EPSC Abstracts,
Vol. 4, EPSC2009-302, 2009
European Planetary Science Congress,

Meteoroid Sulfur and Iridium-group Elements in the Earth's Upper Mantle

M.Maurette

CSNSM, Bat. 108, 91405 Orsay-Campus, France (maurette@csnsm.in2p3.fr),

Abstract

Meteoroids that survive upon atmospheric entry can be collected as Antarctic micrometeorites. (*AMMs*). Their analyses allow predicting the total burdens of sulfur and refractory highly siderophile elements (*HSEs*) delivered to the Earth by meteoroids, in the early post–lunar eon. They well fit the corresponding measured burdens stored in the primitive upper mantle (*PUM*). This fixes new constraints on the functioning of the Earth's mantle, the formation of the core and outer core of the Earth, and the early heavy bombardment of the Earth–Moon system.

A Meteoroid Accretion Equation

About 99% of the total mass of meteoroids accreted by the Earth has been delivered during the first ~200 Ma of the post–lunar eon [1, 2]. The measured peak of the meteoroid mass distribution corresponds to meteoroids with sizes of about 100–200 µm. Those that survive upon atmospheric entry can be collected as unmelted *AMMs*, and about 99% of them are related *(but not strictly similar)* to the hydrous-carbonaceous chondrites. The total amount, **M**(**A**), of a given meteoroid species, **A**, delivered to the Earth since the formation of the Moon, is given by an "accretion" equation [1, 2]:

$$\mathbf{M}(\mathbf{A}) \sim [\mathbf{A}(\text{wt.\%}) / 100] \times \mathbf{\Phi_0}(\boldsymbol{t_0})$$

where **A**(wt.%) and $\mathbf{\Phi_0}(\boldsymbol{t_0})$ are, respectively: – the mean wt.% concentration of species, **A**, measured in AMMs, which was invariant with time; – the integrated meteoroid mass flux (~5.6 x 10^{24}g) since the formation of the Moon by the last planetary embryo to merge the Earth, at time $\boldsymbol{t_0}$ ~4.44 Ga [1, 2]. The largest uncertainty on **M**(**A**) is attached to $\mathbf{\Phi_0}(\boldsymbol{t_0})$. However, relative abundances (*e.g.*, the S/Ir, Os/Ir and Ru/Ir ratios), just scale as the ratios of the corresponding concentrations in AMMs, which are measured with the accuracy of modern analytical techniques (i.e., within 10%). I next focus on S, Os, Ir and Ru in *PUM* (*c.f.*, Ref. 3 for a definition). Sulfur is a volatile element whereas Os, Ir, and Ru (Ir–group) are refractory *HSEs*, which show an equal and extremely strong affinity for sulfide melts.

Meteoroid S, Os, Ir and Ru in *PUM*

Long–term functioning of the Earth's mantle

The mean concentrations of sulfur (5%), Ir (620 ppb), Os (590 ppb) and Ru (1240 ppb) in *AMMs* are given in Refs. 4 (sulfur) and 5 (Os, Ir, Ru). The accretion equation yields the total burden of each meteoroid species accreted by the Earth during the post-lunar Hadean Eon. The Earth's mantle is composed of an upper and lower mantle, with masses of about 10^{27}g and 3 x 10^{27}g, respectively. Two conflicting conjectures have been proposed for its functioning. For Richter [6], there is no convection between the two mantles and meteoroid species scavenged to *PUM* will be confined into it. In the other conjecture [7], there is a coupling between the two mantles, and meteoroid species introduced in *PUM* would be redistributed into the whole mantle. If these species were confined in *PUM***,** the predicted concentrations of S, Ir, Os, and Ru would be about 280 ppm, and 3.4, 3.3, and 6.9 ppb, respectively. They well fit the corresponding observed *PUM* values of about 254 ± 30 ppm for sulfur (*c.f.*, Ref. 8, p. 1259), and 3.5 ± 0.4, 3.9 ± 0.5 and 7.0 ± 0.9 ppb, for Ir, Os and Ru, respectively [3]. Therefore, they would invalidate the second conjecture that predicts 4x smaller concentrations.

Formation of the Earth's core and outer core

With the Richter's conjecture there is no discernable excess of S, Ir, Os and Ru in *PUM* with regard to the values expected from the meteoroid flux effective since the formation of the Moon. Consequently, the scavenging of these elements to the lower mantle and/or iron core of

EPSC Abstracts,
Vol. 4, EPSC2009-302, 2009
European Planetary Science Congress,

the Earth had to be very efficient during the pre–lunar period as to leave a clean "niche" in the upper mantle, which could be subsequently fully loaded with the post-lunar meteoroid burden of S, Os, Ir and Ru. This "super–cleaning" was possibly related to the enhanced impact activity of ≥ 10 km–size impactors and/or the Moon forming impact. This fit would exclude (for at least S, Ir, Os and Ru), inefficient core formation and/or addition of material from the outer core.

Previous Chondritic "Veneer" Models

The previous popular models quoted in Ref. 3, have attributed *HSEs* in *PUM* to veneers of large chondritic impactors that imprinted their signature on the Moon as both lunar cratering rates and a CM–type chondritic contamination (*c.f.*, Ref. 2, p. 94). They have been interpreted either as a late spike of impactors during the "Late Heavy Bombardment" (LHB; 4.0–3.8 Ga), or as an earlier exponentially decaying flux of left–over planetesimals during the "Early Heavy Bombardment" (EHB; 4.44–3.8 Ga) of the Earth–Moon system. It was further stated that "*no known chondrite group perfectly matches the PUM composition*" in refractory *HSEs*. This is supported by the combination of chondritic (Os/Ir ~1.12 ± 0.09) and modestly suprachondritic (Ru/Ir ~2.03 ± 0.12) ratios in the Ir–group elements (i.e., relatively to CI chondrites), in both *PUM* and Apollo 17 impact breccias [3]. The chondritic composition had thus to be either reworked or delivered by new types of chondritic impactors.

An Early Meteoroid Veneer

This veneer was probably fed by collisions between comets in the "Debris–Disk" of the Sun (*c.f.*, Ref. 2, p. 104). Greaves [9] first suggested that "*the debris phase might be analogous to Earth's early period with a high impact rate called the heavy bombardment*". It yielded the right budget of both volatile species in the global Earth's atmosphere [1, 2, 10] and Ir–group elements in *PUM*, including Os/Ir and Ru/Ir ratios of about 0.95 (chondritic) and 2.0 (suprachondritic), respectively. These fits between meteoroid predictions and observations now include a wide variety of species (Ne, N_2, H_2O, CO_2, SO_2, Os, Ir, and Ru). They would invalidate late spike models, while strongly strengthening the EHB–type fast decay of relative lunar cratering rates with time conjectured by Hartmann [11], beyond ~4 Ga ago, which also scales that of the meteoroid mass flux in the meteoroid model (*c.f.*, Ref. 1, section 4.2).

Summary and Challenges

The good predictions of the meteoroid model are still hard to believe. Nevertheless, they well support the robustness of the *PUM* estimate of Becker et al [3], which is still challenged. The S/Ir ratio looks promising. Its values (relatively to the CI ratio) are very similar in *PUM* (**0.62**) and AMMs (**0.69**), but clearly different in CM (0.39), CV (0.26), CR (0.24), H (0.22), EH (0.84) and EL (0.47) chondrites. Lorand [13] noted: "*an objection to your model is that one should see a mass independent isotopic fractionation of ^{33}S and ^{36}S, due to photolysis in the atmosphere. But diamonds of peridotic inclusions, which represent the Archean mantle, do not show this effect, yet*". Could this objection turn to support the meteoroid model?

References

[1] Maurette M. (2009) Forthcoming. Hydrous-Carbonaceous Meteoroids in the Hadean Eon. *ASP Conf. Series*.

[2] Maurette M. (2006) In *Comets and the Origin and Evolution of Life*, eds. Thomas P.J. et al. New-York: Springer-Verlag. pp. 69–111.

[3] Becker H. et al. (2006) *GCA*, 70, 4528–4550.

[4] Duprat J. et al. (2007) *Adv. Space Res.*, 39, 605.

[5] Kurat G. et al. (1994) *GCA*, 58, 3879–3904.

[6] Richter F.M. (1979) *JGR*, 84, 6783–6795.

[7] Van der Hilst R.D. et al. (1997) *Nature*, 386, 578–584.

[8] Morgan J.W. et al (2001) *Meteoritics & Planet. Sci.*, 36, 1257-1275.

[9] Greaves J.S. (2005) *Science*, 307, 68–71.

[10] Lefort M. and Maurette M. (2009) This issue.

[11] Hartmann W. K. (2003) *Meteoritics & Planet. Sci.*, 38, 579–593.

[12] Lorand J.P. 2008. Personal communication.