THE ORIGIN OF CHONDRITES: METAL-SILICATE SEPARATION EXPERIMENTS UNDER MICROGRAVITY CONDITIONS - II.

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Introduction: Chondrites are categorized into different groups by several properties, including the metal-to-silicate ratio[1]. Various processes have been suggested to produce distinct metal/silicate ratios, some based on sorting in the early solar nebular [*e.g.*, 2] and others occurring after accretion on the parent body. Huang *et al.* [3] suggested that a weak gravitational field accompanied by degassing, could result in metal/silicate separation on parent bodies.

We suggest that asteroids were volatile-rich, at least early in their histories. Spectroscopic evidence from asteroid surfaces indicates that one-third of all asteroids maybe rich in clays and hydrated minerals, similar to carbonaceous chondrites [4,5]. Internal and/or external heating could have caused volatiles to evaporate and pass through a surface dust layer [3]. Spacecraft images of asteroids show they have a thick regoliths [6,7]. Housen [8] and Asphaug and Nolan [9] proposed that even a 10 km diameter asteroid could potentially have a significant regolith. Grain size and grain density sorting could occur in the unconsolidated layer by the process known as fluidization. This process occurs when an upward stream of gas is passed through a bed of particles which are lifted against a gravitational force. Fluidization is commonly used commercially to sort particulates [10]. This type of behavior is based upon the bed, as a whole, and differs from aerodynamic sorting [11].

Two sets of reduced gravity experiments were conducted during parabolic flights aboard NASA's KC-135 aircraft. The first experiment employed 310 tubes of 2.5 cm diameter, containing mixtures of sand and metal grains. A gas source was used to fluidize the mixture at reduced gravity conditions and mixtures were analyzed after the flight [12]. However, this experiment did not allow a description of the fluidization as a function of gravity. A second experiment was conducted on the KC-135 aircraft in the summer of 2001, consisting of two Plexiglas cylinders containing a metal/silicate mixture, and video cameras to record the experiment on tape. Here we summarize this experiment and discusses the implications for metal-silicate separation on asteroid bodies.

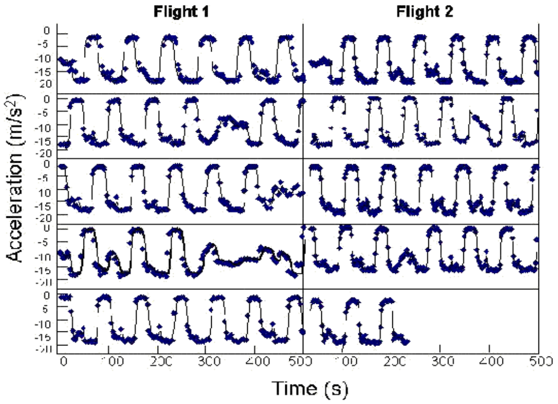

Fig. 1. Accelerometer data for the KC-135 flights demonstrating the actual trajectories achieved. With a few exceptions, the parabolas were remarkably reproducible.

Experimental Methods: Two Plexiglas cylinders, 14 cm in diameter and 35 cm long, were about one-quarter-filled with a mixture of 90 vol % sand (~450 µm grain size) and 10 vol % iron filings (~100 µm grain size). The behavior of the beds under microgravity conditions was recorded with fixed and hand-held digital cameras. Air flow could be conducted through the bed from a diffuser at the base of the cylinder. A gas cylinder provided the air supply through a flow meter and valve. A one-way valve in the top of the cylinder prevented a build-up of pressure in the cylinder. The whole apparatus was enclosed in a Plexiglas dust cabinet. An accelerometer attached to a graphing calculator recorded the effective gravity throughout the flight. The apparatus was flown on two flights.

We cannot fully calibrate our data to fluidization calculations, because the accelerometer was not visible on the tape, and thus the accelerometer data cannot be exactly correlated with the fluidization phases.

Results: In Earth gravity experiments, the same sand/metal mixture was sorted during fluidization, with metal grains being conveyed to the top of the bed [10].

Accelerometer data was collected on 34 parabolas on the first flight and 30 on the second. The accelerometer data showed that the parabolas were reproducible (Fig. 1). Useful images of the beds were obtained for 42 parabolas; instrumental difficulties prevented data being obtained for the others. The behavior of the beds was also very reproducible for 42 recorded parabolas and is summarized in Fig. 2.

Phase 1 (Fig. 2a). Under positive gravity, no changes occurred in the bed. The gas flow was insufficient to cause any motion in the sand-iron mixture.

Phase 2 (Fig. 2b and 2c). Under microgravity, there was considerable activity in the bed. In cases where air was allowed to flow upwards through the bed, the surface bubbles as if boiling. During this process, metal segregates from the mixture, rising to the surface. The turbulence often had a wavelike motion, and there was a central "spouting" of metal-rich material on the surface and often the mixture exhibited a right-hand rotation.

In cases where there was no flow of air through the beds, there was no increase in bed volume, no fluidization effects, and no segregation of metal and silicate.

Phase 3. (Fig. 2d) During the period of negative gravity, material was violently thrown towards the top of the cylinder and agitated. Some mixing of silicates and metal occurred.

Phase 4. At the end of the period of negative gravity, the bed abruptly fell to the bottom of the container. In a significant number of instances the segregation produced in Phase 3 survived the major mixing episode of negative gravity and metal was enriched on the surface.

This experiment showed that metal/silicate separation occurred during fluidization under reduced gravity conditions with results similar to those at earth gravity. However, metal/silicate fractionation was not seen for experiments without gas flow.

Fluidization is attained at a lower minimum fluidization velocity in reduced gravity conditions. Our results agree with previous work showing that only one-half to one-third of the gas flow needed on Earth was required to fluidize a lunar-like regolith at one-sixth earth gravity [13]. This could imply that fluidization is easily achievable on the surfaces of asteroids, making metal/silicate fractionation by this mechanism very probable.

Conclusions: We find that metal/silicate separation occurs readily in microgravity, with finer-grained metal grains transported to the surfarce when in a mixture with coarser-grained sand, with sizes of each similar to metal and chondrules, respectively, in ordinary chondrites.

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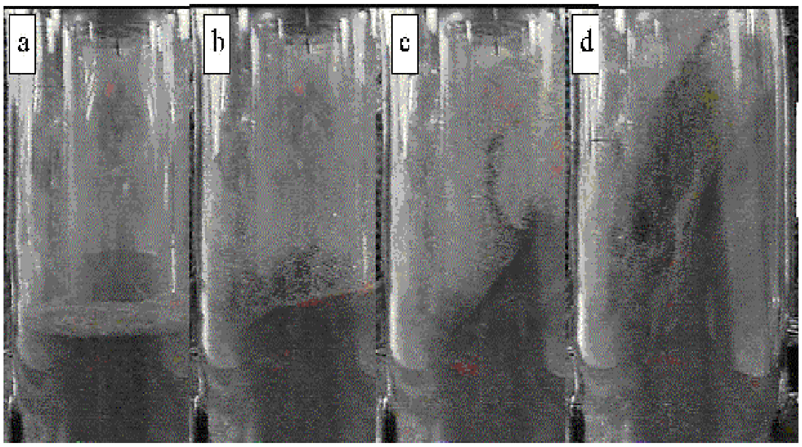

Fig. 2. One of the experimental beds through a cycle of (a) positive gravity, (b) microgravity, (c) transitioning from microgravity to negative gravity and (d) negative gravity while air flows vertically through the beds from below.