HEAT FLOW PROBE DEPLOYMENT IN LUNAR REGOLITH SIMULANT USING A PERCUSSIVE PENETROMETER.

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Introduction: Measuring internal heat flow (i.e., heat flow that originates deep within the interior of the Moon) is important since it tells us about the origin of the Moon and its compositon. If we know the age of the Moon, then the heat flow will reveal if it had a hot or cold origin. In addition, heat flow will reveal information on the bulk structure and composition of the Moon relative to heat producing elements (radioactive ^{40}K, ^{232}Th , ^{235}Uand ^{238}U) and the extent of crustal differentiation.

The shallow subsurface temperature of the Moon is strongly influenced by the diurnal, annual, and other fluctuations of the insolation. Therefore, the best way to measure the internal heat flow is to insert a probe to a depth beyond the reach of the surface fluctuation. Such depth is considered to be 5 to 7 m [1,2].

Apollo astronauts deployed heat flow probes by drilling with a 400 Watt rotary-percusive drill, a fiberglass casing to a depth of ~2.4 meters and inserting a heat flow probe into it. The biggest problem encountered by Apollo 15 astronauts was caused by poorly designed auger flutes. With redesigned bore stems, Apollo 16 and 17 had little problem in reaching the required depth.

Proposed Deployment Method: Although the rotary-percussive approach has been proven, it is possible to make the heat flow probe deployment simpler by using a pure percussive approach. The percussive penetrometer uses high frequency and low energy impacts to penetrate the regolith. When a rod is inserted into regolith, the resistance to insertion comes from two sources: displacing or crushing regolith ahead of the probe and regolith sliding against the rod as it is being inserted. (The latter is referred to as sleeve friction.) The combination of high frequency and low energy percussive impacting reduces both resistance forces. The regolith ahead of the pointed tip of a penetrometer gets displaced, packed, and crushed due to the vibration; this allows the cone to penetrate deeper. Simultaneously, the regolith rubbing against the penetrometer surface continuously vibrates and reduces the sleeve friction; this makes insertion of the penetrometer much easier.

This method of heat probe deployment is simpler than drilling. The penetrometer head can be made lighter since no rotation is required. In addition, each penetrometer section can form the heat flow probe itself. The connection of consecutive probes is also easier; since there is no rotation, there is no need for sliprings. The lack of an auger (screw profile) also makes data interpretation easier.

Laboratory and Field Tests: Several different penetrometer designs were built and tested. Each design consisted of three parts: the rotary percussive actuator for creating the hammering penetrating force, the detachable cone that was hammered into the lunar regolith simulant, and the connecting rod that held the detachable cone to the rotary percussive hammer. Tests were carried out by penetrating into columns of compacted (1.9 g/cc) lunar regolith simulant, JSC-1A to a depth of 0.9 meters and GSC-1 to a depth of 9 m.

Initial laboratory testing using JSC-1A yielded promising results (see Figure 1). All penetrometer designs were able to deploy down to nearly one meter in 1-3 minutes (depending on the design). Subsequent testing and analysis resulted in a final cone size of 25-mm at the base with a 30° point angle, and a final rod outer diameter of 21.3-mm with an inner diameter of 15.8-mm (to house wires, instruments, etc.).

With satisfactory results from the initial testing, a full scale test setup near Goddard Space Flight Center was built (see Figure 2). This setup used a ten meter tall section of pipe with an inner diameter of 18 inches filled with GSC-1 regolith simulant. Several one meter long rods were connected together to form a long penetrating string. A depth of 9 meters was achieved in a few minutes and greater penetration depth is possible with an addition of extra rods.

Figure1. Percussive actuator with a rod penetrating compacted JSC-1A.

Figure 2. 10 meter testing column, filled with GSC-1.

References: [1] Saito, Y. et al. (2007) *LPS XXXVIII*, abstract #2197. [2] Nagihara, S. et al. (2008) *LPSC XXXIX* abstract #1087.