MAGNETIC STUDIES OF RETURNED SAMPLES FROM MARS. B. P. Weiss[1], I. Garrick-Bethell[1], and J. L. Kirschvink[2], [1]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, 54-814, 77 Massachusetts Avenue, Cambridge, MA 02139, bpweiss@mit.edu, [2]Division of Geological and Planetary Sciences, California Institute of Technology, 170-25, 1200 E. California Blvd., Pasadena, CA 91125.

Introduction: Although Mars today has no global dipole magnetic field, the twin discoveries of crustal magnetic anomalies in the ancient southern cratered terrane by the Mars Global Surveyor [1] and 4 billion year old remanent magnetization in Martian meteorite ALH 84001 [2] suggest that Mars had a core dynamo during the Noachian epoch. Knowledge of the timing and intensity of the Martian field is critical for understanding the thermal evolution of the Martian core, the possibility of an early period of plate tectonics, and the history of atmospheric loss on Mars. Because the crustal anomalies are sufficiently intense to deflect or focus incoming particle radiation, knowledge of the crustal magnetization pattern may also be important for locating possible human settlements.

Science from magnetic studies: When magnetic minerals crystallize, cool, or are aqueously deposited in presence of a magnetic field, their magnetic moments tend to align themselves in the direction of the local magnetic field and become magnetized with a magnitude that scales with the field intensity. Therefore, paleomagnetic studies of rocks yield two main pieces of information: the *intensity* and the *direction* of ancient fields. Because the original orientations of Martian meteorites on Mars are unknown, all paleomagnetic studies to date on Martian materials have only been able to measure the field paleointensity. *In situ paleomagnetic studies of Mars rocks and analyses of returned Martian samples afford the critical advantage of (a) knowing the geologic context of the samples and (b) providing the first opportunity to get paleodirectional information on Martian fields.*

Paleodirectional data. We regard paleodirectional data as the most important product to be gained from returned samples. Such information can be used for three very important investigations: 1) confirming that ancient magnetic fields were due to a core dynamo, 2) characterizing the temporal behavior of the Martian dynamo (reversal frequency and secular variation) and 3) chronicling local and planetary scale tectonic evolution (motion of the crust and/or mantle with respect to the background field).

1. While it is generally believed that an ancient dynamo once operated on Mars, it is not known for certain if magnetic fields observed from orbit were produced by impact processes [3] or a core dynamo. In extremely old or altered geologic units, it may be very difficult to determine if the magnetization is due to one effect by a combination of both effects. If the paleofields were generated by impacts, then rocks of similar ages would likely have random magnetization directions. However, rocks magnetized by an axial geocentric dynamo like that of the Earth should have average magnetization that points to either spin pole with inclination given by a characteristic latitudinal dependence. Discovery of such an effect would by itself be revolutionary in proving Mars had a dynamo. Only when the field generating mechanism is established can one proceed to investigations 2 and 3.

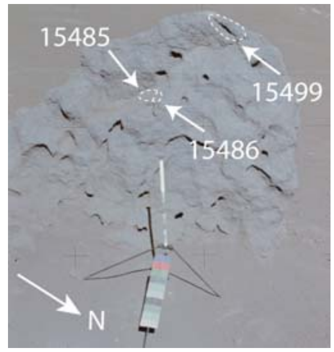

Fig. 1. Gnomon used to orient Apollo 15 samples 15485, 15486 and 15499 extracted from a boulder at Dune Crater. The gnomon rod points to vertical and its shadow can be used to determine geographic north.

2. If one assumes that a crustal block was originally magnetized in the direction specified by a Mars-centric axial dipole, then the measured magnetization direction in an oriented sample from a known site can be used to infer the secular variation and reversal frequency of the field. These data can constrain the nature of core convection, the mechanism of field generation, and possibly the age of any solid inner core.

3. The same dataset can be used to test the hypothesis that Mars has experienced plate tectonics and/or local crustal tectonics. A properly designed study could even also locate the paleorotational axes of the planet. For example, it has long been thought that the formation of Tharsis resulted in true polar wander (TPW) which moved the center of mass of this edifice to the equator where it now lies [4]. Paleomagnetic investigations coupled with other forms of geochronometry would be able to test this hypothesis and place constraints on the timing and rate of this motion. Post-Tharsis TPW has recently been invoked as a mechanism for disrupting the elevation of putative shoreline features on the North Polar Basin [5]; elevation differences along these features have been the major evidence against their interpretation of shorelines. Paleomagnetic study of *in situ* or returned oriented Martian samples is one of the few mechanisms capable of testing the TPW/shoreline hypothesis.

Paleointensity data. Paleomagnetic studies of returned samples can also provide a wealth of information concerning the cooling history of the planet by monitoring the strength of the Martian dynamo versus time. This information can also be used to determine when the planet had a dynamo and when it decayed, which will give more information about the mechanism generating the dynamo and planetary thermal evolution. A strong dynamo may have also provided protection from solar wind destruction of the Martian atmosphere and radiation protection for any primitive life.

Ideal samples and sampling strategy. *The ideal targets for paleomagnetic studies are oriented samples taken from coherent bedrock with well-defined paleohorizontal indicators.* Samples should be orientated with respect to present true north and vertical before they are removed from the outcrop. An established method from the Apollo missions for orienting samples is to photograph the sample in the same field of view as a gnomon (Fig. 1). A gnomon is a tripod and sun compass with a freely rotating gimbaled bar that always points toward true vertical (such that sample inclination can be inferred) and whose shadow can be used for obtaining geographic declination [6]. A similar device could be afixed to a sampling arm on a rover.

The ideal lithologies for paleomagnetic investigations are bedded basalts because of their high magnetization intensity, excellent fidelity for recording paleodirectional and paleointensity information, and the simple process by which they become magnetized. Sediments (both siliclastic and chemical) would also be very useful for paleomagnetic studies, but they are less favorable than basalts because of their relatively weaker magnetization, tendency to record a magnetization direction shallower than the true direction (particularly for claystones), and the lack of robust absolute paleointensity techniques for sediments. For either rock type, the samples should be collected from units with identifiable stratigraphy, bedding, layering, or other paleodirection indicators. This will greatly facilitate determining how the orientation of the unit has changed since the time of magnetization.

Landing site. The choice of the landing site is critical. Impact melts and regions heated by impacts should be avoided because they will likely have been demagnetized or remagnetized by impact processes (which may generate strong fields [3]). The samples ideally should be unshocked and unweathered. Interesting sites are the high crustal magnetic anomaly localities (which likely record an ancient dynamo) and bedrock outcrops at Meridiani [7] and Gusev [8] (which afford the possibility of sequence stratigraphy).

Sampling strategy. It is advisable to either collect multiple samples from each stratigraphic level with a coring device or to drill a long core perpendicular to the stratigraphic sequence. Multiple samples afford the possibility of determining the temporal behavior of the field and can be averaged to obtain statistically meaningful aggregate properties of the geomagnetic field. Using a coring device also ensures that orientation can be reconstructed in the laboratory. For basalts, a minimum mass of 0.03 cm^3 per sample would be measurable with modern superconducting rock magnetometers. Sedimentary samples might require one or more orders of magnitude more sample mass (depending on the lithology). The drill used to collect the cores should ideally be made from nonmagnetic materials to avoid contaminating weakly magnetized rocks.

Sample handling requirements. There are two main sample storage requirements for this investigation: 1) samples should ideally not be heated above ambient Martian (or at least terrestrial) temperatures and 2) samples should not be exposed to magnetic fields greater 10 microtesla and ideally no greater than ~ 0.1 microtesla. The latter requirement can be easily fulfilled if the samples are shielded inside of a high magnetic permeability container for the return trip to Earth. Because Apollo samples were not returned in magnetically shielded containers, part of their magnetic record was overprinted by spacecraft magnetic fields [9]. On Earth, samples should be stored in a magnetically shielded environment to prevent the acquisition of viscous remanent magnetization in the Earth's field.

In situ magnetic field measurements: While not required for analysis of returned samples, measurements of the local magnetic field with a magnetometer could provide useful information about the large-scale magnetization of the unit being sampled. This information would help interpret the magnetization of sample cores. For example, if several bedrock localities sampled 500 m apart are found to have similar magnetization directions, it would be helpful to know if a similar ambient magnetic field direction is observered between sites at km scales. If the directions were found to be similar, it would greatly strengthen the case for a homogenous field produced by a core dynamo.

References: [1] Acuna M. et al. (1999) *Science*, 284, 790-793. [2] Weiss B. P. et al. (2002) *EPSL* 201, 449-463. [3] Crawford D.A. and Schultz P.H. (1993) *Int. J. Impact. Eng.* 14, 205-216. [4] Melosh H.J. (1980) *Icarus*, 44, 745-751. [5] Perron J.T. et al. (2007) *Nature*, 447, 840-843. [6] Allton J.H. (1989) *Catalog of Apollo Lunar Surface Geological Sampling Tools and Containers* (NASA, Houston) 97 pp. [7] Squyres S.W. et al. (2006) *Science*, 313, 1403-1407. [8] Squyres S.W. et al. (2007) *Science*, 316, 738-742. [9] Pearce G.W. and Strangway D. W. (1972) in *Apollo 16 Preliminary Science Report* (NASA Spec. Pub. SP-315) 7-55 to 7-58.