FLUIDIZATION FROM CONTINUOUS OUTGASSING AS A CAUSE OF GEOLOGICAL STRUCTURES ON 433 EROS. J. D. Haseltine[1,2], M.A. Franzen[1,3], D.W.G. Sears[1,3]. [1]Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR 72701, [2]Abilene Christian University, Abilene, TX 79699, [3]Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701.

Introduction: The Near-Earth Asteroid Rendezvous (NEAR) mission was launched in 1996 and went into orbit around Eros on February 14th 2001. It orbited for one year during which it performed photoreconnaissance (with a resolution of 1m/pixel) and a variety of scientific observations.

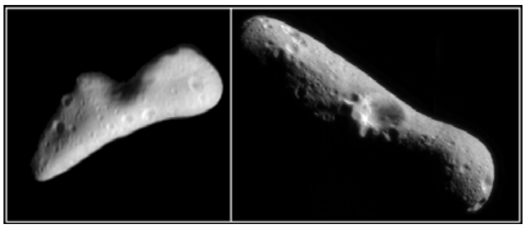

Fig. 1 Eros from orbit, taken by NEAR Shoemaker

Several notable features were found on the surface the asteroid, probably the most interesting being the ponded craters that were discovered in the equatorial regions. These ponded craters appear to be impact craters that were subsequently partially filled with fine grained regolith. The ponded regolith is much younger than the crater itself, implying an impact-independent process for pond creation.

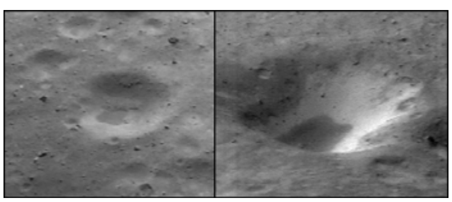

Fig. 2 Ponded craters on Eros

Particle sorting can be seen in the regolith lining of craters closer to the asteroid poles. Seismic shaking, electrostatic levitation, and fluidization have been suggested as explanations for ponding and particle sorting.

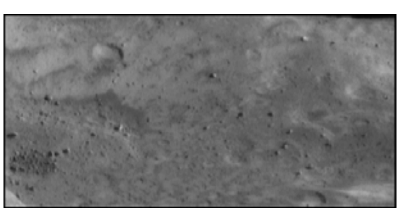

Fig. 3 Particle sorting on Eros

Still other craters show streaks of clearly differentiated particle size materials. Similar streaks have been found on the surface of Mars. It is theorized that on Mars, these streaks are caused by the sorting of particles due to wind. On an asteroid such as 433 Eros, possible explanations include solar wind or gas flow during fluidization.

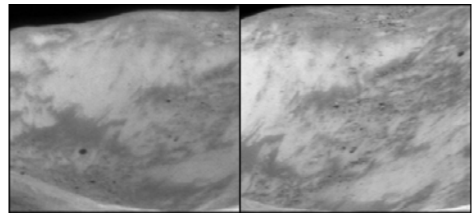

Fig. 4 Differentiated streaks on Eros

Orbital History 433 Eros was originally a main belt asteroid. Its current near-Earth orbit has a lifetime of typically only ~10^7 years, implying that Eros has been in its present orbit for less than 10^7 years. The black body temperature of a main belt asteroid of Eros' size and mass is –81°C at 2.25 AU from the sun. When Eros entered an orbit between 1.13 and 1.73 AU, this would increase to -35°C. Fluidization could have begun at approximately the time Eros entered its new orbit. The density of Eros suggests that it could be composed of up to ~40% subsurface water, if we assume negligible porosity. The range of volatile flow rates for an asteroid of ~10 km radius is .1-1 mm/s [2]. A 40% mass percentage of subsurface water fluidizing between these rates would be enough to continue fluidization until the present. It is the purpose of this abstract to examine experimental data found in attempts to recreate geological structures found on Eros through the fluidizing of regolith.

Experimental Procedure: Using the Andromeda environmental chamber, we have performed experiments to explore the effects of subsurface volatiles emerging from inside the asteroid. Ice, water, and nitrogen gas were used as subsurface volatiles, buried at varying depths in a low-density soil simulant with a variety of grain sizes 500-50 μm. A room temperature air atmosphere was pumped down to < 4 torr (as low as < 2 torr), which caused the volatiles to fluidize through the regolith. Video cameras were placed in the chamber to monitor the fluidization process, and photographs were taken of the final results.

Results:

Ice: Experiments were initially performed using 20 g of de-ionized water ice, buried at a depth of 9 cm in a large container holding 18 cm of regolith. During these experiments, small bubbles appeared above the buried ice, continuing for up to thirty minutes. When fluidization stopped, the experiment was continued for up to twenty minutes. The chamber was then opened to reveal particle sorting in the fluidized areas.

Fig. 5 Particle sorting resulting from the evaporation of ice compared with particle sorting in crater on Eros.

Water: 10 mL of de-ionized water was placed in a beaker and buried at 9 cm. Within the first ten minutes of the experiments, a single large outgassing was observed. This outgassing formed a crater centered on the location of the beaker. After the initial outgassing, fluidization began. Bubbling could be seen in the floor of the crater, similar to but often stronger than the bubbling seen with ice as the volatile. The resulting surface structure was a crater, formed by strong outgassing, with a fluidized pond, composed of smaller particles from the regolith, in the center.

Fig. 6 ***Ponded craters resulting from loss of water compared with a ponded crater on Eros.***

Nitrogen: In order to better understand the phenomena associated with the differing volatiles and to eliminate several uncontrolled variables such as phase transformations of water, nitrogen gas was also used as a volatile in some experiments. A gas feed was buried at varying depths, between 3 cm and 9 cm, and nitrogen was fed through the regolith between 1 mm/min and 5 mm/min. The preliminary behaviors of nitrogen as the volatile were similar to the strong outgassing observed during the initial stages of experiments using water. These strong geysers continued even with flow rates as low as 2 mm/min. Final observations revealed craters with centers devoid of smaller particles. On the slopes of the crater walls, differentiated streaks could be seen. The smaller particles were blown out by the outgassing, landed near the rim of the crater, and traveled back down the crater walls in separated streams, leaving a streak of lighter, smaller particles over the darker crater wall.

Fig. 7 ***Streaking as a result of nitrogen gas flowing through the surface compared with streaking on Eros.***

Discussion: Three distinct geological structures were observed by fluidizing regolith with volatiles in different states. The level of fluidization taking place was directly correlated to the rate and volume at which the volatile was flowing through the regolith. Nitrogen gas produced a much more violent fluidization process, resulting in a crater composed primarily of larger, heavier particles that were not thrown by the gas. Water as a volatile resulted in craters, but did not have the same effect on smaller particles. The lighter particles were fluidized by the gas instead of being ejected from the crater, thus forming a pond on the crater floor. In the case of ice, particle sorting was seen as the sublimated water vapor seeped upward. No crater was formed, as the gases in the water that caused the initial outgassing were also frozen and therefore had to sublimate before outgassing could occur.

Ponded craters have been identified on Eros in the equatorial regions, which are exposed to the sun for longer periods of time. Craters in the polar regions show signs of particle sorting, but not ponding. [1] The added heat from the sun on subsurface volatiles around Eros' equator could cause a more violent reaction than the fluidization at the poles, where the subsurface temperatures are significantly lower. The violent reaction causing differentiated streaking could be caused by high-velocity impacts on the asteroid surface, which would both heat and release the subsurface volatiles.

Conclusions: Initial experiments have shown that fluidization is a possible explanation for several observed geological structures on the surface of Eros, as structures were produced that are similar to those on Eros. More research needs to be conducted on the effect of fluidization on preexisting structures such as craters, valleys, and hills. A more in-depth study also needs to be performed on the effect of differing gas flow rates on the resulting structures, since preliminary results suggest that resultant structures are linked to the evaporation rate and state of the fluidizing volatile.

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References:

[1] M. S. Robinson, et al. Meteorit. Planet. Sci., 37 (2002). [2] S. Huang, et al. J.Geophys. Res., 101: E12 (1996). [3] M. S. Kareev, et al. Origins of 433 Eros ponds: Laboratory Investigations of Regolith Fluidization by Volatile Degassing (unpublished manuscript).