CHONDRULE AND METAL SIZE-SORTING IN ASTEROIDAL REGOLITHS: EXPERIMENTAL RESULTS WITH IMPLICATIONS FOR CHONDRITIC METEORITES

Glen Akridge and Derek W. G. Sears, Cosmochemistry Group, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, Arkansas 72701, USA. E-mail: cosmo@cavern.uark.edu

Chondritic meteorites have unique chondrule and metal abundances and sizes. This metal-silicate fractionation has been generally attributed to localized processes occurring in the solar nebula prior to accretion. We have been exploring the possibility that asteroidal heating can liberate trapped volatiles creating a dynamic regolith in which particles can separate based on size and density characteristics. Laboratory measurements in which a gas is passed upwards through a bed of simulated regolith indicate that metal grains can remain suspended in the gas longer which creates a metal-rich zone near the surface. This fractionation of metal from silicate (chondrules) can explain the chondrule and metal abundances in chondrites and may have implications for undifferentiated asteroids which based on spectral data appear to possess metal-rich surfaces.

Metal-Silicate Sorting:

The fact that chondritic meteorites contain unique Fe oxidation states and abundances was demonstrated by Urey and Craig [1] nearly a half century ago. Since then particle size analyses have also shown that chondritic meteorites can also be distinguished by their chondrule and metal grain sizes (Table 1). Chondrites, with their unmelted textures, appear to have undergone a fractionation process in which metal and silicates (chondrules) could be separated without parent body melting. Aerodynamic sorting in the nebula has been the most popular scenario [2-4] but remains highly speculative and difficult to test experimentally. Models proposing nebula sorting typically require high gas densities and nebula-wide movement of solids to obtain the proper particle size ratios observed in meteorites [5].

We have been exploring the possibility that metal-silicate sorting may have occurred in the surface dust layers of accreting volatile-rich planetesimals [6]. Release of volatiles (H_2O) from impact or radiogenic heating could mobilize regolith material by aerodynamic drag on particles. The upward flow of gas can sort particles based on size and density and is similar to the industrially important process known as fluidization [7]. Fluidized size-sorting is believed to be occurring in the expanding gas cloud of pyroclastic flows giving rise to well sorted deposits [8].

	H	L	LL	EH	EL
chondrule diameter, mm	0.3	0.7	0.9	0.25	0.5
metal diameter, mm	0.19	0.16	0.14	0.04	0.1
chondrule abund. vol%	~70	~70	~70	~30	~30
metal abund. wt%	16	7	2.4	22	18

Data from [3] and [9-10].

Table 1. Metal-Chondrule Data for Chondrites.

Experimental Procedure:

Experiments were carried out in a Plexiglas tube 2.5 cm in diameter and 80 cm in length (Figure 1). Air was passed upwards through the column containing various mixtures of particulate material (primarily quartz sand and iron powder). In-line flow meters were used to measure air velocities between 0-195 cm/s. A diffuser containing packed cotton was constructed in order to distribute air evenly upon entrance into the tube. A water manometer measured the pressure drop across the bed. Ten access holes each with a diameter of 6 mm were placed vertically along the column at approximately 15 mm intervals. The holes allowed removal of material for analysis after each fluidization run. Particle abundance and sizes were determined for each removed sample. Abundances in each removed sample was determined by magnetically removing iron from quartz and subsequent weighing of each fraction. A mean quartz grain size was determined by weighing 100 grains and assuming spherical geometry. Fluidized runs typically required 0.5-2 minutes of gas flow for segregation to occur.

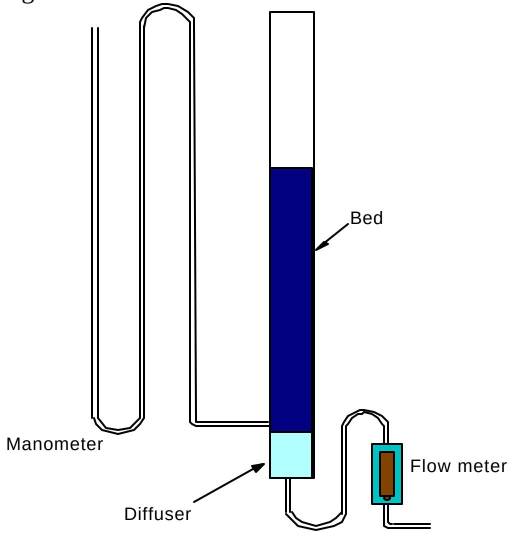

Figure 1. Schematic of Fluidization Apparatus.

Results for Metal-Silicate Fractionations:

Fluidization runs were carried out using quartz sand and iron as analogs for chondrules and metal grains. For typical engineering applications sorting occurs when the denser component sinks in the bed. For chondritic abundances the denser component (iron) actually rises in the bed forming a iron-rich layer near the surface (Figure 2). Maximum segregation occurs during the terminal phases of degassing when the gas flow is sufficient to fluidize the smaller iron grians but not the larger quartz grains. If the quartz to iron size ratio is >3.5 the gas flow can carry the iron grains upward through the pore spaces of the quartz. If the size ratio is comparable (<2) iron becomes jetsam. For L, LL, EL, and EH chondrites the large size ratio between chondrule and metal grains indicate that metal probably behaves as flotsam. H chondrites have a similar chondrule to metal size ratio and may be the result of mixing processes.

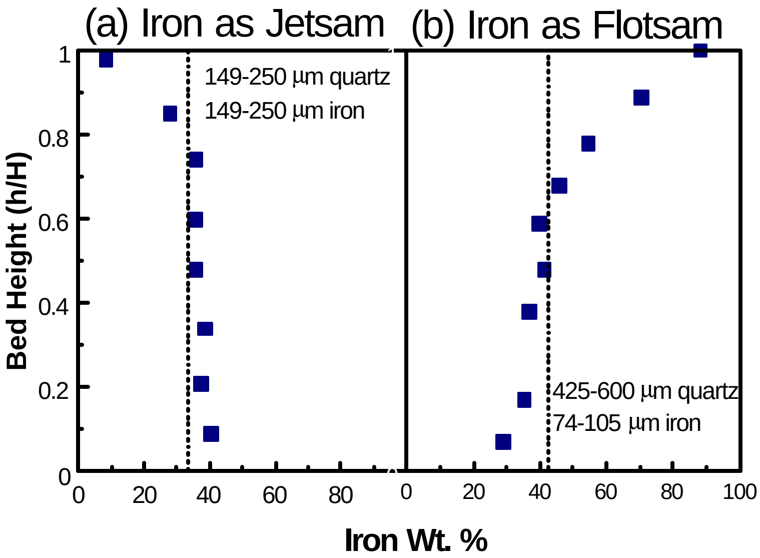

Figure 2. Bed sorting for chondritic analogs. (a) When particle sizes are similar fluidization results in the denser (iron) particle traveling downward (jetsam) in the bed resulting in an iron-poor surface. (b) When particles of large size difference are placed in the bed iron travels upward (flotsam) forming an iron-rich surface layer. Particle size ratios similar to experiment (b) occur in chondritic meteorites. Dashed vertical line represents the mean iron wt.% of the bed.

Results for Size Sorting:

We have also examined the potential for fluidization to segregate particles of similar densities but differing diameters. Figure 3 shows a fluidization run for chondritic analogs of appropiate size, density, and abundance. There appears to be only a slight trend toward larger quartz grain size with depth in the bed despite the wide range of sizes. The behavior of iron in this case is similar to Figure 2b in which it becomes concentrated in the upper parts of the bed. The size-sorting occurring between quartz and iron but not within individual quartz grains may indicate that chondrule sizes were determined prior to fluidized segregation of the iron. Thus the ordinary chondrite classes, with their distinct chondrule sizes, must originate from different parent bodies or at least from differing locations on the same parent body. Our experiments suggest that chondrules would experience only minor size-sorting as a result of a degassing event on the parent body, although metal grains can be efficiently segregated near the surface of the parent body.

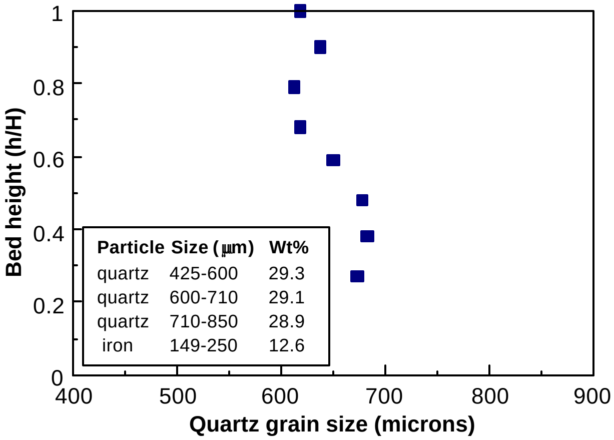

Figure 3. Mean size for quartz grains after fluidization run. There is a slight tendency for increasing quartz grain size with depth in the bed. In this run, iron grains concentrated near the surface of the bed similar to Figure 2b.

References:

[1] Urey H.C. and H. Craig (1953) *GCA* 4, 36-82. [2] Whipple F. (1972) *From Plasma to Planet, Nobel Symp. 21*, pp. 211-232, John Wiley. [3] Dodd R.T. (1976) *EPSL* 28, 479-484. [4] Rubin A.E. and K. Keil (1984) *Meteoritics* 19, 135-143. [5] Liffman K. *et al.* (1997) *Icarus*, submitted. [6] Huang S. *et al.* (1996) *JGR* 101, 29373-29385. [7] Kunii D. and O. Levenspiel (1991) *Fluidization Engineering*, Butterworth-Heinemann. [8] Wilson C.J.N. (1984) *J. Volcan. Geotherm. Res.* 20, 55-84. [9] Grossman J. *et al.* (1988) *Meteorites and the Early Solar System*, pp. 619-659, Univ. Arizona Press. [10] Jarosewich E. (1990) *Meteoritics* 25, 323-337.