Meteoritics 30 (1995)

251

paleogeographic maps, where seashore lines for various geological epochs are usually limited by the margin contours of corresponding sediments successfully preserved from erosion within the Khatanga Depression. The large Popigai Crater, ~35 Ma in age, with its well-preserved impact formation, may provide new insight into the open sheets of regional Phanerozoic history. The Popigai impact formation should contain a full collection of target sedimentary rocks in a large, ~100-km-diameter, area of cratering. The explosion cloud deposits (suevites) and the suevite megabreccia among them, should be the most interesting in this respect, especially if one takes into account a new model [1,2] of their transport during cratering (subvertical excavation for cape target formations). The following data are presented in order to support the thesis mentioned above.

The fragments of K1 rocks collected by one of us (S.V.) from the suevite megabreccia contain well-preserved *in situ* Early Valanginian fauna of Buchia keyserlingi (Lah.) (layered leptochlorite sandstone, northeast part of the crater, specimen 2315/2) as well as Early Valanginian fauna of Costacolpus septentrionales Beisel, Buchia sp. ind., Praeexogyra cf. anabarensis Bodyl., and others (phosphate sandstone, north part of crater, specimen 2374/6). This fauna is evidence of open (100 km to seashore, at least) and shallow (20–40 m) sea. Other marine fauna of Valanginian age (bivalves and cephalopods) had been found in suevites of the crater by L. P. Smirnov (1957) and others, so there was an ocean regime in the Valanginian time on the northern part of the Anabar Shield.

M. T. Kirjushina reported [3] that Late Aalean-Bajocian fauna of Pseudomonotis (Eumorphotis)? (Arctotis, in modern terminology) cf. lenaensis (Lah.), was collected in the central part of the crater (sandy-carbonaceous concretion). Again, it is evidence of a shallow (<100 m) sea on the northern part of the shield.

A special quest for Paleogenic rocks incorporated in Popigai impactites, was unsuccessful, but reworked Paleogenic tree pollen (Tsuga, Abus), as well as marine Diatomea, were reported by A. O. Yefomov (1966) and others to be present in postimpact N2-Q2 crater fill. Therefore, continental as well as marine regimes were also possible for the area in Paleogenian time. The bulk composition of Popigai suevites enables us to estimate the approximate thickness for Mz + Pg(?) cape of target. Subvertical excavation of this cape during cratering should provide relatively uniform deposition of mobilized material. The top of the suevitic column (suevite sands, suevite megabreccia, and Daldyn breccia) is widespread in the crater and is primarily made up of Mz + Pg(?) material (up to 60–75 vol%). This top's minimum thickness is up to 200 m (drilling data). So, the top should correspond to Mz +Pg(?) target cape of up to 120–150 m in thickness, at least, and the northern part of the Anabar Shield was not a positive area only, but depositional (including marine regimes) basin also during the time considered. The examples described are only the first steps in the use of such unique storage of regional paleogeographic data as the Popigai Crater.

References: [1] Vishnevsky S. A. (1994) *Novosibirsk: UIGGM Preprint*, 1–66, in Russian. [2] Vishnevsky S. A. (1994) *2nd Intl. Workshop*, ESF Sci. Network, Ostersund, May 31–June 5, 50. [3] Kirjushina M. T. (1959) *Geology, 1*, 50–55.

SAMARIUM-NEODYMIUM AND MANGANESE-CHROMIUM SYSTEMATICS IN THE EUCRITE CALDERA.

M. Wadhwa and G. W. Lugmair, Scripps Institute of Oceanography, University of California, San Diego, La Jolla CA 92093-0212, USA.

Caldera, a find from Chile, is one of only two known unbrecciated noncumulate eucrites (the other being Ibitira). For this reason, it was deemed of great importance to perform on this meteorite extensive radiochronological studies in an attempt to better constrain the time of solidification of basalts on the eucrite parent body (EPB) and thus the evolutionary timescale of planetesimals.

Compared to other noncumulate eucrites, Caldera has a very coarse grain size. Unfortunately, there is extensive yellow-brown staining on almost all grain surfaces pervading the entire meteorite. Because of the meteorite's unknown terrestrial residence time, and the possible terrestrial origin of this staining, it was clear that it had to be removed before reliable isotopic measurements on mineral separates could be attempted. This proved to be very difficult, and up to 2 hr of etching in 1.8N HCl was required to achieve satisfactory results.

Mineral separates of plagioclase (Pl) and pyroxene (Px), although partially etched but mostly clean of the surface coating, together with an aliquot of an acid-cleaned bulk sample and an unetched chip, were dissolved and analyzed for Sm-Nd isotopic systematics. There is a large spread in $^{147}Sm/^{144}Nd$ ratios between Pl and Px (0.0896 and 0.278 respectively). Excellent isochrons for both the $^{147}Sm-^{143}Nd$ and the $^{146}Sm-^{142}Nd$ systems were obtained. Note that even the data from the unetched bulk sample fall on the isochrons, which indicates that only insignificant amounts of REE could have been introduced on Earth. The $^{147}Sm-^{143}Nd$ system yields an age of 4.544 ± 0.019 Ga, with an initial $^{143}Nd/^{144}Nd = 0.506741 \pm 24$. The short-lived $^{146}Sm-^{142}Nd$ system results in a $^{146}Sm/^{144}Sm$ ratio of 0.0075 ± 0.0010 and an initial $\varepsilon_{142} = -3.1 \pm 0.5$. All these results from Caldera are indistinguishable from data obtained previously in our laboratory on angrites [1,2] and the noncumulate eucrites Juvinas [3] and Chervony Kut (CK) [4], and indicate that both Sm-Nd systems in these meteorites closed contemporaneously within the uncertainties afforded by the data (i.e., 20–30 m.y. for $^{147}Sm-^{143}Nd$ and ≥15 m.y. for $^{146}Sm-^{142}Nd$).

In contrast, the fine resolution of the $^{53}Mn-^{53}Cr$ system paints a different but nonetheless totally consistent picture. In spite of a wide range in Mn/Cr ratios from ~0 (chromite) to ~7 (Px), the $^{53}Cr/^{52}Cr$ ratios in all samples measured (chromite, etched bulk, Px, and silicates) are the same. Although the typical errors are 10–12 ppm, the range in the $^{53}Cr/^{52}Cr$ excesses is only 1.14–1.17 ε units (parts in 10^4 above the terrestrial ratio), with an average of 1.15 ε. Thus, the slope of the best-fit line through these data points is $0 \pm (2 \times 10^{-7})$. This means that ^{53}Mn was no longer extant when the Mn-Cr system closed in Caldera. When compared to the $^{53}Mn/^{55}Mn$ ratio of 3.6×10^{-6} found for CK [5], this indicates that formation of Caldera occurred ≥15 m.y. after that of CK. Similarly, if the angrite parent body [6] formed with the same initial $^{53}Mn/^{55}Mn$ as the EPB, then the angrites are ≥10 m.y. older than Caldera. Thus the true age of Caldera has to be ≤4.548 Ga. This upper limit is totally consistent with the Sm-Nd results and probably very close to the true age, since the lower limit on the obtained $^{146}Sm/^{144}Sm$ ratio will not allow an age much lower than 4.548 Ga. Note, however, that this "age" may well indicate the time of extensive recrystallization [7], probably from a melt, when the Cr isotopes were totally equilibrated.

References: [1] Lugmair G. W. and Marti K. (1977) *EPSL, 35*, 349. [2] Lugmair G. W. and Galer S. J. G. (1992) *GCA, 56*, 1673. [3] Lugmair G. W. et al. (1975) *EPSL, 27*, 79–84. [4] Wadhwa M. and Lugmair G. W. (1995) *LPS XXVI*, 1453–1454. [5] Lugmair G. W. et al. (1994) *LPS XXV*, 813–814. [6] Lugmair G. W. et al. (1992) *LPS XXIII*, 823–824. [7] Boctor N. Z., personal communication.

THE ABUNDANCE OF ORDINARY CHONDRITE DEBRIS AMONG ANTARCTIC MICROMETEORITES.

J. Walter[1], G. Kurat[1], F. Brandstätter[1], C. Koeberl[2], and M. Maurette[3], [1]Naturhistorisches Museum, Burgring 7, A-1010 Vienna, Austria, [2]Institut für Geochemie, Universität Wien, Geozentrum, Althanstrasse 14, A-1090 Vienna, Austria, [3]C.S.N.S.M., Bat. 104, F-91405 Campus Orsay, France.

Interplanetary dust and meteorites are widely believed to originate predominantly from the asteroid belt [e.g., 1,2]. However, these two types of matter, which represent distinct mass classes (≈10 μg and ≈100 kg respectively), seem to sample different reservoirs, as they are dominated by different types of extraterrestrial matter. The dust is mostly related to the CM-type chondrites [3], which are rare among meteorites that are otherwise dominated by ordinary chondrites (OCs) [2]. To quantify the contribution to the interplanetary dust by OC parent bodies, we have studied 427 particles from the 100–400-μm size fraction of dust recovered from Antarctic ice [4], 303 of which were found to be of extraterrestrial origin. Of these, 41 (≈13.5%) are cosmic spherules (CSs), 136 (≈44.9%) scoriaceous micrometeorites (MMs), 65 (≈21.5%) consist of dehydrated phyllosilicates, 11 (≈3.6%) consist mainly of phyllosilicates, and 50 (≈16.5%) are coarse-grained crystalline MMs.

Phase compositions of the crystalline MMs suggest a close relationship between these MMs and CM-type carbonaceous chondrites [e.g., 3]. Low-Ca pyroxenes and olivines are rich in Mg, Cr, and Mn, typical for carbonaceous chondrite phases [e.g., 5]. Only three crystalline MMs (≈1% of the total extraterrestrial particle population) have phase compositions that are compatible with derivation from an OC precursor: Particle M6 (≈200 μm diameter) has a porphyritic texture with olivine ($Fa_{18.7}$) and low-Ca pyroxene ($Fs_{16.6}$, $Wo_{0.6}$) in a fine-grained matrix. Micrometeorite AM1 (410 μm long) has also a porphyritic texture with olivines ($Fa_{16.2}$) set in a fine-grained, clinopyroxene-bearing matrix. Particle Mc7/10 (150 μm long) has a granular mosaic texture of intergrown olivine ($Fa_{17.6-19.8}$), low-Ca pyroxene ($Fs_{14.1-16.3}$, $Wo_{\approx 1.2}$), and plagioclase (An_{14}), with very little intergranular matrix. Minor-element contents of olivines in all three particles are low (CaO <0.05 wt%, Al_2O_3 <0.05 wt%, TiO_2 <0.05 wt%, Cr_2O_3 <0.05 wt%, NiO <0.02 wt%). The FeO/MnO ratios in olivine vary between 33 and 49, comparable to those of H-chondrite olivines [e.g., 6]. Two of the three particles were also analyzed by INAA [3]. Their trace-element abundances match those of ordinary chondrites [e.g., 7].

We conclude that the three particles M6, AM1, and MC7/10 are related to H chondrites, and thus are likely to represent an asteroidal belt contribution to the interplanetary dust population. The abundance of OC-like dust is very low (1%), and up to now limited to H-chondritic particles, two equilibrated and one unequilibrated.

Acknowledgments: This work was supported by FWF (project P10688-GEO).

References: [1] Brownlee D. E. (1981) in *Comets and the Origin of Life* (C. Ponnamperuma, ed.), 63–70. [2] Dodd R. T. (1981) *Meteorites.* [3] Kurat G. et al. (1994) *GCA, 58,* 3879–3904. [4] Maurette M. et al. (1991) *Nature, 351,* 44–47. [5] Steele I. M. (1986) *GCA, 50,* 1379–1395. [6] Brandstätter et al. (1985) *Ann. Naturhist. Mus. Wien, 87A,* 11–20. [7] Wasson J. T. and Kallemeyn G. W. (1988) *Philos. Trans. R. Soc. Lond., A325,* 535–544.

ANGRITES: A VOLATILE-RICH VARIETY OF ASTEROIDAL BASALT (EXCEPT FOR ALKALIS AND GALLIUM!).

P. H. Warren[1,2] and G. W. Kallemeyn[2], [1]Mineralogical Institute, Graduate School of Science, University of Tokyo, Tokyo 113, Japan, [2]Institute of Geophysics, University of California, Los Angeles CA 90024, USA.

Angrites are commonly viewed as extremely volatile depleted, and a related notion is that they formed by differentiation of a very CAI-rich material [e.g., 1]. Partial melting experiments reportedly reproduce the bulk compositions (although not fassaite-rich mineralogy) of angrites with Allende as starting material [2], but highly CAI-rich parent materials are difficult to reconcile with isotopic and REE data [3,4]. Mittlefehldt and Lindstrom [5] inferred from the low Na/Al ratios of angrites that outgassing, and thus primordial magmatism, was more intense on their parent body than on the eucrite parent asteroid.

Of seven elements that (1) have been adequately determined in angrites, and (2) are far more volatile (solar-nebula 50% condensation T [6] ≈ 690–430 K) than the alkalis (1000–910 K), four are enriched, and none is significantly depleted, in average angrite compared to average eucrite or low-Ti mare basalt (Fig. 1). Gallium, which is of intermediate volatility (830 K), is depleted to roughly the same extent as Na and K. Results for Asuka 881371 [3] are incomplete (Zn, 6 μg/g, is near INAA detection limit), but even based only on Angra dos Reis and the two Lewis Cliff angrites, this pattern seems firmly established. Apparent gas cavities in Asuka 881371 [7] also suggest that volatiles are far from uniformly depleted.

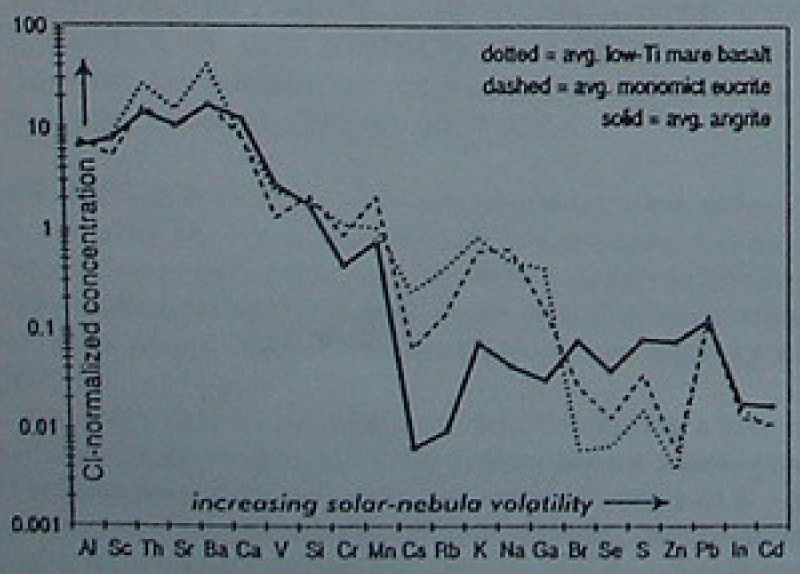

Fig. 1.

The only elements known to be depleted, as volatiles, by clearly significant factors in angrites vs. eucrites or lunar basalts, are alkalis plus Ga. Besides being moderately volatile, a noteworthy characteristic shared by Ga and alkalis (and not shared with elements such as Br, Se, and Zn) is that these elements probably tend to partition into crustal feldspar during gross differentiation of small (low-pressure) bodies. If Ga + alkalis were depleted by a single process starting from "normal" chondritic material, that process would seem to require selective exposure of a feldspar-enriched region (i.e., crust) to extremely high temperature. Igneous crystallization of the angrites occurred when the solar system was still extremely young, and apparently ≤2 Ma after the volatile-depletion process [4]. The data of [4] eliminate ^{26}Al as a potential heat source for magmatism. The angrite volatile pattern may be the product of heating by an intense, short-lived heat source that melted and partially vaporized the crust of an asteroid(s) (not necessarily the final angrite asteroid), without really affecting the deep interior(s), which later (through mixing and/or magmatism) replenished the angritic materials in most volatiles, but not alkalis and Ga. Exogenic heating, as in the often-conjectured (but hard to test) hypothesis that a major early heat source was enhanced solar luminosity (as in FU Orionis cycles), would seem to be required. Lewis Cliff 87051 and Asuka 881371 are rich in compositionally diverse olivine xenocrysts, and Asuka 881371 contains a possible FeS xenocryst [7]. These, and the angrites' great siderophile diversity [3], tend to suggest that magmatism and intensely disruptive cratering (with mixing of precursor materials) were contemporaneous. This scenario is admittedly speculative, but the volatile-depletion pattern is difficult to rationalize with any other model.

References: [1] Prinz M. and Weisberg M. (1995) *Antarc. Meteorites, XX,* 207–210. [2] Jurewicz A. et al. (1993) *GCA, 57,* 2123–2139. [3] Warren P. et al. (1995) *Antarc. Meteorites, XX,* 261–264. [4] Lugmair G. and Galer S. 1992) *GCA, 56,* 1673–1694. [5] Mittlefehldt D. and Lindstrom M. (1990) *GCA, 54,* 3209–3218. [6] Wasson J. (1985) *Meteorites.* [7] Warren P. and Davis A. (1995) *Antarc. Meteorites, XX,* 257–260.

SIDEROPHILE TRACE ELEMENTS IN ALLAN HILLS 84001 AND OTHER ACHONDRITES: A TEMPORAL INCREASE OF OXYGEN FUGACITY IN THE MARTIAN MANTLE?

P. H. Warren[1,2] and G. W. Kallemeyn[1], [1]Institute of Geophysics, University of California, Los Angeles CA 90024, USA, [2]Mineralogical Institute, Graduate School of Science, University of Tokyo, Tokyo 113, Japan.

We have employed neutron activation, including radiochemical NAA, to investigate SNC/martian meteorites ALHA 77005, ALH 84001, and LEW 88516, along with 15 eucrites. Our data for 10 manifestly monomict eucrites confirm previous indications [e.g., 1] that compositionally pristine eucrites are generally extremely siderophile poor, although for several of the most extremely siderophile-depleted eucrites we find slight enhancements in Re/Os (Fig. 1). Our RNAA data are the first for highly siderophile elements in polymict eucrites, and show a broad similarity with lunar polymict breccias.

In general, our data (e.g., Ga/Al ≈ 4.3×10^{-4}) confirm SNC affinity [2] for ALH 84001. However, siderophile concentrations are, by SNC standards, extraordinarily low: Ni ≈ 5.8 μg/g and (in pg/g) Au ≈ 9.4, Ir ≈ 80, Os ≈ 10.2, and Re ≈ 1.66 ± 0.25(1σ); Ge (1080 ng/g) is typical for SNCs. Like terrestrial basalts [1], other SNCs have relatively constant Re, ranging from 28 (Lafayette [3]) to 102 pg/g (ALHA 77005) among seven analyzed meteorites of various types, in which Os ranges from <2.3 to 4400 pg/g. A plot of Os vs. Re/Os (Fig. 1) shows that ALH 84001 has 23× lower Re than expected for a young SNC of similar Os content.

On Earth, Re generally behaves as a mildly incompatible element, whereas Os behaves as a strongly compatible element. A plausible explanation for this divergence [1] is that Re is more prone to enter higher oxidation states, such as Re^{4+}, which would tend to behave like W^{4+}. This model is