speculation on their origins. These particles, termed Al-primes (Brownlee et al., 1976), are characterized by a high concentration of Al and variable, minor amounts of Mg, Si, S, Ca, Ti, Fe, Ni and Cu. Other elements may also be present in minor quantities. On the basis of Mg/Si ratios, and relative abundances in the U2 collection, Flynn et al. (1982) have suggested that Al-prime particles are unlikely to be from natural terrestrial sources, and propose an extraterrestrial origin. The relative abundance of Al-primes in the Johnson Space Center collection has been documented by Mackinnon et al. (1982) using similar criteria to Flynn et al. (1982). The relative abundance of Al-primes is not unlike that of certain groups of known extraterrestrial particles in the JSC collection (Mackinnon et al., 1982). Al-prime particles in the JSC collection may be classified into three smaller sub-groups; one of which is similar to the group of Al-prime particles reported by Flynn et al. (1982).

We have analysed in detail a selection of Al-prime particles allocated from the JSC collection using high resolution SEM and backscattered imaging. Materials rich in high atomic number elements (e.g. $Z>20$) are readily distinguished from those with low-Z elements using backscattered electron imaging. In this study, we have observed Al-prime particles which show (a) a homogeneous elemental distribution (b) light element "cores" with heavy element nodules randomly distributed and (c) aluminum and/or silicon spheres with a heavy element (Fe,Cu) aggregate attached. Two particular observations lead us to suggest that not all Al-primes are extraterrestrial in origin. An Al-rich sphere with a Si and Ca abundance similar to refractory materials has a high concentration of Cu which cannot be attributed to instrumental spectral contamination. Backscattered imaging indicates that the Cu concentration corresponds to small mounds or nodules ($<1\,\mu m^2$ area) on the surface of the sphere. A high Cu abundance in the absence of other heavy elements may be consistent with a terrestrial source. The second observation concerns an Al-prime particle in close contact with a typical Al_2O_3 rocket exhaust sphere. High resolution imaging shows that the Al-prime and Al_2O_3 sphere are connected by small grains ($<1\,\mu m$) with a low atomic number (i.e. $Z<26$). Material resembling a coating or "glue" is not apparent in our observations. We suggest that this observation links the source of some Al-prime particles to that of the Al_2O_3 spheres.

Possible terrestrial sources of aluminum- or silicon-rich materials include spacecraft ablation products, explosion debris, volcanic ash and industrial ash. All of the above sources may place large quantities of material into the stratosphere over variable periods of time. For example, the volume of spacecraft debris entering the stratosphere in recent years probably exceeds the current yearly meteoritic influx (D. Kessler, pers. comm.). Therefore, in the search for a source of Al-prime particles, we suggest terrestrial alternatives should be thoroughly examined.

We conclude from this study that (a) many Al-prime particles are from man-made sources though a few Al-primes may have an extraterrestrial origin. (b) Bulk composition and morphology alone are not adequate criteria to identify Al-primes. A knowledge of elemental spatial distribution may be necessary to distinguish "composite" particles from true Al-primes. (c) Some Al-prime particles may be related to solid fuel rocket exhaust.

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STRATOSPHERIC COLLECTIONS AS A PROBE OF THE MICROMETEORITE FLUX

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There has been considerable discussion about the composition and internal structure of unmelted micrometeorites collected in the stratosphere, especially with regard to what they may tell us about comets and the early solar system (1). Although the compatability of stratospheric abundances and space measurements has been pointed out (2), relatively little has been said about the usefulness of these collections as probes of the micrometeorite flux. The possibility is attractive, since the "flux density" (∿0.1 $m^{-2} s^{-1}$) of >10 µm extraterrestrial particles on stratospheric impaction collectors is 4 orders of magnitude higher than that in space. Several processes must first be considered: i) heating and fragmentation of the particles on capture by the earth; ii) stratospheric particle settling rates; and iii) sampling biases (human and aerodynamic) against smaller particles.

We discuss here size distribution data from stratospheric collection surfaces which have sampled ∿$4x10^5 m^3$ of stratospheric air (3). The 36 probable extraterrestrial particles ≥ 15 µm in size imply a stratospheric concentration for micrometeorites in this range of ∿9±2 $x10^{-5} m^{-3}$. We expect particles ≥ 15 µm in size to be largely unaffected by the small particle sampling biases mentioned above, and this is supported by the fact that their distribution can be reasonably fit using a power law in size (slope ∿5.4±1.4). The cited errors are 1 sigma counting errors only, and the slope determination results from a Poisson maximum-likelihood fit.

We assume an area-proportional settling velocity in the stratosphere of ∿1 cm/s for 10 µm particles (4), and a typical particle density between 1 and 2 g/cc (5). Models of atmospheric deceleration and the velocity distribution on entry (6) suggest that the fraction of particles ≤ 40 µm in size lost to heating is minor, and that the earth's capture cross-section is ∿2.5 times the geometric area. Neglecting fragmentation effects, then, space measurements (7) predict stratospheric concentrations for micrometeorites ≥ 15 µm in size between 2/3 and 6 times the observed value. Smooth (log-normal) curves through the dust models of Hughes and McDonnell (8) also suggest fluxes between 3/4 and 4/3 of the observed value, with slopes of ∿5. The agreement suggests that stratospheric collections are not dominated by particles fragmented on entry, even though the 1 A.U. mass flux in particles ≥ 40 µm in size is 10-20 times as great as that between 15 and 40 µm. This conclusion is important for interpretation of both space exposure and entry heating measurements (9).

The resulting self-consistent model of airborne interplanetary dust indicates that >90% of the unmelted extraterrestrial mass in the atmosphere is in particles too small to be collected by current techniques. When combined with deceleration models, it also allows prediction of the absolute abundance of particles heated above a given temperature on atmospheric entry.

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INFRARED SPECTRA OF INTERPLANETARY DUST PARTICLES

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We report here the infrared absorption spectra of a number of interplanetary dust particles collected using high altitude aircraft impaction collectors (1)(2). The particles ranged in size from 15 to 40 microns. Infrared transmission spectra between 4000 and 400 cm^{-1} were obtained using a Nicholet 7199 Fourier transform spectrometer equipped with a globar source, a KBr beam splitter, and a mercury-cadmium-telluride detector. The preparation of sample mounts is discussed elsewhere (3).

The observed spectra to date fall into several groups (4). The most commonly found spectra are those of pyroxene and olivine. Pyroxene is recognized by its broad absorption band centered about 1000 cm^{-1}. This band has more detailed features at 1060, 1000, and 920 cm^{-1}. In addition, pyroxene exhibits narrower features at 820, 720, 610, 510, and 420 cm^{-1}. Olivine has its major absorptions at 880 and 420 cm^{-1} with weaker absorptions at 980, 570, and 490 cm^{-1}.

In addition, Several particles exhibit spectra that are almost identical to that obtained from the meteorite Murchison. These particles have broad featureless bands centered at 1000 and 440 cm^{-1} as well as weaker features at 2970, 1610, and 1430 cm^{-1}. A broad shallow featureless band centered at $\sim$3400 cm^{-1} dominates the higher wavenumber range. This feature indicates the presence of hydrated silicates.

Some particles exhibit very little absorption. Weak bands consistent with pyroxene are sometimes observed but the features are too small to make the identification positive. Poorly crystallized silicates may be responsible for the shallow absorption.

One large particle has been found with a single, strong, broad absorption feature centered at 975 cm^{-1}. Although the featureless absorption is similar to that observed in interstellar dust (and commonly attributed to amorphous silicates) we cannot rule out the possibility that the spectrum is produced by a saturation broadening of a Murchison-type spectrum.

A key problem, under active investigation, is the extent to which heating during atmospheric entry may have altered the IR spectra of the particles as they existed in space.

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PYROXENE WHISKERS IN CP INTERPLANETARY DUST PARTICLES: EVIDENCE OF VAPOR PHASE GROWTH. J.P. Bradley and D.E. Brownlee, Dept. of Astronomy, Univ. of Washington, Seattle, WA. 98195; D.R. Veblen, Dept. of Earth and Planetary Sciences, The Johns Hopkins University, Baltimore, MD. 02138.

CP micrometeorites are highly porous and fragile interplanetary dust particles (IDP's) that have chondritic elemental abundances. Among the mineral species found within these particles are pure enstatite crystals, which are unique among the micron-sized constituents of CP IDP's in that they are euhedral. They exhibit at least three distinct forms, henceforth referred to as rods, ribbons and platelets, whose morphologies are totally inconsistent with those of rock-forming pyroxenes that have crystallized from a melt.

Chemical and structural features of the pyroxenes were investigated by analytical scanning and transmission electron microscopy. Rods consist of single crystals that are grossly elongated along the crystallographic [100] direction. Ribbons are blade-shaped crystals that are morphologically similar to rock-forming pyroxenes (1) except that they are also elongated along [100]. Platelets consist of very thin (200-500 Å) angular crystals whose habits lie in a-c projection (i.e. they are thin parallel to [010]).

Each of the three morphological forms were found to possess characteristic crystallographic defects. For example, some of the rods contain axial screw dislocations that run parallel to the lengths of the crystals. High-resolution images and diffraction data indicate that they consist exclusively of clinoenstatite containing isolated [100] stacking defects. Ribbons also consist exclusively of clinoenstatite that contains isolated [100] stacking defects. Platelets consist of pervasively intergrown ortho and clinoenstatite, together with extreme stacking disorder.

The presence of whiskers and platelets in CP micrometeorites has important implications with respect to the origin of CP IDP's. Both synthetic and naturally occurring whiskers of a variety of compositions have been observed (2,3): apart from their distinctive morphologies, a characteristic feature of those grown by direct vapor-to-solid condensation is a rod-like morphology containing an axial screw dislocation (2). Donn and Sears (4) have pointed out that nuclei present in the solar nebula are likely to have lead to whiskers and platelets containing screw dislocations. Such defects would have allowed equilibration of the saturated vapor phase with a stable crystal phase at saturations well below those required for other modes of condensation.

Our observations provide strong evidence that primary condensates from either the solar nebula or pre-solar environments have been preserved in certain IDP's and that they can be identified and studied by electron-beam methods. Analyses of these particles should provide fundamental insights into the kinetic aspects of condensation. One intriguing aspect of this effort is the observation that growth of rods by axial screw dislocation appears to be confined to enstatite.

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XII-6

ON THE FORMATION AND PROPERTIES OF PRIMORDIAL CONDENSATES; Bertram Donn and Joseph A. Nuth,* NASA/Goddard Space Flight Center, Laboratory for Extraterrestrial Physics, Greenbelt, Maryland 20771

Experiments have been carried out on the condensation of grains from SiO and Mg + SiO in hydrogen. The partial pressure of SiO required to initiate nucleation was determined as a function of ambient temperature. In the temperature interval 750 K to 1000 K the critical SiO pressure in the monoatomic system went from 10^{-3} torr to 2.5×10^{-2} torr. For the condensation of SiO grains this would correspond to supersaturations of 4×10^{5} and 2.5×10^{5} respectively. In such experiments metastable solids condense, e.g., Si_2O_3 from SiO vapor; therefore, the concept of supersaturation is an ill-defined measure of the nucleation barrier. With Mg + SiO vapor, the SiO critcal pressure is reduced by about a factor of three for $T < 925$ K as compared to the nucleation of pure SiO. These results cannot be directly extrapolated to the much longer time scales of the solar nebula because of the absence of a theory of nucleation for metastable grains. The sharp cut-off of nucleation with a decrease in the SiO partial pressure suggests that low supersaturations would yield extremely slow condensation rates. Meteoritic evidence indicates that some primordial interstellar grains survived the collapse of the primitive solar nebula. Their presence would lead to heterogeneous nucleation on their surfaces and inhibit nebular grain formation by nuclei formed spontaneously in the vapor. Amorphous laboratory condensates anneal to stable species: amorphous quartz for SiO smokes and Mg_2SiO_4 for Mg + SiO condensates. The temperature dependence of these annealing rates is being determined using infrared and x-ray diffraction measurements. The infrared spectra of partially annealed grains shows suggestive similarities to the spectra of the matrix material of carbonaceous chondrites and to chondritic Brownlee particles.

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ON THE PRODUCTION RATIO OF SOME PAIRS OF ISOTOPES IN METEORITES

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Several pairs of cosmogenic nuclides provide useful tools for studying the exposure history of extraterrestrial materials. These are ^{22}Na - ^{22}Ne, ^{26}Al - ^{21}Ne, ^{36}Cl - ^{36}Ar, ^{39}Ar - ^{38}Ar, ^{40}K - ^{41}K, ^{81}Kr - ^{83}Kr and others. This abstract deal with the first four of them. Our aim is to examine in what extend their respective production ratios P_r/P_s can be considered as independent of the target chemistry and of the shielding conditions of the sample. Also we will try to deduce some limits to P_r/P_s values, starting from nuclear data.

We measured new cross sections (σ) for the production of ^{22}Na, $^{20-22}$Ne and $^{36-42}$Ar in Mg, Al, Si and Ca targets bombarded with several proton energies E_p between 0.059 and 24 GeV. These data are used to better define excitation functions $\sigma(E_p)$ for these nuclides in targets which are abundant in meteorites. Neutron channels are mostly evaluated, since experimental data is generally limited to some specific incident energies. This in fact limits the accuracy of production rates calculations for some nuclides. However, rather strict limits to ^{22}Na/^{22}Ne and ^{36}Cl/^{36}Ar production ratios can be inferred from their σ_r/σ_s cross section ratios. Some limits can also be deduced for ^{26}Al/^{21}Ne and ^{39}Ar/^{38}Ar ratios in iron meteorites, and in the metal phase of stones.

A change in the past galactic cosmic ray intensity may be deduced if two methods for calculating exposure ages, involving radionuclides of different periods, give significantly different results. We will discuss our data in connection with this question, most recently debated in ref. 1, 2 and 3.

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MORE ABOUT COSMOGENIC KRYPTON

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Krypton has been a test element for checking the validity of models dealing with irradiation effects at the lunar surface (1), (2). When not masked by trapped gas, its cosmogenic component comprises 7 isotopes generated in only 4 main target elements. Fissiogenic and (n, γ) components are generally easy to isolate. In meteorites, determination of cosmogenic krypton provides precise exposure ages (3), at least in good cases. We recently submitted for publication a paper (4) giving excitation functions for Kr isotopes produced by the proton bombarment of Y and Zr targets (from measured values) and Rb and Sr targets (from systematics). Our deduced production rates still improve the observed (2) agreement between the measured and calculated cosmogenic krypton in well documented lunar samples. However Rb and Sr targets appear to give significantly different krypton isotopic composition compared to Y and Zr. This effect could be of importance in chondrites and achondrites in which Sr is an abundant target relative to Y and Zr. The inferred $^{81}Kr/^{83}Kr$ production ratio in these bodies, when compared to the interpolation formula of ref. 3, is lower by 5 to 20 % depending on shielding and erosion effects.

When iron meteorites are concerned, the main target elements are Mo, Ru and Pd. We will present new cross sections for krypton isotopes in Pd and Ag targets bombarded with protons of 0.150, 0.600, 1.05 and 24 GeV. We could not measure Kr in Mo, whose melting point is 2622°. However we are trying to calculate the Kr cross-sections in the missing targets by reactualizing the parameters of the Rudstam (5) formula in the A_T = 80 to 110 mass region. This should be made possible by using all newly available data.

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DEPTH PROFILES OF SPALLOGENIC 26-AL, 53-MN, AND NOBLE GAS ISOTOPES IN ALLAN HILLS 78084.

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Concentrations of spallogenic nuclides in meteorites vary both with size and sample location within the meteorite. This is caused by the depth dependence of the production of secondary particles by the primary cosmic radiation. To study this effect in a small meteorite, we have measured the long-lived radioactive isotopes 53-Mn and 26 Al as well as the noble gases in samples from different locations in the H3-chondrite ALHA 78084 (weight: 14.3 kg).

In three samples the 26-Al activity is between 224 and 246 dpm/kgSi. For 10 samples the 53-Mn content varies between 265 and 199 dpm/kgFe, with no apparent correlation between content and shielding depth within the limits of error. The noble gas analyses show a range of 3-He/21-Ne between 5.5 and 6.o, and a variation in 22-Ne/21-Ne between 1.14 and 1.18. The slope of the 3-He/21-Ne vs 22-Ne/21-Ne correlation line is similar to those observed for Keyes (1) and St. Severin (2). The exposure age of ALHA 78084 is 20.5 m.y., calculated with the shielding correction method and production rates of (3).

The activities of 26-Al and 53-Mn are both distinctly lower than the expected saturation values of 298 dpm/kgSi (4) and 478 dpm/kgFe (5). The low value for 26-Al can be explained by a terrestrial age of about 10^5 years, a typical value for Antarctic meteorites. The 53-Mn, however, should be in saturation. The noble gas analyses show that this chondrite was irradiated only as a small meteorite and so pre-irradiation, under more shielded conditions, is not very likely. Instead, the low 53-Mn concentrations might be explained by a lower saturation activity for rather unshielded samples of small meteorites. This is in agreement with recent calculations (6) which showed that the contribution of secondary particles to the production of 53-Mn in small meteoroids is less than previously estimated. Thus, the 53-Mn data as well as those for noble gases presumably represent a characteristic depth profile of a meteorite with a preatmospheric radius of about 15 cm and a loss by ablation of about 5 cm.

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COSMIC RAY TRACK DENSITIES AND ^{60}Co ACTIVITIES AS DEPTH MONITORS IN ALLENDE METEOROID.

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Cosmic ray track densities in olivines from 5 Allende stones were analyzed in order to compare the depths inferred by cosmic ray track data (1) with those obtained through ^{60}Co activities (2,3). For each stone, 4 to 5 spot samples were taken from a slice centrally located. Taking into account the different depth profiles for cosmic ray track densities and neutron capture products within an object having a preatmospheric radius of 55 cm, the agreement was found to be rather good for 4 out of 5 Allende stones ranging in depth between ∿1 and ∿25 cm (Table 1). For the fifth stone (3512 C, N.M.N.H.) the two methods give, however, very different depths (^{60}Co : 1-3 cm; c.r. track data : 7-11 cm). This disagreement has already been observed by Stapanian and Burnett (4). We conclude that either a mislabelling occurred, or a wrong ^{60}Co value was attributed to the 3512 NMNH stone.

TABLE 1

	^{60}Co (dpm/kg)	Depths (cm) from (2)	from (3)	C.R.track in OLV (10^4.cm^{-2})	Depths (cm) from (1)
0013-B (MPI Heidelberg) (5)	9 ± 2	1.5-2.5	0-2	>142-32	1.3-3.5
3512-C (NMNH) (6)	14 ± 3	2-3	1-2	12-3.5	7.5-11
3515-G (NMNH) (6) (7)	41 ± 3	7-8	∿4	28-6	5-9
3531-D (NMNH) (8)	90 ± 2	∿15	∿11	1.6-0.8	13.5-16.5
3529-D (NMNH) (8)	166 - 185	27-32	20-23	0.12-0.06	21-25

When depths inferred from both methods are compared, one should note that the ^{60}Co data correspond to average values mostly measured on large samples of several hundreds of grams, whereas track data are obtained on ∿1 g sample. With these geometrical differences in mind, the agreement found between the two depth monitors is excellent.

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CONFIRMATION OF AN EXTREMELY SHORT 2nd STAGE EXPOSURE OF JILIN CHONDRITE

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More extensive track data than before (1) have been obtained from olivines on 17 aliquots previously analyzed for spallogenic products (2,3,4,5). In these samples the ^{21}Ne contents range between 0.31 and 1.78 $.10^{-8}$ ccSTP/g. The track densities are the lowest measured so far in meteorites and they define 2 groups: A) one representing 15 samples comprises the track densities in the range of 130± 100/cm^2. All the spectrum of ^{21}Ne contents is contained in this group. The respective track data correspond to the noise level (fissions, cracks... dislocations) which completely masks the very low cosmic ray track densities. B) Two samples (VI-42-04 and VI-21-057) show high ^{21}Ne contents and track densities clearly outside the noise level (663 ± 108 and 1442 ± 175 cm^{-2}, respectively). Due to the relatively large number of c.r. tracks counted, the track data of these two samples should be considered as having a high level of confidence.

METEOROID EXPOSURE. We confirm our first results (1) that no relationship is found in 13 samples between the ^{60}Co values and the track data, contrary to what is observed in Allende (6). Actually, the lowest ^{60}Co activity measured in Jilin (50 ±6 dpm/kg, U. Herpers, personal communication, 1982) corresponds to sample A which also shows the lowest track density. From the dimension of sample A (∿4 cm), it was located within a depth between 4 and 9 cm from the preatmospheric surface (6,7). If so, the c.r. track densities expected to be registered in olivines during an exposure of 10^5 years should be comprised between 8300 and 1000/cm^2. These expected values have to be compared with the measured track density of 45 ± 15/cm^2. From this evidence, even taking into account the observed shortening of track length in Jilin olvines, a strict upper limit of 10^4 years is set for the meteoroid exposure. Up to date, no other spallogenic data are precise enough to deny this estimation for T_2.

FIRST STAGE EXPOSURE. From the above constraint on T_2, it remains to explain the similar excesses of ^{26}Al (3) and ^{10}Be (G.F. Herzog, pers. com. April 1982) found in sample VI-20-065 (49 ± 8 and 16 ± 2 dpm/kg, respectively). These excesses cannot be explained together by a meteoroid exposure of 0.3-0.5 $.10^6$yr. as suggested (2,3,4,5). Therefore, they should be attributed to the 1st exposure stage during which - for this specific sample--the irridiation should have occurred with a geometry > 2 Π, and at an "effective" depth (>100 g/cm^2) such that essentially no c.r. tracks were registered during the T_1 period (∿10^7yr.). However, two results do not easily fit into this scenario: 1) Thermoluminescence data show no evidence of heating effects during the last ∿10^5 year (G. Wagner, pers. com. 1981). 2) Strong rare gas diffusion losses should have occured between (during?) the meteoroid extraction from its larger parent object and its capture by the earth (8).

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COSMOGENIC RECORDS IN GAS-RICH CHONDRITES AND ACHONDRITES. J. N. Goswami[1] and K. Nishiizumi[2], [1]Physical Research Laboratory, Ahmedabad 380 009, India; [2]Dept. of Chemistry, Univ. of California, San Diego, La Jolla 92093, U.S.A.

The gas-rich meteorites are generally believed to be breccias from asteroidal regoliths. The solar-wind, solar-flare records observed in these meteorites are attributed to the exposure of their individual components to the energetic solar radiations, during their residence in the asteroidal regoliths. It has been pointed out recently (1, 2) that the solar flare irradiation records in the gas-rich carbonaceous chondrites cannot be explained in terms of the regolithic irradiation scenario because of the constraint imposed by the short precompaction irradiation durations of these meteorites.

We have now carried out nuclear track and radionuclide (^{53}Mn) studies in aliquot samples from several gas-rich ordinary chondrites and achondrites, to obtain information on their precompaction irradiation durations and to understand the exposure and evolutionary histories of these meteorites in their finer details. We define the precompaction irradiation duration as the difference between the stable and radio-nuclide exposure ages of these meteorites. Saturation effect in ^{53}Mn activity effectively constrains our studies to gas-rich meteorites with noble gas exposure ages < 10 m.y. All the samples analysed in the present study are H-chondrites, except for the Kapoeta howardite. The ^{53}Mn results indicate a near saturation activity level in the meteorites Cangas-de-Onis, and Nulles, and undersaturation for the meteorites Kilbourn, Leighton, Pantar and the Kapoeta howardite. Comparison of the ^{53}Mn exposure ages with noble gas exposure ages of the meteorites, based on literature data, indicate very short precompaction exposure duration of $\leq 10^6$ yr. in all the cases.

Nuclear track studies reveal that individual track-rich grains were exposed under different shielding conditions during their precompaction irradiation. About 3 to 5% of the analysed grains in the meteorites Leighton, Kilbourn and Kapoeta are track-rich. Absence of solar flare irradiated grains among the grains analysed from the meteorites Cangas-de-Onis, Nulles and Pantar put on upper-limit of 0.5% for the percentage of track-rich grains in them.

As in the case of carbonaceous chondrites, the observed nuclear-track records and the short precompaction irradiation duration for the gas-rich ordinary chondrites and achondrites put important constraints on the regolith irradiation scenario for these meteorites. The nature of these constraints and their implications to the evolution history of gas-rich meteorites will be discussed.

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COSMOGENIC NUCLIDES IN SMALL METEORITES RECOVERED FROM THE ANTARCTICA.

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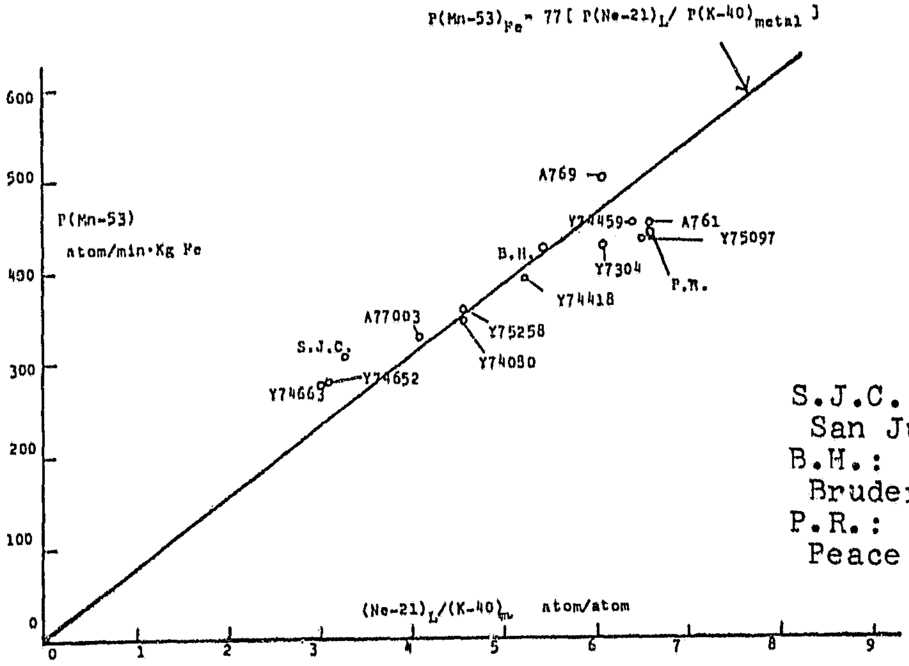
Among antarctic meteorites, the probability of finding samples which have a smaller preatmospheric size is expected to be higher than among other non-antarctic samples. However, the fragmentations when they fell on the ice surface and later mechanical disintegrations might also have taken place more extensively during their long terrestrial histories. We have selected some candidates for this study, mainly from the Yamato collection. Those weighing less than one kg and indepenent of the larger showers were examined. The contents of Mn-53, Be-10, stable light noble gases, and K-40 in metal have been determined. Some of these samples seem to be actually smaller than usual, or equivalent to known small samples, such as San Juan Capistrano. Yamato 74663, 74652, and 74455 seem to be typical small objects. Y74447 is also similar to ALHA77081 based on the noble gas data.

The net effects of lower secondaries contribution, would be demonstrated by, (1). lower Mn-53 than 300 atom/m.kgFe; (2). lower Ne-21/K-40 than 4; (3). higher Ne-22/Ne-21 than 1.2, and higher He-3/Ne-21 than 8; (4) relatively high Be-10 production. On the other hand, near surface samples of ordinary size chondrites will also show similar tendencies, ocurring to a less extent exemplified by Y74080 and A77003. These estimations may also be difficult for the secondary objects having multi-stage irradiation histories.



S.J.C.:
San Juan Capistrano
B.H.:
Bruderheim
P.R.:
Peace River

^{10}BE AND OTHER RADIONUCLIDES IN ANTARCTIC METEORITES AND IN ASSOCIATED ICE,

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The ^{14}C ($t_{1/2}$=5730 y) and ^{36}Cl (3.0x10^5 y) data shows that the terrestrial ages of Allan Hills meteorites range from 1x10^4 to 7x10^5 years. Many meteorites which have different terrestrial ages were concentrated in a very narrow region due to characteristic ice movement. For understanding the accumulation mechanism of the Antarctic meteorites, we have attempted to measure the age of blue ice using ^{10}Be-^{36}Cl dating. Because the age of blue ice was expected to be much older than the half-life of ^{14}C, a new dating technique was necessary. In this study, cosmogenic ^{10}Be ($t_{1/2}$=1.6x10^6 y) in four Allan Hills meteorites and in ice samples lying directly under the meteorites were measured. The ^{10}Be measurements were carried out using the University of Pennsylvania Tandem Van de Graaff accelerator. The results are shown in Table 1, together with ^{36}Cl, ^{26}Al ($t_{1/2}$=7.2x10^5 y) and ^{53}Mn (3.7x10^6 y) [1,2,3]. One-2 kg of ice samples were melted together with 2.43 mg of Be carrier. The ^{10}Be/^{9}Be ratios were measured to be 5-7x10^{-13}. The ^{10}Be and ^{36}Cl concentrations in ice change from sample to sample for several reasons: an annual production rate change due to changes in solar activity, precipitation rate change, or different ages. Since both nuclides are produced by relatively similar nuclear reactions from atmospheric ^{14}N and ^{40}Ar, the production ratio may be constant during a solar cycle. The age, ΔT, of ice [A] compared to ice [B] will be calculated from the following equation:

$$\Delta T = (\lambda_{36} - \lambda_{10})^{-1} \ln \left\{ [^{10}\mathrm{Be}/^{36}\mathrm{Cl}]_A / [^{10}\mathrm{Be}/^{36}\mathrm{Cl}]_B \right\}$$

The preliminary results indicate that the ^{10}Be/^{36}Cl ratios in an ice core were constant within ±15% [1]. The ages of the ice samples relative to M382 are shown in Table 1. Ice M382 is about 3-4x10^5 years younger than the other two ice samples, but the meteorite (78114) which is associated with M382 ice is older than the others. One explanation is the following: ALHA 78115 and 78130 probably fell on an old ice surface and horizontally moved to the recovered location. On the other hand, ALHA 78114 was found on the east side of an exposed small land area. The old meteorite was transferred to a young ice region recently. The other ^{10}Be measurements in the ice samples are in progress.

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TABLE 1:

Meteorite	Class	^{36}Cl 1) ($t_{1/2}$ = 3.0x10^{5}y)	^{26}Al 2) (7.2x10^{5}y)	^{10}Be (1.6x10^{6}y)	^{53}Mn 1) (3.7x10^6)	Terr. age (10^{5}y)
ALHA 78112	L6	13.4±0.5	42±3	20.8±2.2	347±16	2.3±0.8
ALHA 78114	L6	7.8±0.3	38±2	13.8±1.9	360±14	4.6±0.8
ALHA 78115	H6	21.6±0.6	42±3	15.9±1.8	334±14	<0.9
ALHA 78130	L6	20.7±0.5	51±4	17.9±1.9	380±15	<1.0

Ice	Wt. (g)	Atom ^{10}Be /g ice (10^4)	Atom ^{36}Cl 3) /g ice (10^3)	^{10}Be /^{36}Cl	Relative age (10^{5}y)
M-382 (78114)	1701	7.33±1.10	7.5±0.3	9.8±1.5	0
M-294 (78115)	2047	4.70±0.47	2.8±0.2	16.8±2.1	2.9
M-386 (78130)	1263	7.42±0.98	3.6±0.2	20.6±3.0	4.0

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3) Finkel, et al. (1980).

CARBON-14 AGES OF ANTARCTIC METEORITES: E.L.Fireman, Smithsonian Astrophysical Observatory, Cambridge, MA 02138

It is of interest to measure the ^{14}C terrestrial and weathering ages for meteorites at Victoria land locations away from the main Allan Hills meteorite concentration, 159°E, 76°45'S. ^{14}C terrestrial ages are determined by comparing the activity per kg of meteorite obtained in high temperature (above melting) extractions with the average activity in recent falls. ^{14}C weathering ages are obtained by comparing the specific activity of carbon in compounds extracted at 500°C with contemporary radiocarbon. The ^{14}C released at high temperature originates from cosmic ray spallation of oxygen in the meteoritic material; the ^{14}C released at 500°C is from terrestrial radiocarbon which became incorporated in weathering products (1). If the weathering process is rapid shortly after the meteorite emerges on the surface of the ice compared to other times, then the weathering age is the time of emergence on the ice surface. Ten of twelve measured meteorites recovered at the main Allan Hills concentration had ^{14}C terrestrial ages greater than 30×10^3 years and weathering ages greater than 10×10^3 years. Most of these ages were determined by low-level counting (1,2,3) a few were determined by the Chalk River Van de Graaff accelerator (4).

ALHA 78084, an H-3 chondrite with (B,C) weathering category, was recovered 34 km west-southwest of the main Allan Hills concentration. Its ^{10}Be activity and rare gas concentrations are known (5) and its ^{36}Cl activity of 16.4 dpm/kg indicates a terrestrial age of $(140\pm70)\times 10^3$ years (priv. comm. K. Nishiizumi, 1982). Its ^{14}C terrestrial and weathering ages, determined by low-level counting are $(20\pm3)\times10^3$ and $(4.3\pm0.7)\times10^3$ years respectively.

The ^{14}C ages for EETA79002, diogenite with (B,B) weathering category we determined by low-level counting; ^{14}C ages for EETA79003 L6 chondrite (B,B), RPA79001 L6 chondrite (B,C), and META 78028-L6 chondrite (B,B) were determined with the Chalk River Van de Graaff accelerator. Their ^{14}C terrestrial ages are older than 30×10^3 years and their ^{14}C weathering ages are less than 10×10^3 years. It appears that these meteorites have ^{14}C terrestrial ages similar to those at the main Allan Hills concentration but have younger weathering ages (emergence times).

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EXPOSURE AGE AS A CLUE TO METEORITE STREAMS.

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The exposure age distribution for H chondrites is strongly peaked at about 5 m.y., suggesting that fragmentation of a large body occurred at that time (Crabb and Schultz, 1981). I have shown that meteorites in the peak have fall characteristics that differ significantly from H chondrites with older exposure ages (Wood, 1982). Preliminary examination suggests that meteorites younger than those in the 5 m.y. peak (i.e. exposure ages 2 m.y.) are remnants of a separate fragmentation event, which occurred recently enough that the meteorites still have similar orbits.

FALL STATISTICS. Table 1 lists the 9 known H chondrites with exposure ages 2 m.y. (Group A; data from Wood and Lee-Berman, 1982). These meteorites are strongly clustered in their season of fall - all fell during the 6 month period of October to March. In contrast, only 35% of the H chondrites with exposure ages between 2 and 8 m.y. (Group B) fell during the same seasonal interval, whereas meteorites with ages 8 m.y. (Group C) fall uniformly throughout the year. The seasonal equality of fall for the older exposure age stones demonstrates that social factors (people out of doors in warm summers but not during cold winters) are not involved. The hour of fall for the youngest meteorites also differs from that of older H chondrites and indeed all chondrites in general. Only 1/3 of the group A stones fell after noon, whereas 2/3 of all chondrite falls occur after noon (Wetherill, 1968). The average weight of group A falls is 29 kg (excepting the estimated 2600 kg in the Jiling fall). Although the average weights of group B and C meteorites have not been calculated, it appears that both are less than 10 kg, with Bs being significantly more massive than Cs. About 50% of the group A falls have been showers (S in Table), whereas only 25% and 15%, respectively, of groups B and C have been showers. Since 1300 AD only 8 recovered H chondrites have been found to belong to group A, vs. 123 in group B, and 70 in group C.

DISCUSSION. The statistics discussed above demonstrate consistently different fall behavior for H chondrites as a function of their exposure age. Group B meteorites are sufficiently abundant for a 31 year periodicity to be recognized in their falls (Wood, 1982), which, with their seasonal fall pattern, implies that they move through space as meteorite streams. The seasonal clumping for group A meteorites suggests that they may also represent debris from a very recent (1 m.y. ago?) collisional event. The tighter seasonal clumping (6 out of 7 falls occurred in 12 weeks of 11 Oct to 1 Jan) of group A compared to group B meteorites is consistent with a more recent collision, and hence less time for stream dispersal into sporadic meteorites (group C).

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TABLE 1: H chondrites with exposure age less than 2m.y.

Name	Class	Fall Date	Hour	Wt/kg	Exp. Age
Macau	H5	11/11/1836	0500	40S	0.7my
Ohaba	H5	10/11/1857	0015	16	0.7
Bur-Gheluai	H5	10/16/1919	0800	120S	0.8
Sena	H4	11/17/1773	1200	4	0.8
Kalvesta	H	?	?	10	0.8
Jiling	H5	3/08/1976	1500	2600S	1.0
Cullison	H4	12/22/1902?	?	10	1.2
Bielokrynitschie	H4	01/01/1887	1800	2S?	1.5
Abbott	H	?	?	9	1.9

SOLAR WIND NOBLE GASES IN THE WASHINGTON COUNTY IRON METEORITE.

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In the course of an investigation of nitrogen in iron meteorites, we obtained a sample of Washington County (No. 565C, Harvard Mineralogical Museum), to see whether the trapped noble gases previously reported (1,2) were accompanied by trapped nitrogen. Although the nitrogen is not unusual (3), serendipitously the ratio of trapped to spallation noble gases turned out to be much larger than previously seen. This has allowed us to use a three-isotope plot for neon (Fig. 1), combining our data and those of (2), to determine the ^{20}Ne/^{22}Ne ratio of the trapped component. Although there is some uncertainty in the actual number, the ratio is clearly compatible with solar wind Ne, as shown in the inset to Fig. 1. We were also able to subtract out the spallation components in our data, using correlations between spallation noble gases seen in other iron meteorites (4), and determine amounts of trapped ^{4}He, ^{22}Ne and also, roughly ^{36}Ar. The elemental ratios, normalized to solar abundance (5), are plotted in Fig. 2. Also shown are solar wind elemental ratios as measured in foils (6) and in lunar minerals (7). It is apparent that the trapped noble gas component in Washington County has solar elemental as well as Ne-isotopic ratios. (The two separate points in Fig. 1, and for Ar in Fig. 2, are from an initial 80% and a residual 20% combustion on 14.9 mg of sample.)

The trapped gases almost certainly were incorporated into the meteorite during or before its accretion. The essentially unfractionated solar composition suggests implantation into metal grains, rather than trapping of an adsorbed gas component. We may thus be seeing evidence for solar wind irradiation of nebular dust grains prior to accretion into larger bodies. If the trapped component observed in Piñon (8), a meteorite which appears to have contained nucleosynthetic ^{107}Pd (9), is the same as in Washington County, then this irradiation must have occurred very early in the history of the nebula.

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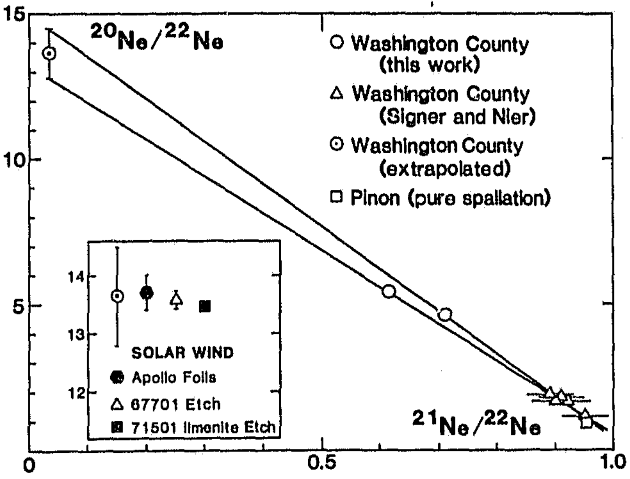

FIGURE 1

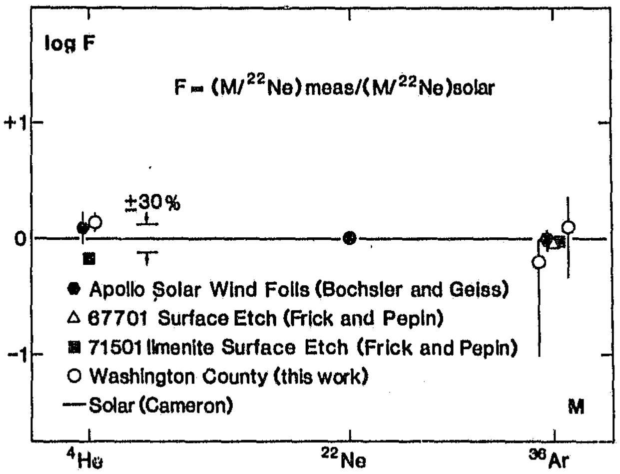

FIGURE 2

MOLECULAR SYNTHESIS BY IRRADIATION IN THE SOLAR SYSTEM.

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The solar wind bombardment of planetary surfaces and interplanetary grains induces the synthesis of molecular compounds within the irradiated grains. By means of IR spectroscopy, we have performed in situ detection of such molecules, both in terrestrial SiO_2 implanted in the laboratory and in lunar fines. We shall present our major results and give a few implications in planetology.

SIMULATION EXPERIMENTS: thin (~ 3000 Å) films and tiny grains of quartz have been implanted with various ions: ^{12}C, ^{13}C, ^{1}H, ^{2}H, ^{4}He, at energies from 1 to 5 keV/amu, and fluences from 2.10^{14} cm^{-2} up to 10^{18} cm^{-2}. The major results are as follows: the C implantation leads to the synthesis of CO and CO_2. The absorption features of these implanted species differ from the ones corresponding to the gaseous phase in two ways: they appear as single bands, showing no rotational structure, and they are slightly shifted towards smaller wave numbers. The CO/CO_2 radio is a function of the fluence F_C of the implanted C. At "low fluences", $F_C < 5.10^{15}$ cm^{-2}, CO_2 is by far the dominant product, with more than 50 % of the implanted C converted into CO_2 and less than 10 % in the form of CO. When $F_C > 5.10^{15}$ cm^{-2}, the number of CO_2 molecules $N(CO_2)$ remain nearly constant (~ 2,5 10^{15} cm^{-2}), while N(CO) increases as F_C^2. Consequently, the CO dominates at high C fluences, with CO/CO_2 ~ 10 when $F_C = 5.10^{16}$ cm^{-2}. When the C implantation is followed by that of H, $N(CO_2)$ is not modified but N(CO) is reduced by a factor of ~ 10. This result is not obtained when H is either replaced by He or implanted before the C. It demonstrates that H chemically reacts with the synthesized CO; we have detected some of the plausible reaction products in the form of hydrocarbons.

LUNAR FINES: We have analysed a mature lunar soil, 10084, and compared the spectra with those obtained 1) with lunar grains of same bulk composition, having never been exposed to the solar wind, produced by crushing the rock 12021 and 2) with the simulation experiments. The main result is the detection in 10084 of CO_2 synthesized by the solar wind implantation together with CH_4. No CO has been detected so far, in agreement with the simulation experiments.

IMPLICATIONS IN PLANETOLOGY: As a result of their interaction with the lunar surface, most of the reactive species present in the solar wind are converted into molecules within the lunar grains. When outgassed from the grains, they constitute a molecular component in the tenuous lunar atmosphere. A similar scenario is likely to apply to Mercury and other planetary bodies directly bombarded by the solar wind. It might be responsible for some of the organic compounds within meteorites. The synthesis of molecules by implantation is not restricted to silicates and to implantation energies in the keV region. It concerns a large variety of grain compositions, including ices, and a wide range of irradiation energies, from a few eV (suprathermal gas particles) to cosmic rays energies (MeV). Consequently, the sites where these chemical effects might take place are quite numerous within the solar cavity: for example, the satellites of Jupiter are known to be bombarded by huge fluxes of MeV particles accelerated by the jovian magnetosphere; similarly, grains in planetary rings are good candidates. An other exciting also still very speculative possibility would concern the cometary nuclei: their high molecular content, responsible for the observed secondary products in the tails and halos, might originated from the sublimation of ices containing organic compounds synthesized by their irradiation; this irradiation could have occurred either i) during their latest orbital exposure to the solar wind and cosmic rays or ii) before the grains were compacted as cometary nuclei; in this later scenario, cometary atmospheres would originate from the primordial irradiation of material constituting the protosolar nebula.

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FORMATION CONDITION AND PROCESS OF PLAGIOCLASE IN METEORITE

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A new method to estimate formation condition and process is applied to extraterrestrial substances (Miura, 1982a, b; Miura and Tomisaka, 1982).[1,2,3)

Formation condition of plagioclase is related to Or content in ternary plagioclase. Formation process of plagioclase can be explained by distance and slope (DS) parameters between the mean values of bulk An and Or contents[1,2,3) with and without exsolution lamellae (Miura, 1982a, b; Miura and Tomisaka,1982).

Fig. 1 shows the relationship between DP parameters(cooling rate) and Or-content (temperature) in terrestrial (plutonic, hypabyssal, metamorphic, and xenolith of volcanic rocks) and extraterrestrial (Holbrook L6-5 chondritic meteorite; lunar coarse-grained mare basalt and fine grained basalt).

It is found in Fig. 1 that Holbrook meteorite(HM-3) was formed under relatively high temperature and rapid cooling, compared with terrestrial and lunar plagioclases. Research supported by Japanese Fundamental Scientific Research.

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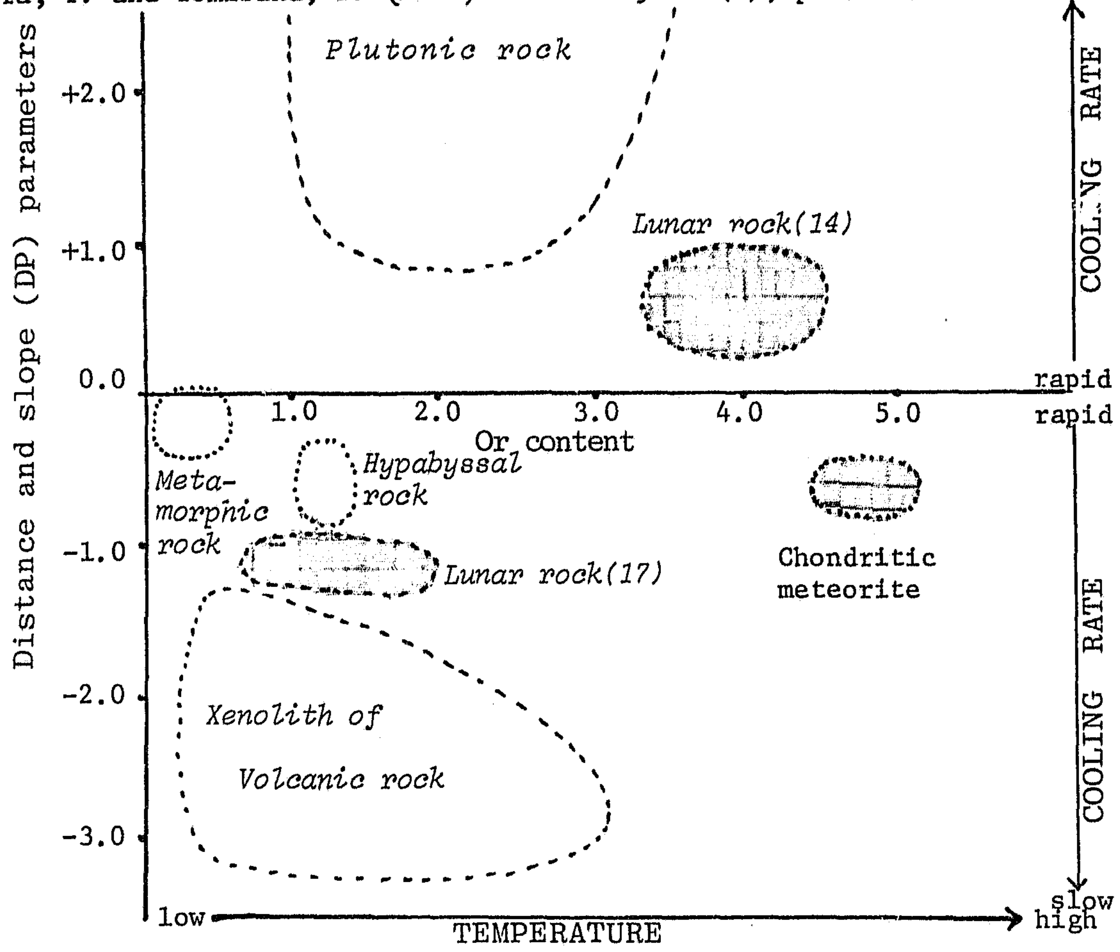

Fig. 1. Relationship between DP parameters(cooling rate) and Or content (temperature) in terrestrial and extraterrestrial plagioclases.

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ZONING OF EUCRITIC FELDSPARS

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The textures and mineral zoning of mafic clasts in eucrites and polymict eucrites are functions of igneous cooling rates and metamorphic overprint. Fe-Mg zoning of pyroxene is easily obliterated by metamorphic annealing whereas slow Si-Al diffusion kinetics in plagioclase allow the preservation of original igneous Ca-Na-K zoning. Feldspar in mafic clasts from polymict eucrites Allan Hills A78040, Elephant Moraine A79004 and A79011 were compared with those in the eucrites, Pasamonte, Juvinas and Chervony Kut. Dynamic crystallization experiments (1) have produced textures similar to those observed in these clasts. Juvinas and Chervony Kut typically have tabular crystals, Pasamonte has ophitic to subophitic intergrowths while clasts in polymict eucrites have tabular and hollow-skeletal crystals. These morphologies reflect increasing supercooling (1,2). Traverses across these grains showed normal, reverse and complex zoning. Reverse zoning and unzoned grains in Juvinas, Chervony Kut and Pasamonte are similar to grains produced by isothermal crystallization in dynamic crystallization experiments (2). Normal zoning in Chervony Kut, Pasamonte and at the edges of reverse zoned grains in Juvinas reflects growth during cooling. Complex zoning profiles in ALHA78040, EETA79004 and 79011 are usually caused by simultaneous inward and outward growth of normally zoned hollow crystals. Some profiles suggest oscillatory zoning and in shocked, metamorphosed clasts from 79004 and in Chervony Kut unusual K, de-coupled from Na, enrichment is present. Feldspar morphology and zoning suggests that:(i)Juvinas suffered little supercooling followed by isothermal crystallization with minor growth during cooling; (ii)Chervony Kut and Pasamonte were increasingly supercooled with minor isothermal growth and most crystallization occurred during cooling; (iii) Many mafic clasts in polymict eucrites were greatly supercooled and all growth occurred during cooling. The eucrites may have crystallized at various depths with Juvinas deepest and Pasamonte shallowest. Most eucrites seem to preserve a two stage cooling history consistent with a volcanic origin. The very rapid cooling of many mafic clasts in polymict eucrites suggests they arrived at the surface at superliquidus temperatures and no evidence of passage through a "volcanic plumbing system" has yet been recognised. The textures and composition of polymict eucrite clasts suggests that some are late additions to the breccias (3,4) which were previously metamorphosed (5,6). These clasts, therefore, represent either vigorous late volcanism or impact melting. If the earlier metamorphism of the breccias represents the waning stages of planetary differentiation on the basaltic achondrite parent body, then the later formed mafic clasts in the polymict eucrites are probably impact melts of achondritic regoliths and are not directly related to planetary differentiation.

Funding by NSG#7258, M Prinz (Principal Investigator) who is thanked for supporting this study.

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EVIDENCE FOR PRIMITIVE PHOSPHATES IN HIGHLY UNEQUILIBRATED ORDINARY CHONDRITES.

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While in equilibrated ordinary chondrites phosphates, like feldspars, occur interstitially among olivine and pyroxene grains, phosphates have never been identified in highly unequilibrated chondrites.

During recent textural and compositional studies of opaque mineral assemblages in highly unequilibrated ordinary chondrites, areas rich in Ca and P were found in association with metal and sulfide[1,2,3]. This discovery prompted a more careful search for Ca,P-rich areas in these meteorites in order to identify phosphates and define their origin. The preliminary results of this study are presented below.

Ca,P-rich areas have been identified and analyzed: 1) in the interior of highly reduced chondrules, at the interface between Si,Cr-rich metals and the enclosing sulfides; 2) in the matrix, in the interior of metal-sulfide nodules when the metal is Si,Cr-rich. In both cases, the sulfides contain variable amounts of Ca, Cr, P, and Si in solid solution and enrichments of Cr, presumably as chromite, are also present adjacent to the phosphate-rich areas. In all cases, the phosphate grains were too small to be analyzed by electron microprobe. Occasionally, enrichments in Ca or P were found in small areas, suggesting the presence of other mineral phases, possibly oldhamite and schreibersite. It appears that these complex mineral assemblages may have formed by exsolution of components originally present in solid solution in metal and sulfide, and reaction with O_2 diffusing into the metal-sulfide assemblage.

Phosphates were positively identified and analyzed in the following matrix textural location: 1) inside metal-sulfide nodules when the metal is Si,Cr-free; 2) inside coarse polycrystalline metalgrains; and 3) in large troilite-rich areas that include variable amounts of metal and traces of silicates. There appears to be no difference in the composition of phosphates in these different locations. The analytical results for Krymka (9 grains) and Chainpur (24 grains) are shown below.

	P_2O_5	CaO	FeO	NiO	Na_2O	MgO	Total
Chainpur	44.5±1.1	46.5±1.1	3.4±1.7	.14±.28	1.97±.04	3.2±.2	99.71
Krymka	43.5±1.9	43.2±2.0	7.2±.42	.70±.42	1.88±.13	2.5±.6	98.98

These phosphates are whitlockites with Na_2O contents and MgO/FeO ratios lower than whitlockites from equilibrated chondrites and other meteorite groups. The excess of FeO in Krymka is probably due to the presence of Fe oxide in intimate association with the phosphate and derived from oxidation of metallic Fe. The unusual composition of these phosphates and their textural location, restricted to highly reduced metal and sulfide-rich areas, seem to suggest that their trace element composition may be unique and considerably different from that of phosphates found in less unequilibrated chondrites.

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ANNEALING STUDIES IN METEORITIC PHOSPHATES

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A series of annealing experiments with meteoritic whitlockite (merrillite) and chlorapatite have been performed with a view to determining the effective track-retention temperatures of these minerals. The approach has been to obtain curves of surviving track density in the mineral crystals against temperature, for annealing times of 1 hour and 14 days at up to 460°C. The temperatures corresponding to various degrees of fading are extrapolated to a time-scale corresponding to the cooling rate of the meteorite parent body, and the closing temperature obtained by the method of Haack (1977).

It is found that the annealing properties of tracks in the two minerals, whitlockite and apatite, are significantly different. The annealing of composite whitlockite/apatite crystals for 1 h at 400°C results in the tracks in the apatite being completely removed, while those in the whitlockite are only partly affected. The effective track-retention temperature of chlorapatite (from the Estacado chondrite) was calculated to be 66°C, on the basis of fossil-track studies, assuming a cooling rate of 1°C/Myr. Closing temperatures estimated for whitlockite were found to depend on the meteorite used, and whether fossil or freshly-induced tracks were investigated. Results varied between: 200°C (Bondoc mesosiderite, fossil tracks, cooling rate 0.2°C/Myr); ∿135°C (Bondoc, fresh tracks); 138°C (Estacado Track-in-Track lengths); and 84°C (Estacado fossil-track densities).

The partitioning of ^{244}Pu between the phosphate minerals in the same meteorite is also being investigated by means of track studies. The effect of assuming a higher closing temperature for whitlockite than for apatite is to reduce the calculated ratio $(Pu)_{WHT}/(Pu)_{APAT}$.

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TRACE ELEMENTS IN PEÑA BLANCA SPRING OLDHAMITE

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Murrell & Burnett (M-B)(1)reported that oldhamite(CaS) is the primary host phase of U and Th in the E6 chondrites. E-chondrite Th/U values were all cosmic, indicating a lack of Th-U fractionation in both oldhamite and in the bulk meteorites. In Khairpur(E6),they attributed excess fossil fission tracks to the presence of ^{244}Pu in oldhamite.Rare earth(REE) enrichments were inferred for an Abee (E4) water soluble phase(s)(2), presumably oldhamite, and perhaps niningerite. These led M-B to suggest that the enstatite chondrites may be well-suited for Pu-U chronology and possibly for providing the initial Pu/U value in the solar system. If minimal Th-U-lanthanide fractionation were obtained for CaS, then minimal Pu-U fractionation could be expected. The most striking CaS U enrichments were found in the enstatite achondrite,Peña Blanca Spring (PBS): 1920±100 ppm U in 2 large CaS grains. M-B attempted REE electron-microprobe analyses for these but only established upper limits of < 700ppm Ce, < 500ppm Nd, < 150ppm Y.

Because of their large size compared to those in the E chondrites, we have analyzed the same two PBS CaS, using the proton microprobe(3) at the Los Alamos Van de Graaff. Our proton beam energy was 2.0 MeV. We typically ran at 1-2 nA currents and obtained 6-12 μ Coul integrated doses.The beam spot was 10 by 40 μ . The proton-induced X-rays were detected with a 160eV (Mn K α) resolution Si(Li) detector with a 1.5 mil Al absorber. Deadtimes were typically < 5%. We used a glass comprised of 25% Durango apatite in order to estimate absolute contents. Published analyses of the apatite contents vary significantly(4); consequently, it is not a satisfactory standard and our present data must be considered tentative. Further, we have not yet done a detailed deconvolution of the spectra. From this preliminary analysis , we obtain ~ 30ppm Ce and ~ 20ppm Nd, after correction for the ~ 30% difference in the X-ray absorption in the CaS relative to that in the reference glass. The REE data from the two CaS grains are consistent. We also find Y (195±35ppm, 390±75ppm), Sr (55±15ppm, 80±20ppm), and Se (30±10ppm and 75±25ppm). No Se data are available from the reference sample; the absolute concentrations were inferred from the Sr data, using published relative thick target yields. The estimated uncertainties for all but the REE are dominated by the spread in the data for the reference sample(4).The counting statistics for all the trace element peak counts range from 5-12%,but we consider the REE results to be good to only a factor of two, due the large uncertainties in our background corrections, as well as those in the reference data(4).Our Ce-Nd estimates are consistent with a chondritic Ce/Nd ratio. While significant enrichments of the REE occur in CaS, the enrichment factors, relative to chondritic REE abundances, are ~ 45, or at most ~ 100. U enrichments in PBS CaS, on the other hand, are more like ~ 200 (1). Thus, it appears that U-REE fractionation did occur for PBS CaS. Whether this fractionation occurred in E6 meteorites is still in question, and we will attempt analyses of the smaller E6 CaS grains. We are presently analyzing data from ferroan alabandite(Mn,FeS), where Cr, Cu & Ni are clearly evident; daubreelite(Fe,CrS), containing Zn & Cu; troilite, bearing Ni; and enstatite showing Ti,V,Cr,Mn & Zn.

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CLUSTER AND FACTOR ANALYSIS OF DIOGENITE PYROXENE DATA.

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Heyse (1975) showed that Garland is a polymict diogenite containing two distinct orthopyroxenite types. Hewins (1980, 1981) has suggested that all pyroxene grains in diogenites can be sub-divided by their chemistry and correspond mainly to types I and II of Heyse. In order to remove subjective bias, multivariate statistical techniques (cluster and factor analysis) were performed on a compilation of all pyroxene analyses (nine oxides) made on one microprobe (AMNH). The data were treated without regard to host rock (ALHA 77256, Roda, Garland, Ellemeet and Aioun el Atrouss) or preconceived ideas of chemical types (Al-Cr groups).

Cluster analysis expresses the interrelationship among diogenite pyroxenes as a dendrogram in which two principal pyroxene groups are identifiable: Garland analyses originally classified as type I and pyroxene from the other diogenites together with Garland type II. Type III (low Cr, high Al) pyroxene is not distinct from type II (as suggested by Hewins (1980)) and this term should be discarded. When analyses of intercumulus and other late pyroxene are added to the file of cumulus pyroxene data, a few analyses from other diogenites plot along with Garland type I. However, cluster analysis classifies the data better than Al concentration, which being very low in late pyroxene in type II diogenite causes overlap of I and II. This multivariate technique considers all nine oxides and shows that elements other than Al and Cr are important in the classification of diogenite pyroxenes into groups. The second-level subdivision made in cluster analysis separates the most Fe-rich Garland pyroxenes from the rest of type I and the most Mg-rich Ellemeet pyroxenes from the rest of type II. These divisions may be real gaps in the rocks sampled by these two polymict diogenites.

In factor analysis, the interrelationships among diogenite pyroxenes are expressed in terms of a reduced number of factors influenced by specific elements. 96.56% of the original variance present in the data (cumulus plus intercumulus pyroxenes) is preserved by three factor axes, on which the data are projected. 70.85% of this variance is represented by factor A, along which the same four groups identified by cluster analysis are observed. The projection of diogenite pyroxenes onto factor A is most influenced by Mg, Si and Al. Factor B represents 15.94% and factor C represents 9.76% of the total variance and they are controlled by the elements Mg, Fe and Al, Ca, Cr respectively. The four groupings identified by multivariate techniques are much more clearly distinguished on the pyroxene quadrilateral than on Al-Cr diagrams.

Statistical analysis confirms the existence of two pyroxene types in diogenites. Pyroxenes in the diogenites studied overwhelmingly resemble Garland type II but Peckelsheim and Ibbenbuhren (Gooley, 1972) resemble Garland type I pyroxene. Tatahouine (Gooley, 1972) is classified with Type II, despite low Al. Since the two pyroxene types cannot be explained as the result of a single igneous fractionation process or of reequilibration in the solid state, two igneous lineages seem to be represented in diogenites.

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ALLAN HILLS A77156, AN EH4 ENSTATITE CHONDRITE: SOME EVIDENCE AGAINST FORMATION FROM RED AND BLUE LUMINESCING PLANETESIMALS.

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ALH A77156 and the paired specimen (A77295) are from the 1977 Allan Hills collection of 145 previously unclassified small meteorites ($\leq$ 150g) and represent the first enstatite chondrite from that locality and only the second from Antarctica. In addition to the CO3 (A77029) and L3 specimens (A77011), which we have previously described, the collection also includes two unpaired LL specimens, another unpaired L3, two unpaired H3 and 118 equilibrated H and L specimens.

A77156 contains well defined chondrules typical of EH4 chondrites. We searched unsuccessfully for a fine-grained matrix equivalent to the recrystallized matrix of H-L-LL4 chondrites. Silicate phases (72 vol.%) include clinoenstatite (En98), the most abundant phase, and minor olivine (Fo99.2), albite (Ab98.5), and silica. Kamacite (12 vol.%) and niningerite (0.7 vol.%) are less abundant, whereas troilite (9 vol.%), perryite (1.8 vol.%), schreibersite (1.3 vol.%), zincian daubreelite (1.0 vol.%), and oldhamite (1.5 vol.%) are more abundant than in other EH4s. Minor sphalerite and weathered caswellsilverite are also present.

Total Fe (313mg/g), calculated from chemical compositions and modal abundances, falls within the EH range [1]. Mineral compositions typically lie within the ranges of EH4 chondrites; those outside are usually close to mineral compositions of Kota-Kota (EH4) [2]. For example; 1) Ni and Si in kamacite in A77156 (2.8 and 2.5 wt.%) and Kota-Kota (3.2 and 2.0 wt. %) are below the range of other EH4 chondrites (6.3-8.5 and 3.0-3.7 wt.%) [3]; 2) Cr in troilite in A77156 (.54 wt.%) and Kota-Kota (.43 wt.%) is below the range of other EH4 chondrites (1.42-3.11 wt.%). Using the MgS-FeS-CaS geothermometers of [4] we calculate equilibration temperatures for A77156 of 650°C for oldhamite and 475°C for niningerite. The latter value agrees well with that for Kota-Kota (485°C). These are the lowest temperatures determined for EH4 chondrites. These results and the low abundances of minor elements in some phases imply that A77156 and Kota-Kota cooled more slowly around 500°C than other EH4 chondrites.

Leitch and Smith [2] propose that enstatite chondrites formed by the collision and mixing of two planetesimals: one with red, the other with blue luminescing enstatite. This model is based on the bimodal composition of enstatite; they find that red enstatites are consistently higher in Mn, Ti, Cr, and Al than blue enstatites. However, random analysis of 168 enstatite grains in A77156 shows that Mn and Cr concentrations and color are not strongly correlated. For example bright blue enstatites have low Mn and Cr contents ($\lesssim$0.1%); red enstatites may have higher Mn ($\gtrsim$0.1%) but a broad range in Cr contents ($\sim$0.04-0.5%) and dull blue enstatites may have highly variable Mn ($\sim$0.04-0.2%) and Cr ($\sim$0.04-0.5%) contents. Our data do not require aggregation of enstatite grains from two distinct sources for the formation of A77156.

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HIGH-RESOLUTION TRANSMISSION ELECTRON MICROSCOPY OBSERVATION OF "POORLY CHARACTERIZED PHASE" IN THE MIGHEI C2(M) CARBONACEOUS CHONDRITE

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The identity of "Poorly Characterized Phase" (PCP) (1) is one of the more mysterious problems of carbonaceous chondrites. Their puzzling compositions do not fit known terrestrial minerals, and the X-ray diffraction pattern obtained by Fuchs et al. (1) could not be identified. Based on a petrographic observation, Ramdohr (2) described a similar Fe-C-S phase as a new layer structure mineral. McSween and Richardson (3) suggested Fe-Ni-S-O phase may be related to a primordial condensate such as the "Q-sulfide". On the other hand, Bunch and Chang (4) suggested that PCP is an *in situ* alteration product of matrix components. We believed that direct observation by high-resolution transmission electron microscopy (HRTEM) would provide information regarding the nature of PCP.

PCP occurs in various morphologies and occurrences in the Mighei C2(M) meteorite. The composition varies over a wide range, but seems to be correlated with morphology and occurrence. We extracted PCP from three different locations in a thin section of Mighei after a thorough petrographic characterization. The locations are: (I) PCP surrounding a large kamacite grain, (II) rounded spherules of PCP included in olivine-rich aggregates, and (III) PCP in the matrix. These specimens were ion-thinned.

HRTEM images of PCP in the occurrences (I) and (II) showed the typical fringe texture of a layer structure material. The fringes have a spacing of ∿5.2Å, but in many areas there is a long-range periodicity of ∿10.4Å(2× ∿5.2Å). In places, 7Å-fringes are inserted between those fringes. These observations are consistent with the previous results of the X-ray powder diffraction measurements by Fuchs et al., which showed a sharp peak at 5.4Å. The fringe textures exhibit many variations: fringes are rolled, curved, waved and entangled in complex ways. Beautiful concentric textures are widespread. Such unusual morphologies are common in chrysotile and antigorite, in which these structures result from dimensional mismatching between tetrahedral and brucite layers. However, the origin of the present 5Å-layer structure must have an another explanation.

HRTEM images of PCP in the occurrence (III) also reveal abundant 5Å-fringes, but they are commonly intergrown with 7A-fringes. In some places, those two kinds of fringes form ordered mixed layer structures, and they also show disordered sequences. We frequently observed the ordered sequence of -7-5-5-(17Å) as found by Mackinnon and Buseck (5) in the matrix of the Murchison meteorite. Regions of crystals with 5Å-, 7Å- and 17Å-fringes are commonly coherently intergrown with each other, suggesting a genetical relationship. As energy dispersive X-ray spectra from those intergrown areas show significantly larger Si peaks than from the areas of 5Å-fringe only, the 7Å-fringes may correspond to the serpentine-type phyllosilicate.

Our observations indicate that the layer structure material having a basal fringe spacing of ∿5Å is related to that so far identified as PCP or the material itself is PCP. With work done to date, we are unable to identify this phase as any known terrestrial mineral. However, the lack of evidence of significant Mg indicates that the possibility of brucite can be eliminated as the identity of the 5Å-layer material. REFERENCES: 1) Fuchs, L.H., Olsen, E. & Jensen, K.J. (1973) Smith. Contr. Earth Sci., 10. 2) Ramdohr, P. (1963) J. Geophys. Res., 68, 2011. 3) McSween, H.Y. & Richardson, S.M. (1977) Geochim. Cosmochim. Acta, 41, 1145. 4) Bunch, T.E. & Chang, S. (1980) Geochim. Cosmochim. Acta, 44, 1543. 5) Mackinnon, I.D.R. & Buseck, P.R. (1979) Nature, 180, 219.

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PHYSICAL SEPARATES FROM THE MURCHISON METEORITE

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Extensive studies have been made of the noble gases in the residues of carbonaceous chondrites subjected to chemical treatments of varying severity (see e.g. 1, 2, 3). This study, which is the first step in what is planned to be a major reinvestigation of the noble gases in Murchison, was undertaken to determine whether the host phases of any of the anomalous noble gases could be separated or enriched by purely physical means.

Bulk chips of Murchison were disaggregated by 65 cycles of freezing (-196°C) and thawing (∿70°C). The resultant material was sieved in acetone into six grain-size ranges and each size fraction was separated by density using bromoform ($\rho = 2.89$ g-cm^{-3}) and diiodomethane ($\rho = 3.325$ g-cm^{-3}). Each of the separates was characterized by one or more of the following methods: optical microscopy, x-ray diffraction, SEM/EDS, and INAA.

Samples with grain sizes greater than 100 μm appeared to consist mainly of miniature pieces of bulk meteorite. The most effective mineral separation occurred in the size ranges 40-100 μm and 4-40 μm. The light fractions of these grain sizes ($\rho < 2.89$ g-cm^{-3}) contained mainly serpentine (80 to ∿100 vol %) while the heavy fractions ($\rho > 3.325$ g-cm^{-3}) were dominated by olivine (35-75 vol %) and pyroxene (26-6 vol %). The average olivine composition ranged from Fo_{97} in the light fractions to Fo_{75} in the heavy fractions. In addition, the fractions with $\rho > 3.325$ g-cm^{-3} were observed to contain magnetite (∿10 vol %) and the sulfides pentlandite and troilite (2-15 vol %).

Noble gases in aliquots of several separates were analyzed with the mass spectrometer locally referred to as BMS5. In general, gas contents increased with decreasing particle size and decreasing density. Olivine-rich separates showed evidence for CCF-Xe. In particular, xenon delta values (‰) normalized to AVCC (4) for a separate with $\rho > 3.325$ g-cm^{-3} that contained particles ranging in size from 4-40 μm were measured as follows: 124:126:128:129:130:131:132:134:136 = 68(48):175(67):37(17):45(13): ≡ 0:12(12):23(9):28(13):38(15) where the numbers in parentheses are 1σ errors for the mean. Macdougall and Phinney (5) observed similar isotopic effects in an olivine-enriched separate, but with smaller excesses at the heavy isotopes. While this enrichment of anomalous xenon is not as large as those that evolve from chemical treatments, it exceeds any yet seen from purely physical separations of meteorites.

Macdougall and Phinney (5) suggested chromite as the primary candidate for the host phase of the anomalous gas. They found ∿1% chromite in their olivine separate while our separate contained <0.3% chromium as measured by INAA and <0.1 vol % chromite from SEM/EDS analyses. Based upon the gas contents of Murchison chromite given by (2), the amount of chromite present in our separates is insufficient to account for the anomalous gas. We are currently using magnetic separation methods in an attempt to isolate the carrier phase further without using destructive chemistry and to understand the association of the host phase with olivine content.

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Petrography and Mineralogy of Two Basalts and Olivine-Pyroxene-Spinel Fragments in Achondrite EETA 79001

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Three lithologies occur in shocked achondrite EETA 79001 (1,2,3,4): A1, exotic irregular crystals and clusters of coarse-grained olivine (Fo_{81-55}: CaO 0.2, Cr_2O_3 0.06, NiO 0.5 wt.%), low-Ca pyroxene ($En_{82}Wo_2$ - $En_{58}Wo_{12}$), and low-Ti chromite (Cr_2O_3 59, FeO 27, TiO_2 0.7 wt.%); A2 basaltic host to A1 containing pyroxene (mainly pigeonite $En_{67}Wo_{12}$ - $En_{52}Wo_{13}$), maskelynite ($An_{61-55}Or_{0.7}$), high-Ti chromite (some rimming low-Ti chromite), whitlockite, minor Cl-apatite, ilmenite, pyrrhotite and mesostasis; B homogeneous basalt containing augite laths (~$En_{40-50}Wo_{25-35}$) in a matrix of pigeonite-augite, maskelynite ($An_{62-56}Or_{1.2}$), ulvöspinel-ilmenite intergrowth, whitlockite, Cl-apatite, and mesostasis. Mineral compositions indicate an oxidation state similar to that of shergottites. Lithology A1represents an unmetamorphosed cumulate that was disrupted and partly resorbed by a basaltic magma. Incorporation of low-Ca magnesian pyroxenes and olivine increased the Mg/Fe ratio of the basaltic magma responsible for A2, and resulted in abundant crystallization of pigeonite. Lithology B was generated from a distinct magma lacking fragments of A1. The parental spinel harzburgite of A1 was not annealed, and it may be a near-surface igneous cumulate from a shergottite-type basalt. Ringwoodite and majorite (optical and microprobe identification only) were found in shock veins.

A complex igneous history is required for a region of the parent body of the 79001 achondrite, but no mineralogical or petrographic feature provides an obvious clue to the type of parent body. Detailed study is needed of all the "oxidized" achondrites (especially shergottites) to determine their genetic relationships. Different source regions in the same parent body must be considered, as well as different parent bodies. The term shergottite must be defined carefully.

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A PROGRESS REPORT ON FLUID INCLUSIONS IN METEORITES

Fluid Inclusion Study Team*

Fluid inclusions, both primary and secondary, have been discovered and studied in chondritic and achondritic meteorites. Fluid inclusions are important probes of the petrogenesis of natural rock systems because they yield direct information about the chemical nature of the fluid present in the system at some stage in its history, and place constraints on the rock's P-T history between formation and collection. Such data would be especially important in the study of meteorites because the lack of a geologic context for meteorites hampers inferences about their history.

At least seven meteorites (both falls and finds) are known to contain fluid inclusions: chondrites-Faith H5, Jilin H5, Bjurbole L4, Holbrook L6, Peetz L6, St. Severin LL6 and diogenite ALHA 77256. Surprisingly, fluids in chondrites have the same properties as those in the diogenite achondrite. These include: (1) shapes, sizes and occurrences: equant, rounded varieties, up to 20-30 µm, commonly along healed fractures and larger isolated irregular ones, up to 100 µm; (2) presence of both two phase (liquid + vapor) and three phase [liquid + vapor + glass(?)] inclusions; (3) a broad range in temperatures of homogenization (T_h) of liquid + vapor to liquid from 30° to > 220°C with no preferred temperature; (4) apparent difficulty in observing freezing phenomena, i.e. recognition of an observable crystalline phase at low (-180°C) temperatures; (5) increase of vapor phase volume (V_v) on heating from -180°C; and (6) Raman vibration bands at 3200-3600 cm^{-1}. Properties (3) and (6) are characteristic of an aqueous fluid, but the fluid cannot be pure H_2O because of (4) and (5). If observations of change in vapor bubble morphology from deformed to spherical at -20° to -25°C are inferred to represent final melting, this would indicate large quantities of dissolved components, possibly salts. Laser Raman spectroscopy on many inclusions show no vibration bands characteristic of CO_2, CH_4, H_2, N_2, O_2 or S-bearing species. Our most recent Raman spectroscopic work resulted in precipitation of a dark solid phase, with vibration bands resembling graphite. This was observed for both ALHA 77256 and Jilin. In one inclusion in Jilin, we obtained a broad Raman signal between 2850 and 3000 cm^{-1}, which is characteristic of C-H stretching. This observation must be confirmed by further Raman studies.

In the chondrites, inclusions occur in olivine both inside chondrules and within chondrule fragments, as well as in pyroxene (Jilin). In the diogenite, inclusions are only present in orthopyroxene. Occurrence of fluid inclusions within chondrules represents another factor which must be accounted for in any model of chondrule origin. Clearly, inferences about the origin of the fluids must await further characterization of their chemical composition. Morphologic, microthermometric, Raman spectroscopic studies along with direct analysis of trapped fluids using the laser microprobe/gas analysis technique are presently underway and the latest findings will be reported.

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MAGNETIC PROPERTIES OF LOW-PETROLOGIC GRADE NON-CARBONACEOUS CHONDRITES

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Magnetic properties of low petrologic non-carbonaceous chondrites are of particular interest because their metallic grains are relatively fine-grained and could possess stable remanence, and because they are likely to preserve the record of the magnetic field in the early solar system as recorded in carbonaceous chondrites, because they were not reheated to high temperatures.

In this study we describe the magnetic properties of Chainpur (LL3), ALH77304 (LL3), Mezo Madaras (L3), Bjurbole (L4) and Indarch in detail. Three chondrites (Yamato 74191 (L3), Yamato 691 (E3) and Abee (E4)), which were previously studied, are also included in the discussion.

NRM (natural remanent magnetization) intensity of E chondrites is by far larger than that of L and LL chondrites. The difference is only partly explained by the difference in the amount of ferromagnetic materials. The bulk coercive force of L and LL chondrites is strongly influenced by the amount of tetra-taenite. Cohenite and schreibersite and their grain sizes also seem to be important factors determining the coercivity of E chondrites.

NRM in unequilibrated chondrites is generally more stable than that in metamorphosed chondrites. The difference in NRM stability seems to be due to the presence of coarse, well-annealed kamacite in metamorphosed chondrites.

Indarch and Yamato 691 have a single component NRM, which is less stable than anhysteretic remanence. These can be interpreted as a partial thermoremanence (pTRM) acquired after a shock event.

ALH77304 has two components of NRM, which could be interpreted as primary TRM plus pTRM.

Bjurbole, Chainpur, Mezo Madaras and Yamato 74191 have random (and stable) NRM component which is probably carried by tetra-taenite. The former two chondrites have a soft overprinting NRM component. Since Mezo Madaras and Bjurbole are thought to have been reheated to >500°C after their accretion, it is difficult to explain the random NRM directions on the basis of pre-accrectional NRM. It is possible that highly anisotropic tetra-taenite acquired random NRM whose direction is mostly controlled by the crystallographic orientation. In the case of Chainpur and Yamato 74191, which were probably not reheated to high temperatures after accretion, the random NRM component is probably due to pre-accretional remanence.

Paleomagnetic field intensities estimated for E chondrites are larger than several oersteds, while those for L and LL chondrites are less than 1 oersted.

PRIMITIVE He IN SOME DIAMONDS, M. Ozima and S. Zashu, Geophysical Inst., Univ. of Tokyo, Tokyo 113, Japan

We have measured ^{3}He/^{4}He, ^{40}Ar/^{36}Ar and He, Ne, Ar abundances in 13 diamond stones (0.1∿0.3 gram each) which were commercially available and believed to come from various mines in South Africa. However, no further identification of the source of the diamonds was possible. Noble gases were extracted at 2050°C by graphitization. The ^{3}He/^{4}He ratio was measured with a double collector. Hot blanks (at 2050°C) were $4\sim0.5 \times 10^{-14}$ cm^{3}STP for ^{3}He, $5\sim2 \times 10^{-9}$ cm^{3}STP for ^{4}He, $2\sim0.5 \times 10^{-11}$ cm^{3}STP for ^{20}Ne and $2\sim0.5 \times 10^{-8}$ cm^{3}STP for ^{40}Ar respectively. Repeated analyses on air He (^{4}He = 3.66×10^{-9} cm^{3}STP) gave ^{3}He/^{4}He = $1.16 \pm 0.018 \times 10^{-6}$. The measured ^{3}He/^{4}He ratios were calibrated against the air He ratio.

The ^{3}He/^{4}He ratios range from 10^{-8} to 3×10^{-4}, where two stones gave as high as $2\sim3 \times 10^{-4}$, three stones $2\sim3 \times 10^{-5}$ and the remainder were less than 10^{-5}. The diamond stones which gave the ^{3}He/^{4}He ratio of more than 10^{-4} are characterized by a very high content of ^{3}He ($\gtrsim 10^{-11}$ cm^{3}STP/g), but by low ^{4}He ($\lesssim 5 \times 10^{-7}$ cm^{3}STP/g). Also these stones appear to have a rather high content of Ne and ^{36}Ar, though the latter measurements were not precise enough to make a definite conclusion. A clear inverse correlation between the ^{3}He/^{4}He ratio and the amount of ^{4}He was observed.

The very high ^{3}He/^{4}He may be attributed to (i) thermal neutron irradiation ^{6}Li (n,α) T → ^{3}He in the crust where the thermal neutron flux may be considerably high, or (ii) indigeous trapped mantle He. In the former case, assuming that the thermal neutron flux in the crust is about 8 neutrons/cm^2·day (Gorshkov, 1966 quoted in Tolstikhin, 1978) and that the age of the diamond is 4.5×10^{9} years, more than 10 ppm of Li will be required to explain the observed amount of ^{3}He in the diamond, which we believe quite unlikely. Also, the high abundance of Li in the diamond would suggest a high content of other trace elements such as K and U. However, these diamonds have much lower ^{4}He content than the diamonds having a low ^{3}He/^{4}He ratio and also ^{40}Ar/^{36}Ar is relatively low ($< 10^{3}$). Hence, we prefer the second interpretation, that is, the high ^{3}He/^{4}He ratio in the diamonds reflects the He in the mantle source region where the diamonds were formed.

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RAPID BULK ANALYSIS OF SMALL SAMPLES OF STONY METEORITES, ROCKS AND MINERALS.

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A rapid micro-technique originally developed for the analysis of individual chondrules (DeGasparis et al., 1975; Fredriksson, 1982) has been adopted for bulk analysis of major and minor elements in the silicate portion of ordinary chondrites (>300), small samples of achondrites (Fredriksson, 1976) and other scarce minerals and rocks or rock fragments. The technique may possibly be extended to trace elements, e.g. Sc, Y, Ba, Sr and some REE, employing the ion-microprobe. Encouraging experiments, including "spiked" trace element standards, are presently being conducted with the Cameca IMS 3f in Mainz. The technique for sample preparation and the relatively simple equipment needed will be described and illustrated. The samples, one or two $\lesssim$1g pieces of chondrites, $\lesssim$0.1g for, e.g. some achondrites or $\lesssim$1mg for individual chondrules or other small entities or homogeneous materials, are split and gradually reduced to extremely fine powder (in chondrites, malleable metal is intermittently removed magnetically). Milligram quantities of powder are pressed at $\sim$30 Kb into pellets, $\sim$3 mm in diameter by $\sim$0.1 mm, between WC anvils. The pellets, mounted on disks and given a conducting coating (C, Al or Au), are analyzed under the electron-probe with a 50 μm spot, continuously moving the sample; in the ion-probe the sample remains fixed, but is sampled at different depths as material is sputtered off.

Table 1 compares analyses obtained with the pellet technique to standard wet chemical analyses by Jarosewich (E.J.) and Nelen in our laboratory. Allegan powder pressed into pellets was used as standard. Also compared in Table 1 are chemical and modal determinations of metal (Fe + Ni) and troilite (FeS). This type of analysis should be sufficient for ordinary chondrites when only small samples are available or when some basic data on a large number of samples (the Antarctic meteorites!) are needed in order to identify anomalous specimens.

Table 1. Chemical Composition of Silicate Portion

	Allegan H5		Plainview H5		Bjurbole L4		Bishunpur LL3	
	E.J. Std.	Pellet	E.J.	Pellet	Nelen	Pellet	E.J.	Pellet
SiO_2	45.8-	45.2-	42.2-	43.2-	44.5-	44.8-	43.9-	43.7-
Al_2O_3	2.43	2.63	2.65	2.23	2.63	2.21	2.42	2.29
FeO	11.4-	11.4-	15.1-	16.8-	16.2-	16.4-	12.9-	14.2-
MgO	28.7-	28.5-	27.0-	26.4-	28.2-	26.8-	27.2-	27.2-
CaO	2.06	2.41	2.08	2.02	2.26	2.09	1.98	1.95
Na_2O	1.06	1.14	.81	1.06	1.19	1.03	1.03	1.05
Ni	--	.09	--.	.64	--	.23	--	.32
FeS	6.91	7.18	6.92	5.61	4.30	3.53	7.01	5.74
Total*	100.3-	98.7-	100.0-	98.2-	100.4-	97.3-	100.0-	96.6-
				Modal Composition				
Silicate	--	76.6-	--	75.0-	--	88.9-	--	86.0-
Metal Fe	17.9-	17.5-	13.0-	17.0-	4.48	6.1	6.62	7.0
Ni	1.76		1.64		1.08		1.05	
FeS	5.54	4.1-	5.90	6.0-	4.06	4.3	6.47	7.0

*Includes some minor elements, also H_2O, C in the wet chemical analyses.

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Cryogenic Techniques in Isotopic Studies of Neon in Terrestrial and Meteoritic Matter

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Investigations of the isotopic compositions of noble gases found in meteorites have steadily become more difficult as interest has shifted from 'total rock' samples to incremental heating studies of pre-solar system grains. The need for high precision isotopic measurements at very low gas levels has been met by a new generation of mass spectrometers utilising such devices as laser melting of samples, more sophisticated ion sources (for example, the Baur-Signer design) and low level ion counting. With the sensitivities achieved by these instruments new demands have been placed on gas handling and clean-up systems as distinct from the mass spectrometers themselves.

Although the problems associated with very low gas contents are comparatively new to meteoritic mass spectrometry they are all too familiar to workers involved in the study of the isotopic compositions of the noble gases present in terrestrial samples. As an example, the application of cryogenic techniques to the measurement of the isotopic composition of neon in terrestrial rocks and minerals has considerably improved measurement precision. Terrestrial data obtained using this technique will be discussed together with the implications for its use in meteoritic studies.

CATHODOLUMINESCENCE OF CARBONACEOUS CHONDRITES: ANOTHER PETROGRAPHIC DIMENSION.

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Many minerals luminesce under electron bombardment as frequently observed for small areas in the electron probe. Using a defocused beam in a luminescence microscope to irradiate standard polished thin sections, petrographic and qualitative chemical details of C2 and C3 meteorites are brilliantly revealed by luminescence and recorded on film. Carbonaceous chondrites are particularly conducive to luminescence studies since inclusions typically have low concentrations of transition metals whose presence generally shifts luminescence out of the visible spectrum. Minerals commonly found in inclusions in C2 and C3 meteorites - spinel, melilite, plagioclase, forsterite, hibonite, grossular, sodalite, enstatite - as well as many glasses often luminesce with characteristic colors providing a technique for rapidly locating interesting inclusions, frequently with mineral identification. Since luminescence arises only at surfaces, fine-grained optically opaque regions can be clearly recognized when transmitted light is useless. The sensitivity of luminescence color to minor element abundances also makes this technique useful for identifying small variations in chemical composition.

The most distinctive luminescence feature in Ca-Al-rich inclusions (CAI) from Allende and Leoville is the variation in blue luminescence associated with zoning of Mg and Na within individual plagioclase grains. Melilite exhibits darker blue than plagioclase with major element zoning clearly recognizable. Alteration of plagioclase and melilite is readily revealed by changes in luminescence from blue to olive-green and pink, indicating formation of grossular and monticellite. Veins of alteration appear as light blue streamers through dark blue melilite. Spinel shows the widest range of luminescence, commonly appearing red with color turning blue with increasing Fe content and rarely appearing bright yellow. Ti-Al-pyroxene generally does not luminesce although occasionally luminesces dull red with included orange spinel. Adelaide contains numerous small CAI comprised of melilite, spinel, diopside, fassaite, and hibonite. Luminescence is particularly useful for revealing textural relationships among these phases which commonly are intergrown on a 10 to 20 μm scale. Optical microscopy is nearly useless for these objects and luminescence photographs complement SEM backscattered electron images. Diopside rims surround most CAI in Adelaide and Murchison and the distinctive blue luminescence of diopside provides a means for locating these small, rare objects in thin section without resorting to disaggregation techniques.

Although luminescence is at best semi-quantitative, the ease of rapid surveys and the unambiguous identification of many mineral phases offers distinct advantages over optical microscopy. In combination with analytical SEM-EDS, luminescence is a powerful technique for the study of CAI's in carbonaceous chondrites.

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