INVESTIGATING POTENTIAL MARTIAN TRUE POLAR WANDER WITH ALH84001. J. Buz[1], T. Murphy[1], and J.L. Kirschvink[1,2], [1]Department of Geological and Planetary Sciences California Institute of Technology (jbuz@gps.caltech.edu) [2]Earth-Life Science Institute, Tokyo Institute of Technology

Background: True Polar Wander (TPW) is the solid body rotation of a planet or body with respect to its spin axis. It is a phenomenon observed on Earth as the distribution of mass has changed through time from processes such as plate tectonics. Because Mars has undergone changes in its mass distribution from volcanism and cratering, TPW is also expected to have occurred in Martian history. Some evidence for it have been suggested such as: layered and mantled terrain similar to polar deposits at low latitudes [1], shifting geoid due to emplacement of Tharsis [2], long wavelength shoreline variation consistent with geoid deformation [3] post-Tharsis emplacement, and magnetic anomalies inferred to show low latitude poles (e.g.[4]). The timing of any potential Martian TPW is poorly constrained, though many models use the emplacement of Tharsis as a driving force. Tharsis emplacement is thought to have occurred starting in the early Noachian [5]. In paleomagnetic studies on Earth, TPW can be observed as paleopoles lying far from the current spin axis (after accounting for the effects of plate tectonics). The lifetime of the Martian dynamo is hotly debated, but some evidence suggests that Mars is believed to have sustained a core dynamo starting in the Noachian and continuing into the Hesperian [4]. Similarly, the timing of TPW is debated although the most liberal estimates suggest it is active between ~4-2 Ga [3]. Given an oriented Martian sample from the time the Martian dynamo was active, this should be observable on Mars as well.

Motivation: All previous studies of Martian TPW have been based on remote sensing observations or modeling. On Earth, much of the evidence for TPW comes from paleomagnetic studies of oriented magnetized rocks. Unfortunately, we do not have oriented samples from various ages from Mars to do such work. However, Martian meteorite sample ALH84001 has multiple magnetic carriers and may be suitable for TPW analysis. ALH84001 was collected in the Alan Hills of Antarctica in 1984 and was later determined to be a Martian meteorite related to the SNC meteorite class [6]. ALH84001 is an orthopyroxenite which is dated to ~4.1 Ga [7] which contains secondary carbonate blebs found throughout fracture surfaces. The carbonates are believed to be ~3.9 Ga [8], i.e. active during putative TPW. Additionally, pyrrhotite crystals are found within the orthopyroxenite matrix. The sample retains magnetization from its time on Mars [9]. Small, single-domain magnetite crystals are found within the carbonate blebs and are excellent magnetic recorders [10]. Pyrrhotite is also a magnetic recorder and has a low blocking temperature. Because of the low and spread out blocking temperatures of the pyrrhotite grains, its magnetic record can be easily partially or fully reset. Additionally, if the sample were to have cooled slowly enough during a time of shift in the regional Martian dynamo field, this shift should be recorded in the sample. The addition of the carbonate blebs gives a separate sample of time of magnetic field recording. Importantly, it has been demonstrated that the sample has not been above the blocking temperature of the magnetic grains neither during the carbonate emplacement event or during transfer to Earth [9].

Methods: *Sample Preparation.* We sought to observe the magnetization in individual magnetic particles (both magnetite and pyrrhotite). We sliced three separate pieces of ALH84001 in order to maximize the number of dipoles sampled. The orientation of the pieces was maintained relative to each other in order to later combine the data.

SQuID Microscopy. We use a scanning SQuID microscope which is capable of resolving magnetic fields as weak as a few nanotesla at a spatial resolution of tens of micrometers. The microscope is magnetically shielded allowing us to visualize the remanent magnetization in the sample. We scanned our oriented slices of ALH84001 which pass through the carbonate-containing fracture surfaces.

Dipole Fitting. We select individual dipoles from our mapped magnetic fields and determine their most likely direction and position using a modified fitting routine from Lima and Weiss [11]. Because our successive slices are mutually oriented we can combine all of the dipoles for each sequence of slices and treat them as a set.

Bingham Statistics. Bingham statistics evaluate if the dipoles lie along a girdle distribution. To calculate this we represent each dipole as a unit vector and multiply it by the principal direction for the set of dipoles:

$$S = \frac{1}{n}\sum_{i=1}^{n}(\mu x_i + \alpha y_i + \beta z_i)^2$$

Where S represents the Bingham statistic, n is the number of dipoles, μ, α, and β represent the principal axis of the data, and x, y, and z represent the fit dipoles. We then compare this to the critical value for the null hypothesis that they are uniformly distributed.

Results: We found and fit a total of 96 dipoles (Figure 1). We observe that the magnetization within the sample is heterogeneous, as was previously observed [9]. We computed the Bingham statistic for the three slices, the results are reported in Table 1. For two of the three slices the statistic indicates that the dipoles are distributed in a girdle. Only 8 dipoles were found in the third slice and thus rejection of the null hypothesis was not achieved.

Conclusions: Although not conclusive evidence, the arc distribution of dipoles is consistent with a TPW origin for the magnetization in ALH84001. Further work is needed to characterize the dipoles and identify their magnetic mineralogy. Other explanations include movement of the rock during magnetization recording.

Future Work: We are obtaining X-Ray Fluorescence maps to correlate the mineralogy of the samples with the dipoles present. The dipole fitting was semi-qualitative as the dipoles were picked by hand/eye and there is possibility for observational bias. We are working on a routine which can fit a set number of dipoles within the data without input on their location.

References:

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Bingham Statistics

slice seq.	232	241	228
n	18	70	8
S	0.0885	0.1175	0.1131
critical value	0.179	0.253	0.111
reject null?	yes	yes	no

Table 1: Summary of statistical results.

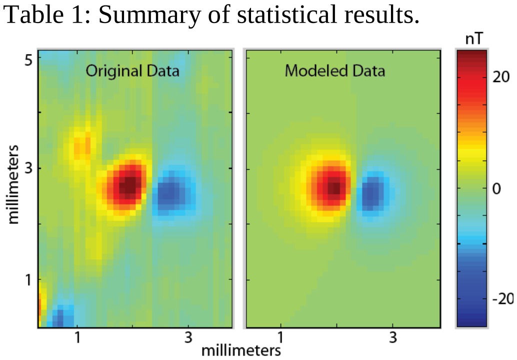

Figure 1 (above): Example of a dipole fit

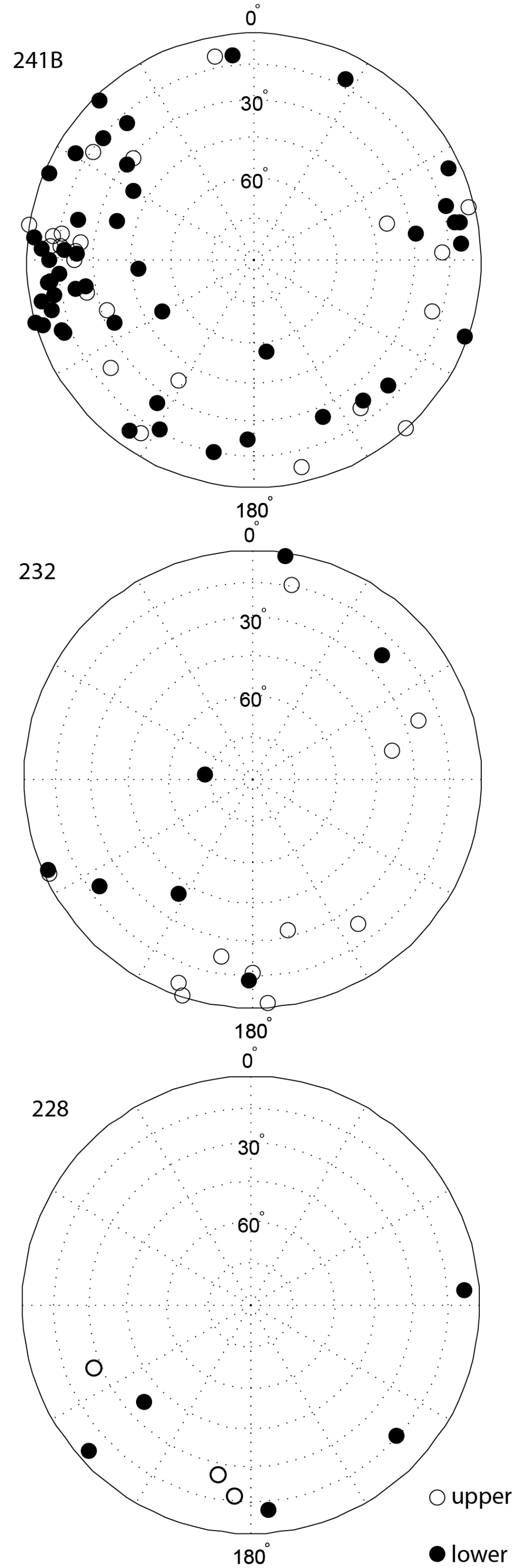

Figure 2 (right): The distribution of dipoles in our three slices. Slice 241B demonstrates a strong horizontal preference and the dipoles appear to lie along a great circle distribution.