TECHNOLOGY AND TECHNIQUES FOR PALEOMAGNETIC STUDIES AT THE LUNAR POLES.

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Introduction: One of the great unresolved questions in lunar science is the origin of remanent magnetization discovered in the lunar crust and Apollo samples. The planned return of crewed missions to the Moon and the establishment of a long-term base will offer an unprecedented opportunity to advance our understanding of paleomagnetism on the Moon and other solar system bodies. In a past white paper we described general scientific objectives for lunar magnetism studies [1]. Here we explore the scientific possibilities offered by a base at the lunar poles and address the technological and strategic requirements for realizing these possibilities. We conclude that paleomagnetic studies at a lunar pole would achieve the greatest results if the following capabilities were present: (1) Deep drilling and/or excavation down to 100-1000 m, (2) Long-range roving up to 1000 km from the lunar base, (3) Sample handling using nonmagnetic tools and sample storage in magnetically shielded environments.

1. Drilling and excavation. As recently recommended by the National Research Council [2], oriented samples of undisturbed basalt flows or large impact crater melt sheets offer the best opportunity to test if and when a dipolar lunar core dynamo was operating on the Moon. Sampling intact crater melt sheets could potentially be accomplished within any multikilometer diameter crater, including those in permanent shadow. While this remains an important objective, such a drilling operation would likely require depths on the order of 100-1000 m, and there is no guarantee that a single drill core will contain intact melt sheet. In contrast, the complexity of the drilling would be greatly reduced if conducted at mare locations, where bedrock is likely to be covered by only tens of meters of regolith. These lower depths would permit faster drilling times and the collection of multiple cooriented cores. The chances of hitting consolidated bedrock are also increased by using multiple cores. In addition, exposed bedrock is often present at mare locations and may be sampled without drilling [1]. Finally, many other scientific disciplines would benefit from drills capable of collecting 10-30 meters of bedrock.

2. Roving and site access. A polar base will likely be as close as possible to permanently shadowed crater interiors. For example, NASA has identified the rim of Shackleton crater on the south pole as a possible landing site. While close proximity to a large crater is good for drilling, the cold interior temperatures will make the operation of a kilometer-scale drill technically difficult. Except for some locations on the lunar north pole, permanently shadowed crater floors do not usually abut sunlit areas. Therefore, deep crater drilling at the poles may require moving the equipment at least several kilometers from the base location.

If crewed missions are landed only at polar locations, then it may be useful to drive to areas of mare basalt to sample bedrock. According to geologic maps the mare units closest to the south pole are a mare filled crater in the Australe basin (-76º, 86ºE), and the mare filled crater Antoniadi in the South Pole-Aitken (SPA) basin (-70º, 183ºE) [3]. The mare in Antoniadi is about 910 km away, and would probably require about 1000 km of driving (distances to reach mare units on the north pole are comparable). Pressurized rovers capable of reaching these distances have been proposed [e.g. 4]. If the rover were driven continuously (perhaps by ground control) at an average speed of 10 km/hr, the trip would take about 4 days. While a journey of 1000 km would be an enormous undertaking, there are many reasons why it may be worthwhile. In particular, a trip to Antoniadi would take astronauts over the outer rims of the SPA basin and into its interior. This would provide many opportunities to sample SPA materials, including the first basalts from the far side. Since the rover would have likely departed from a polar base, drilling equipment used in the search for polar volatiles could be used for bedrock drilling. The use of long range rovers also has technology development applications for future Mars exploration.

Access to cold traps. Although a mare location is ideal in many ways for obtaining bedrock, the cold temperatures of the permanently shadowed craters could provide some unique advantages for paleomagnetic studies. Most Apollo and Luna samples have been exposed to temperatures up to 110º C at lunar noon, usually for millions of years. This continual heating can destroy up to one half the rock's magnetic remanence. Surprisingly, even subsurface residence below the diurnal temperature wave (at about -20º C) can destroy some of the rock's remanence after billions of years.

Lunar cold traps offer a unique opportunity to collect materials that formed and have remained at cryogenic temperatures for up to 2 billion years. Such samples would have retained nearly all of their original magnetization. One type of sample of particular interest in cold traps is glass that formed by small impacts (1-4 m craters). Unlike rocks, which may have complex heating histories, such glasses would have been kept at extremely low temperatures (40-100º K) since formation. When sampled with proper field-free techniques these glasses could provide the most pristine record of impact-generated magnetic fields. Sampling such glasses would not strictly require a rover, since they could be found within walking distance of the start of a permanently shadowed area.

3. Sample collection and handling. Most lunar rocks have remained in a low field environment since their formation. If these rocks are exposed to higher fields from a spacecraft or spacesuit, they will acquire a contaminating magnetic remanence. While this remanence is small, and is not believed to be a major factor in interpreting lunar magnetism, contaminating fields can be over 100 times the ambient lunar surface field. It would greatly benefit lunar paleomagnetism studies if a number of carefully selected samples could be brought to Earth completely free of contamination. Once back on Earth a subsample can be processed in a completely field-free environment, while the rest of the sample can be allocated for other studies.

Spacesuit and rover contamination: During the Apollo missions rocks were in very close proximity to the astronaut spacesuits, which may have exposed them to strong magnetic fields. The highest spacesuit fields are likely to originate from the portable life support system (PLSS). These fields could be reduced by wrapping key components in magnetic shielding (μ-metal), but this may be technically difficult and costly. Another option is to measure the spacesuit magnetic field on Earth and establish the distance where the field falls to low levels. At this distance nonmagnetic scoops or similar sample collectors could be used for a sample that is to be dedicated to magnetism studies (Fig. 1). To avoid contaminating the sample when brought close to the PLSS, a scoop could be lined in μ-metal foil. A spring loaded lid could clamp down with another piece of foil to completely enclose the sample. The sample would then be ready for carrying near the PLSS or on a rover.

Spacecraft and rover contamination: Since fields from the rover and spacecraft may be especially high, it is worthwhile to protect all samples in μ-metal containers or foils during transportation, not just those destined for paleomagnetism studies.

Sample examination in a habitat: If a lunar habitat is established some samples will likely be evaluated in a small laboratory for their significance ("high-grading"). It is also likely that fields in the habitat will be much higher than ambient lunar fields, and therefore select samples for magnetic studies should not be subjected to laboratory evaluation.

Earth contamination: Even though most samples will have been temporarily exposed to high fields while near the spacesuit, rover, or lunar habitat, once on Earth it is still worthwhile to store all samples in magnetically shielded rooms or containers. This is because the acquisition of magnetic contamination is a time-dependent process, and the longer the storage in the Earth field, the greater the contamination.

Fig. 1: Astronaut using a scoop near the Apollo 17 Station 8 boulder. A similar scoop lined with μ-metal foil could protect select samples from magnetic fields. Image AS17-146-22371.

Astronaut training: Astronaut training should include the basic principles of rock magnetism and paleomagnetic measurement techniques. In combination with these concepts, practical skills such as differentiating shocked breccias from unshocked pristine samples will help an astronaut determine the suitability of samples for collection.

Conclusions: 1) Accessing oriented bedrock for paleomagnetism studies may require kilometer-scale drill depths at melt sheets, but would require shallower depths at mare locations. 2) Long-range roving is a possible means to reach mare locations from a polar base. 3) Trivial changes to sampling equipment can greatly diminish magnetic contamination.

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