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**FIRST EVIDENCE FOR INFILTRATION METASOMATISM IN A MARTIAN METEORITE, ALH 84001.** M. Wadhwa and G. Crozaz, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, St. Louis MO 63130, USA.

ALH 84001, originally classified as a diogenite, was recently recognized by Mittlefehldt [1] as a new member of the clan of martian meteorites. It is a coarse-grained orthopyroxenite with the same O isotopic composition as the nakhlites [2]. Most of this meteorite consists of orthopyroxene grains; it also contains maskelynite, chromite, and accessory minerals including apatite, augite, pyrite, and Mg-Ca-Mn-Fe carbonates [1].

With the ion microprobe, we measured the concentrations of REEs and other selected minor and trace elements in individual grains of orthopyroxene, maskelynite, and apatite. In pyroxene, the REEs do not show the striking compositional zoning that is characteristic of all other SNCs [3–6]. This is consistent with the observation that orthopyroxene grains commonly join in 120° triple junctures and the suggestion that ALH 84001 cooled more slowly that the shergottites, nakhlites, or Chassigny [1]. Only Ti and Zr, two of the incompatible elements, show correlated variations in ALH 84001. Titanium concentrations vary by a factor of 1.9 while those of Zr vary by a factor of 4.3. Mittlefehldt [1] noted that the orthopyroxene compositions in ALH 84001 are similar to those of the megacrysts from the lithology A of EETA 79001 and of Chassigny, but this similarity does not extend to their Ti and Zr concentrations. The C1 chondrite-normalized abundances in ortho-pyroxene vary from ~0.03 for La to ~2.0 for Lu, and Eu is strongly depleted. The maskelynite REE pattern, on the other hand, shows a steep decrease from La (~2.3× C1) to Dy (~0.11× C1) and a pronounced positive Eu anomaly (~13× C1). The apatite REE pattern is strongly LREE enriched as well (from La ~400 to Yb ~27) and has a small negative Eu anomaly.

Although in all SNCs phosphate is the mineral with the highest REE concentrations, it is not the major REE carrier in ALH 84001. It accounts for ~90% of the La, but only 30% of Eu, and less than 3% of the Yb in the whole rock. A mixture of 98.85% orthopyroxene, 1% maskelynite, and 0.15% phosphate, consistent with what is known about the modal composition of this meteorite, gives a perfect match with the REE whole-rock composition determined by Mittlefehldt [1].

Using the most appropriate partition coefficients for these minerals in SNCs [3], we estimated the compositions of the melts that may have been in equilibrium with the "average" orthopyroxene, the apatite, and the maskelynite. The orthopyroxene equilibrium melt is slightly LREE depleted (its REE pattern is similar to that of the whole rock), whereas the apatite and maskelynite equilibrium melts have higher REE concentrations and are strikingly LREE enriched. We tried unsuccessfully to derive the apatite and maskelynite melts from the orthopyroxene melt by fractional crystallization. This is the first instance for a SNC meteorite where it is not possible to derive by this process the melts that gave rise to the late-forming minerals (such as feldspar and apatite) from those that were in equilibrium with the earliest-formed REE-bearing mineral (i.e., pyroxene). We therefore suggest that an infiltrating fluid enriched in LREE is responsible for the formation of the apatite and maskelynite that occur as interstitial grains in ALH 84001. The presence of interstitial carbonates and pyrite also indicate that hydrothermal alteration played a significant role in the formation of this meteorite [1]. The similarity of REE patterns for the parent melts of ALH 84001, Shergotty, and Zagami seems to indicate that the new SNC meteorite is more closely related to these two shergottites than to any of the other meteorites thought to have come from Mars.

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**THE CHEMICAL COMPOSITIONS OF OLIVINES AND PYROXENES FROM ANTARCTIC MICROMETEORITES.** J. Walter[1], G. Kurat[1], F. Brandstätter[1], T. Presper[1], C. Koeberl[2], and M. Maurette[3], [1]Naturhistorisches Museum, A-1014 Vienna, Austria, [2]Institut für Geochemie, Universität Wien, A-1010 Vienna, Austria, [3]Centre de Spectrometrie Nucleaire et de Spectrometrie de Masse, Bat. 104, F-91405 Orsay-Campus, France.

In the course of a systematic investigation of micrometeorites (MM) from Antarctica [1] we have investigated selected particles from the 100–400-µm size fraction by INAA, ASEM, EMPA, and optical microscopy. Of the 60 particles analyzed so far, 36 turned out to be of extraterrestrial origin. This collection comprises 7 umelted phyllosilicate-dominated MM, 6 unmelted coarse-grained crystalline MMs, 19 partially melted scoriaceous MMs, and 4 cosmic spheres.

The mineralogy and geochemistry of the unmelted MM population indicates that this most common extraterrestrial matter being sampled by the Earth is similar, but not identical, to the rare CM chondrites [e.g., 2,3]. One of the differences believed to be primary is the high abundance of pyroxenes in MMs and the lack of an olivine and pyroxene population very poor in Fe and rich in refractory elements [e.g., 4–7]. Eight of our unmelted and partially melted MMs contained olivine, 7 pyroxene, 11 olivine and pyroxene, and 10 neither phase. The chemical composition of the phases large enough to be analyzed by EMP are plotted in the Fig. 1. As is evident, both olivine and pyroxene compositions cluster at low Fe contents. However, the low Fe of both minerals is not as low in FeO as that known from CM chondrites [e.g., 8,9]. Correspondingly, the MM phases are also not as rich in refractory elements, as are the most refractory olivines from CM chondrites. Otherwise, their compositions are very similar exhibiting the enrichments in Mn and Cr typical of extraterrestrial olivines and pyroxenes.

According to the model of [10] we can interpret the difference as indicating different intensities in processing of constituents of MMs and CM chondrites in the solar nebula. The more intensive reworking (annealing and metasomatic elemental exchange between mineral grains and the gas phase) of the MM constituents did not allow some primitive phases to survive.

Furthermore, unmelted and partially melted MMs are on average rich in low-Ca pyroxene rather than olivine as are the CM chondrites. In addition, C contents have been found to be higher in phyllosilicate MMs than in Orgueil [11]. Thus, the MMs from the size fraction 100–400 µm, the size fraction

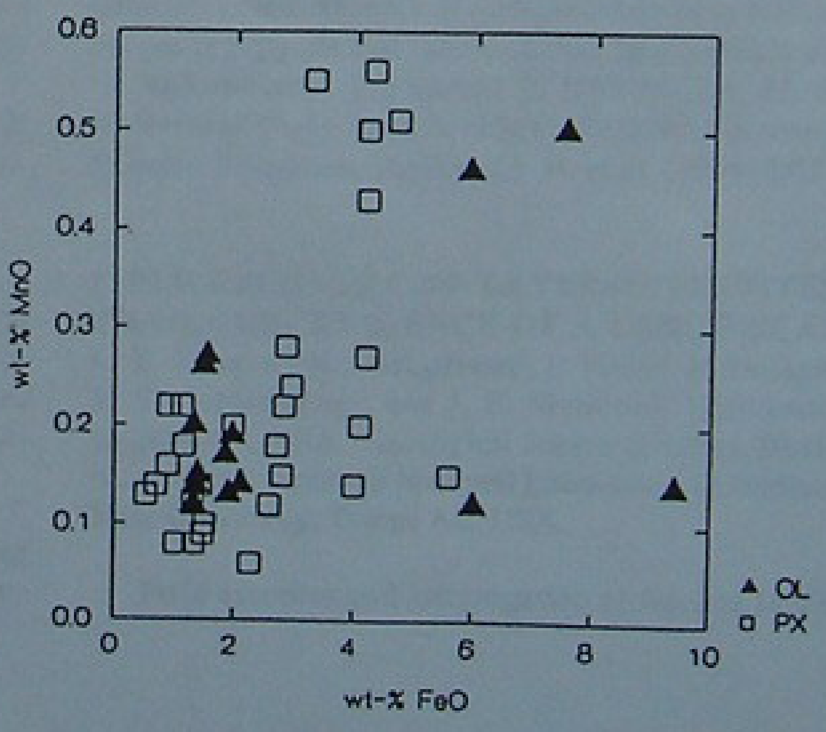


**Fig. 1.** MnO vs. FeO in olivines and pyroxenes from MMs.

that delivers the main mass of extraterrestrial matter onto the Earth, is mineralogically and chemically different from any of the known meteorite classes. It is an extraterrestrial matter of its own but seems to be related to the rare CM-type chondrites.

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## CONSTRAINTS ON UREILITE ORIGIN FROM TRACE-ELEMENT CONTENTS.

M.-S. Wang and M. E. Lipschutz, Department of Chemistry, Purdue University, West Lafayette IN 47907-1393, USA.

While genetic processes of many meteorite groups are debated, ureilites are arguably the most enigmatic of all: even the question of an igneous vs. a nebular origin is unsettled [1]. We do know that the ureilites or their parent material represent at least two and perhaps as many as six batches of nebular material [1,2].

In part, the ureilite enigma reflects the small number of specimens for which data are known. The Antarctic populations provide a disproportionately large number of ureilites and we report RNAA data for 15 trace elements (U, Au, Co, Sb, Ga, Rb, Ag, Se, Cs, Te, Zn, Cd, Bi, Tl, and In in order of increasing volatility) in 18 samples representing 15 separate falls from Victoria Land and Queen Maud Land. While the contents of these elements in the ureilite suite is highly variable, the ureilite data (relative to CI chondrites) reveal several trends: (1) strong depletion of Rb, Cs, and Tl, averaging 0.003–0.007× CI; (2) depletion of highly labile Cd, Bi, and In, averaging 0.01× CI; (3) lesser, but still severe, depletion of moderately labile Ag, Se, and Te, averaging 0.05× CI; (4) surprisingly strong depletions of refractory U (to 0.07× CI) and of siderophilic Au, Co, Sb, and Ga, to averages of 0.1–0.2× CI; and (5) Zn levels averaging 0.6× CI.

The compositions of ureilites seem to exclude carbonaceous chondrites as an immediate precursor. Further, ureilite compositions do not reflect loss of vapor but, rather, geochemical, condensed-phase fractionations involving the presence/absence of components, each having its specific signature. The clearest of these fractionations, loss of feldspar from the ureilite precursor [1], is indicated by data for the alkalis and Tl. In ureilite the mean, CI-normalized concentration of Tl is essentially the same as those of Rb and Cs from this study, and of K, Na, and Rb from prior ones [1]. It is well known that in terrestrial igneous rocks, Tl proxies for K in its minerals because of similarities in their ionic radii. In most meteorites, it is the high thermal lability of Tl that is important in establishing its content in ureilites; it is condensed-state behavior that is responsible for its covariation with alkalis. Perhaps this feldspar loss was also responsible for loss of LREE [1] and U. Contents of Zn accord with the suggestion of its presence in olivine, in which Zn substitutes for Fe [1]. Data for most other volatile trace elements suggest late addition of metal-sulfide eutectic at temperatures near 1000°C. Clearly, while high-intensity shock left its imprint in the minerals of nearly all ureilites, unlike the situation in L chondrites [3] it failed to alter preshock contents of even the most labile of trace elements.

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## SIOUX COUNTY: AN ORTHOCUMULATE, AND SYSTEMATICS OF V AND OTHER TRACE ELEMENTS IN SEVERAL SIMILAR EUCRITES.

P. H. Warren and G. W. Kallemeyn, Institute of Geophysics and Planetary Physics, University of California, Los Angeles CA 90024-1567, USA.

Sioux County (SC) has long been classified as the most "primitive" of the noncumulate eucrites. In an extremely influentual paper, Stolper [1] argued for genesis of most eucrites as little-differentiated partial melts, modified only by slight near-surface fractional crystallization ("crystallization differentiation") starting from "liquids similar in composition to Sioux County" (the paper invoked this approximate phrase ~25 times). In this model, SC is the type example of a primary eucrite melt, where "primary" denotes "a liquid that has not changed since it was generated in its source region by melting" [2]. Recently, Jones et al. [3] suggested that a compositional similarity between SC and a partial melt of Murchison, particularly for Sc, V, and La (an incompatible element), confirms Stolper's [1] model. This claim prompted us to examine the petrology of SC, which seems to have been unstudied for decades.

The texture of SC is in most areas highly brecciated, with sufficient diversity in grain size (etc.) to raise doubts as to whether the rock is even monomict. Most of the unbrecciated portion is extremely coarse-grained. In one large unbrecciated clast, we find grains blocky and up to 5 mm across. Studying a larger piece, BVSP [2] noted grains up to 1 cm (!). We find the pyroxenes are mostly pigeonites that have thoroughly exsolved, with augite lamellae typically 4–6 µm wide, although roughly 10% have widths >6 µm, and the thickest are 12 µm; also, one grain of primary augite with 8-µm-wide opx lamellae. Most analyses have Wo either ≤2.0 or ≥44 mol%. Opx mg ratios are 36.8–39.0 mol%. In addition, the SC bulk composition (literature data) is displaced from the average noncumulate eucrite toward higher mg and V, and lower Sc and REE, which is also true (except to greater degree) of all the obvious adcumulate eucrites. We interpret SC as an orthocumulate. The parent melt was considerably more evolved (lower mg, lower V, higher REE, etc.) than the observed SC composition, and had a slight (–) Eu anomaly. Any compositional similarity between SC and Murchison partial melts [3] must be largely coincidental.

We note a general tendency for the more slowly cooled monomict eucrites, including such Main Group "noncumulates" as Chervony Kut, Haraiya, Juvinas (literature data), and the texturally comparable EET 87520, RKPA 80204 (monomict?), RKPA 80224, Y 791186, and Y 82037 (our new data), to feature compositions, like SC, with higher mg, higher V (Y 791186, at 62 µg/g, is an interesting exception), and lower REE than their more rapidly cooled counterparts. We suspect that all of the above-named eucrites are at least mildly accumulative. If pyroxene exsolution is any indication, they cooled far more slowly than any of several lunar mare gabbros that are known from field context to be orthocumulates. These eucrites are texturally comparable to the main mass of the Palisades Sill, where except for the famous olivine layer, no "cumulate framework" textures are discernible, yet geochemical layering requires that the rocks are mildly accumulative. Another factor causing "noncumulate" eucrite breccias to display relatively primitive compositions may be that some are actually polymict, with substantial comminuted cumulate components in their matrices.

Only a relative few eucrites are likely to be compositionally close to the melts from which they crystallized. Most cumulate eucrites, including SC and other orthocumulates (except Pomozdino), crystallized from melts more ferroan than any noncumulate eucrite [1]. The same parent body has also yielded many orthopyroxenites (diogenites) with mg ratios implying parent liquids more magnesian than any noncumulate eucrite (at least, on average—some diffusive or even convective homogenization of the diogenite mg ratios may have occurred). Intermediate melts presumably once existed, and either evolved into cumulate parent melts, or were quenched into Main Group eucrites. Absence of quenched liquids as ferroan as the cumulate parent melts suggests that the cumulates formed fairly deep within the crust.

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## FIELD RECOVERY OF LAYERED TEKTITES IN NORTHEAST THAILAND: EVIDENCE OF A LARGE-SCALE MELT SHEET.

J. T. Wasson[1], K. Pitakpaivan[2], P. Fiske[3], P. Puttapiban[2], S. Salapongse[2], B. Thapthimthong[2], and J. F. McHone[4], [1]University of California, Los Angeles CA, USA, [2]Geological Survey Division, DMR, Bangkok, Thailand, [3]Lawrence Livermore National Laboratory, Livermore CA, USA, [4]Arizona State University, Tempe AZ, USA.

Field searches and interrogation of farmers in Thailand has led to the