FE/MN/MG CONSTRAINTS ON THE BULK COMPOSITION OF THE EARTH

John Longhi and Sedelia R. Durand, Lamont-Doherty Earth Observatory, Palisades, NY 10964 (longhi@ldeo.columbia.edu)

The Fe/Mn vs. Fe/Mg diagram, as developed by Goodrich and Delaney [1] provides a useful discriminant of metal, volatile, and igneous fractionations in meteorites. Fractionations in chondrites produce a wedge-shaped area emanating from the origin of the Fe/Mn vs Fe/Mg plot that encloses all of the chondrite compositions, as well as "undifferentiated" meteorites [1] — meteorites whose source regions did not undergo a prior metal/silicate fractionation. Volatility-driven fractionations tend to produce near-vertical trends; metal/silicate fractionations produce inclined trends with positive slope; whereas igneous processes, which do not readily separate Fe from Mn, produce a horizontal trend.

Because Fe/Mn does not change appreciably during partial melting, a planet's basalts should retain the Fe/Mn of their source region, and if the planet has differentiated relatively simply, then where the line of a planet's basalt compositions crosses the wedge of chondritic compositions should mark the bulk silicate composition of the planet. Fig.1 illustrates the wedge of chondritic compositions along with the compositions of angrites, Martian and HED meteorites, and lunar basalts.

There are 2 types of composition plotted for each chondrite class. or individual: one is the composition of the silicate free of metal or sulfide (open letters — this composition is an analog for a mantle following core-formation; in the other all of the Fe is oxidized and contained within the silicates (filled letters). As expected, basaltic compositions from each parent body form linear arrays. SNC and HED meteorites have similar Fe/Mn, but lunar basalts and angrites are each distinct. The range of Fe/Mg for "simple" SNC and HED mantle s is 0.13 to 0.28; these values translate to silicate Mg' (Mg/(Mg+Fe) values of 0.88 to 0.78.

Fig. 2 shows the compositions of terrestrial basalts, komatiites, and peridotites in relation to the chondritic wedge. In view of the giant impactor hypothesis [2] it is perhaps not surprising that the range of Fe/Mn for terrestrial igneous rocks (0.44 – 0.70) overlaps extensively with the range of the Moon (0.65 – 0.95). Consequently, the array of terrestrial compositions intersects the chondritic wedge between 0.80 and 0.62. Although the precise value of terrestrial Mg' is not tightly constrained, it is well below the range of typical estimates of the upper mantle Mg' (~0.89 -[3,4]), and is even beyond the range of the more extreme proposed values for the lower mantle (~0.85 [5]).

Such an extreme composition that is well beyond the range of careful analysis suggests that some assumptions are wrong. Most likely is the implicit assumption that terrestrial Fe/Mn fractionations were similar to the meteoritic fractionations. Perhaps there was a pressure or temperature regime in the early earth (a magma ocean?) where fractionation of some low Fe/Mn phase(s) could have raised the Fe/Mn ratio from 0.2 to 0.6. Mn is more volatile than Fe, so volatile loss (giant impact?) would increase Fe/Mn. However, by all estimates Mars is less depleted in volatile elements than the Earth [6], yet Fig.1 shows Mars' mantle to have a lower Fe/Mn. Melt extraction produces minimal change in Fe/Mg. Experiments by [7] have shown that Mn remains much less siderophile than Fe at high temperatures and pressures. Silicate–liquid and oxide-liquid partition coefficients determined for likely high-pressure magma ocean liquidus phases [8] predict that crystallization of an assemblage of magnesian perovskite and ferropericlase actually decreases Fe/Mn and increases Fe/Mg in the remaining magma ocean. The one recognized process that has the capacity to increase Fe/Mn and decrease Fe/Mg is olivine floatation-accumulation [9], although the capacity to increase Fe/Mn by olivine flotation alone is limited. One additional process may have been operative in a deep magma ocean. If convective turbulence [10] was vigorous enough to suspend Mg-perovskite and transport it upward to depths where olivine was stable, then the upper mantle would become enriched not only in an olivine component, but also a resorbed perovskite component in the liquid. Although new Ni and Co partitioning data [11] have eased some of the objections to olivine accumulation, the permissible amount is not likely to account for an increase in Fe/Mn from 0.2 to 0.6, which is what is needed to allow the Earth to be a mixture o chondrites with a bulk silicate Mg' of 0.89.

REFERNCES

[1] Goodrich C. A. and Delaney J.S. (2000, *GCA 64*, 149-160. [2] Canup R. and Asphaug E. (2001) *Nature 412*, 708-712. [3] Hart S.R. and Zindler A. (1986) *Chem. Geol.* **57**, 247-267. [4] McDonough W.F. and Sun S.-S. (1994) *Chem. Geol. 120,* 223-253. [5] Lee K.K.-M., O'Neill B., Panero W.R., Shim S.-H., Benedetti L.R., and Jeanloz R. (2004) [6] Dreibus G. and Wänke H. (1985) *Meteoritics, 20*, 367—382. [7] Chabot N. and Agee C.B. (2003) , *GCA 67*, 2077-2091. [8] Walter M.J., Nakamura E., Tronnes R.G., and Frost D.J. (2004) *GCA 68*, 4267-4284. [9] Agee C.B. and Walker D. (1988) *EPSL 90*, 144-156.[10] Solomatov V.S. (2000) in Origin of the Earth (ed. Canup and Righter) pp. 323-338. [11] Longhi J. and Walker D. (2006) *Lunar and Planetary Science XXXVII,* Abstract #2452, LPI, Houston.

Fig. 1&2. Fe/Mn/Mg relationships in meteorites and planetary basalts