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We were allocated samples of MAC88104 and MAC88105 for noble gas, chemical and radionuclide analysis. Here we report the K concentrations relevant for the calculation of K-$^{40}$Ar ages of aliquot samples analyzed for the noble gases. Furthermore, we measured by RNAA the concentrations of Y, Zr, Ba, Hf, Ta and W. In addition a suite of elements was measured by INAA.

TABLE 1. Concentrations of trace elements in lunar meteorites and in an anorthositic breccia from Apollo 16 (ppm). Errors 1 σ: 5–10%.

| | MAC88104,11 bulk | MAC88105,24 grain size sep. ≤149 μm | Y86032.86 | Apollo 16 61016.3 |
|---|---|---|---|---|
| K | 257 | 857 | – | 184 (2) |
| Ba | 39 | 45 | – | 41 (2) |
| Hf | 0.8 | 1.1 | 0.24 (1) | 1.1 (2) |
| Zr | 28 | 38 | 17 (1) | 51 (2) |
| Ta | 0.4 | 0.15 | 0.10 (1) | 1.0 (3) |
| W | 0.07 | 1.0 | 0.47 (1) | 0.25 (3) |
| Y | 7.4 | 10.6 | 4.6 (1) | 44 (3) |

Preliminary results are presented in Table 1 and compared with values we obtained for the lunar meteorite Y-86032. We include also values of an anorthositic sample of Apollo 16.

Based on earlier chemical and mineralogical examinations the two MacAlpine meteorites were recognized to be paired (4, 5). Our values for MAC88104 are very similar to the results found in the literature (6, 7), whereas our results for MAC88105 are distinctly different indicating some heterogeneity of this meteorite. So far the MacAlpine samples and Y-86032 are the lowest in incompatible elements from the lunar meteorites investigated. This work was supported by the Swiss National Science Foundation. References: (1) Eugster O. *et al.* (1979) *Proc. NIPR Antarct. Meteorites* 2, 3–14. (2) Hubbard N. J. *et al.* (1974) *Proc. Lunar Sci. Conf.* 5th, 1227–1246. (3) Wänke H. *et al.* (1974) *Proc. Lunar Sci. Conf.* 5th, 1307–1335. (4) Palme H. *et al.* (1990) *Lunar Planet. Sci.* 21, 930–931. (5) Lindstrom M. *et al.* (1990) *Lunar Planet. Sci.* 21, 704–705. (6) Koeberl C. *et al.* (1990) *Lunar Planet. Sci.* 21, 645–646. (7) Korotev R. L. *et al.* (1990) *Lunar Planet. Sci.* 21, 666–667.

## Trace-element compositions of Ca-rich chondrules from Allende: Relationships between refractory inclusions and ferromagnesian chondrules.

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Refractory inclusions and ferromagnesian chondrules are a principal source of information about the chemical and isotopic evolution of the solar nebula. However, our interpretations of the chemical and isotopic state of the solar nebula have been limited because we do not yet understand the relationship between these two groups of objects; it is not even known if they formed in related events or whether a real discontinuity exists between the processes that formed them. To investigate the relationship between these objects, we have measured with neutron activation techniques the trace-element compositions of Ca-rich Allende chondrules, part of a group of chondrules which has previously been shown to have bulk major element compositions spanning the gap between refractory inclusions and ferromagnesian chondrules, which is reflected in an assemblage dominated by plagioclase or feldspathic mesostasis, Ca-pyroxene (including fassaite), olivine, and sometimes spinel (Sheng *et al.*, 1988; Kring and Holmén, 1988).

The REE in most of the chondrules examined are unfractionated, similar to those in ferromagnesian chondrules. However, other chondrules contain highly fractionated REE, some of which have patterns similar to volatility-controlled Group II and ultra-refractory patterns seen in refractory inclusions. In addition, one chondrule has positive Ce, Eu, and Yb anomalies, forming an REE pattern unlike any we have analyzed previously, but having some similarities to that of a Ca-rich chondrule examined by Misawa and Nakamura (1988). The processes needed to produce such a pattern are, for the moment, unclear, but may be the result of a combination of crystal-chemical and volatility effects.

The siderophile elements in these chondrules are also fractionated and appear to have been affected by two processes: (1) metal/silicate fractionation producing enrichments in those elements that also behave as lithophiles (W, Fe, and Ga), as seen among Dhajala (H3) CA chondrules (Boynton *et al.*, 1990); and (2) volatility-controlled fractionation similar to that seen among refractory inclusions and their components (*e.g.*, Bischoff and Palme, 1987) wherein the most refractory siderophiles (Ir, Os, W, and Re) are greatly enriched relative to more volatile siderophiles (Ni, Co, Fe, Au, As, and Ga). No correlation was observed between Au and As, indicating that they did not exist together as a single precursor component, in contrast to that seen among Allende ferromagnesian chondrules (Rubin and Wasson, 1987). These results indicate there were several siderophile precursor components in regions of the solar nebula where material was melted to form molten droplet objects.

Our data demonstrate that Ca-rich chondrules have trace-element properties similar to those of refractory inclusions and ferromagnesian chondrules. In some cases the properties are mixed; *e.g.*, the REE in a chondrule may be indicative of ferromagnesian chondrules, but the siderophile elements in the same object may be indicative of refractory inclusions. The relationship between refactory inclusions and ferromagnesian chondrules is thus complicated, however, it is clear that some of the precursor components of these objects may have come from the same reservoir, or from different and isolated reservoirs in which similar processes occurred. References: Bischoff A. and Palme H. (1987) *GCA* 51, 2733. Boynton W. V. *et al.* (1990) *GCA*, submitted. Kring D. A. and Holmén B. A. (1988) *Meteoritics* 23, 282. Misawa K. and Nakamura N. (1988) *GCA* 52, 1699. Rubin A. E. and Wasson J. T. (1987) *GCA* 51, 1923. Sheng Y. J. *et al.* (1988) *LPS* 19, 1075.

## Are igneous processes the only way to make differentiated meteorites?

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The non-chondritic or "fractionated" meteorites are widely believed to be of igneous origin. In addition to being fractionated many of them are also brecciated. And this is generally considered to indicate an impact origin at the surface of a fractionated planetesimal. Both beliefs do not appear to rest on settled grounds and therefore deserve some rethinking.

Chemical fractionations represented by the fractionated meteorites are impressive at first glance. We find Ca-Al-rich basalts and pyroxenites, dunites, Ca-poor pyroxenites, silicate-metal rocks, and metal rocks. Compared with fractionations observed for components of chondrites, the range of fractionated meteorite fractionations appears to be limited. We are therefore faced with the paradoxical situation that rocks containing chemically highly fractionated components (chondrules, aggregates, inclusions, matrix, *etc.*)—the chondrites—are being considered primitive because of their bulk composition and old age. On the other hand, larger units (rocks) fractionated in a way similar to chondritic components are considered secondary, *e.g.*, fractionated by igneous processes on a parent body. This is in spite of the fact that fractionated meteorites have comparable old ages and indicators of primitiveness. Couldn't it be that chondrite components and rocks we now call fractionated meteorites experienced very similar (and apparently highly efficient) fractionation processes early in the solar nebula? The major difference between chondrites and differentiated meteorites could then be the result of sampling: the former were able to collect all (or almost all) of the fractionated matter from within a reservoir whereas the latter happened to collect a non-representative sample, mainly of one but occasionally also of several kinds. Possible reasons for such a behavior could lie in the different grain-sizes of chondrite and differentiated meteorite components and the timing of formation of larger bodies either by aggregation or by growth of large crystals.

The brecciated nature of many fractionated meteorites, if viewed from a different angle, is actually a feature which should not hit us with surprise. Breccias indicate chaotic formation conditions, and these are the conditions we have to expect in a turbulent solar nebula. And chaos is manifested in almost all meteorites. It is a primary, primitive feature of meteorites and there is no necessity for invoking secondary or tertiary processes.

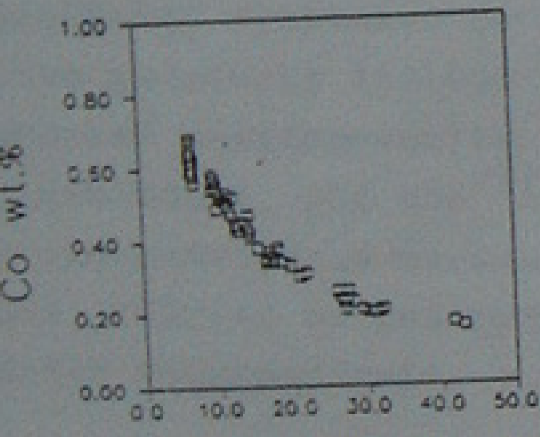
The early solar nebula probably could provide all conditions necessary to fractionate matter in the way we can observe it among chondrite components and fractionated meteorites and to separate fractionated components from one another. Then what is the reason for molten planetesimals?

**Unusual metal from the Chela (H4) chondrite.** G. Kurat,[1] F. Brandstätter,[1] M. Mayr[2] and G. Hoinkes.[3] [1]Naturhistorisches Museum, A-1014 Vienna, Austria. [2]VOEST-Alpine AG, A-4010 Linz, Austria. [3]Universität Graz, A-8010 Graz, Austria.

The Chela (H4) chondrite fell in 1988 in the Kahama District, Tanzania. It is a fairly normal equilibrated chondrite (Fa 17.2) except for its metal. This metal mainly forms large, highly irregular bodies, similar to what has been described by Perron *et al.* (1989) from Forest Vale (H4) and Sainte Marguerite (H4) chondrites. It is also rich in silicate (pyroxene, olivine), phosphate and oxide (chromite, $SiO_2$) inclusions of highly variable sizes (<1–20 μm). Inclusions either show patterns (strings, bridges across the metal grain) or are irregularly distributed such as to appear to be "floating" (compare Ramdohr, 1977). The highly irregular metal bodies are usually compositionally inhomogeneous. The major portion consists of kamacite of constant and unusual composition (7 wt.% Ni, 0.6% Co). Mostly included by this kamacite are grains of taenite which can be of highly irregular (lobate) shape or form subhedral grains. These grains are compositionally zoned. Most commonly they have a core of low-Ni taenite (9% Ni, 0.55% Co) whose Ni content gradually increases towards the surface, usually up to 22% Ni, 0.3% Co. In some cases (commonly associated with asymmetric zoning) the Ni content reaches up to 30% Ni (0.2% Co) and occasionally up to 43% (0.15% Co). Nickel and Co are anticorrelated (Fig.). Some compositional gaps appear to exist between kamacite and taenite and between different taenite compositions.

**Discussion and Conclusions.** The Chela metal apparently has some morphological similarity with metals from Forest Vale (H4) and Sainte Marguerite (H4) which both contain the isotopically distinct FVM-Xe component recently discovered by Marti *et al.* (1989). A search for that component in Chela metal is under way.

The morphology of the Chela metal grains and their chemical zonality suggest that they fill previous pore space which was decorated by vapor-deposited silicates. Deposition of metal into the pore space probably occurred from the vapor. Only in this way it appears to be possible to preserve the delicate silicate crystals and aggregates now included in the metal. The original composition of the metal must have been Ni-poor. Subsequent cooling apparently was fast which did not allow Fe-Ni equilibration but did allow Ni-Co redistribution. The Chela metal also indicates a high mobility of Fe-Ni during the late stage of chondrite formation. References: Marti K., Kim J. S., Lavielle B., Pellas P. and Perron C. (1989) Z. *Naturforsch.* **44a**, 963. Perron C., Bourot-Denis M., Pellas M., Marti K., Kim J. S. and Lavielle B. (1989) *Lunar Planet. Sci.* **20**, 838. Ramdohr P. (1977) *Chem. Erde* **36**, 263.



Contents of Co *vs.* Ni in metal from Chela (H4).

**Cosmogenic noble gases in St. Séverin and Knyahinya meteorites by using a precombustion step.** B. Lavielle, E. Gilabert and G. N. Simonoff. U.R.A. 451 of C.N.R.S., C.E.N.B.G., Le Haut Vigneau 33175 GRADIGNAN CEDEX, France.

In previous work (1), Kr measurements were carried out in gram-size samples of St. Séverin core AIII in order to determine depth profile of the cosmogenic component. Krypton composition was found to be a mixture of cosmogenic and trapped gas, with a small amount of fissiogenic Kr (less than 0.6% for $^{86}$Kr and negligible for the other Kr isotopes). The relatively low abundance of the trapped component (from 60% to 80%) allowed a precise determination of the cosmogenic Kr in St. Séverin core AIII.

As demonstrated by Marti (2), concentrations of trapped Kr and Xe in chondrites are correlated with the chemical-petrology classification according to Van Schmus and Wood (3). They generally are much higher in type 5 or 4 chondrites than in the type 6 St. Séverin making difficult the partitioning of the different components.

Recently (4), concentration and isotopic composition of Xe were analysed in Forest Vale (H4) samples using a precombustion step at 600 °C in $O_2$. For silicate separates and bulk samples, significant fractions (from 30% to 50%) of a major trapped Xe component were released during the combustion step. The measured Xe isotopic composition, called FVC (for Forest Vale Combustion) appeared to represent a trapped gas reservoir, isotopically distinct from other known Xe compositions such as Kenna-type or solar-like Xe as observed in Pesyanoe and in lunar samples.

In this work, a similar procedure is utilized for studying cosmogenic Kr and Xe concentrations in type 6 and 5 chondrites. A piece of about 1 g of each meteorite was gently crushed in a stainless steel mortar to a grain size of approximately 1 mm to avoid Kr or Xe losses.

After a heating of the samples in vacuum to 80 °C for several days, a first pyrolysis at 450 °C removed most of the absorbed atmospheric gases. This first temperature step was followed by a second pyrolysis at 600 °C, by a combustion step at the same temperature under 15 torrs of oxygen pressure and finally by a complete melting of the samples at 1750 °C.

The percentages of the noble gases respectively extracted from the 600 °C pyrolysis, from the 600 °C combustion and from the 1750 °C step relative to the total measured in the sample are 3%, 19%, 78% for $^{86}$Kr and 0.5%, 12.5%, 87% for $^{136}$Xe.

The ratio of cosmogenic $^{83}$Kr to trapped $^{83}$Kr in these three fractions is respectively, 1.2, 0.14, 0.59, indicating a significant release of trapped gases in the combustion step as previously observed in Forest Vale. The composition of the Xe released from this combustion step for St. Séverin agrees quite well with the FVC-Xe composition.

Otherwise, the enrichment of the cosmogenic component of Kr obtained in the 1750 °C step allows a precise determination of cosmogenic ratios. Using the ratio of cosmogenic $^{78}$Kr to $^{83}$Kr as shielding monitor for depth dependence of the $^{83}$Kr production rate, an irradiation age of 40 Ma for Knyahinya is calculated from the calibration given by Eugster (5). References: (1) Lavielle B. and Marti K. (1988) *Proceedings of LPSC* 18, 565. (2) Marti K. (1967) *Earth Planet. Sci. Lett.* **2**, 193. (3) Van Schmus W. R. and Wood J. A. (1967) *Geochim. Cosmochim. Acta* **31**, 747. (4) Lavielle B. and Marti K. (1988) *LPSC* 19 (abstract), 667. (5) Eugster O. (1988) *Geochim. Cosmochim. Acta* **52**, 1649.

**Redox history of metallic Fe-Ni in Renazzo and related chondrites.** Min Sung Lee,* Alan E. Rubin and John T. Wasson. University of California, Los Angeles, CA 90024, USA. *Permanent address: Seoul National University, Seoul 151, Republic of Korea.

In equilibrated meteorites that have two or more metal phases, Co concentrations are high in the kamacite and Ni concentrations are high in the taenite and tetrataenite. As a result, plots of Co *vs.* Ni in the metal show negative correlations. However, positive correlations have been reported for the primitive ungrouped carbonaceous chondrites Al Rais and Renazzo (1, 2). The Co/Ni ratio in their metal is approximately the same as that in bulk CI chondrites (1). This compositional trend has been interpreted to be a nebular effect; *e.g.*, after the condensation of metallic Fe-Ni, oxidation removed Fe (as FeO) and thereby enhanced the Ni and Co concentrations in the residual metal. This is because Fe is oxidized more readily than Ni or Co.

We have analyzed metallic Fe-Ni grains in different petrographic settings (chondrule interiors, chondrule margins, chondrule rims, matrix) throughout Al Rais, Renazzo and MAC87320 in an attempt to shed additional light on the redox history of primitive metal. Most metal grains at chondrule margins are compositionally zoned such that grain edges are lower in Ni and Co (by ~5–10% relative) compared to grain cores. In addition, metal grains in the outer portions of chondrules