MARS COMPASS: A MAGNETOMETER FOR THE MARS 2020 ROVER. B. P. Weiss[1], C. T. Russell[2], B. J. Anderson[3], J. L. Kirschvink[4], M. P. Golombek[5], C. A. Raymond[5], N. Murphy[5], [1]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA, [2]Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA, [3]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, [4]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA, [5]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

Introduction: The Red Planet is a magnetic planet. Orbital observations have shown that the Martian crust is extremely strongly magnetized, while rover observations and meteorite measurements have found that Martian rocks are rich in ferromagnetic minerals [1]. However, this magnetization has been largely left unexplored despite its potentially enormous implications for Martian geologic history, paleoclimate, and habitability. Here we describe the Mars Compass investigation proposed for the Mars 2020 rover, the first mobile magnetometer on Mars.

Objectives: Rover magnetometry measurements of bedrock and regolith rocks would provide the first unambiguous paleodirectional constraints on ancient Martian natural remanent magnetization (NRM) and place high spatial resolution constraints on NRM intensities. This enables 10 major objectives. These collectively address all three threshold objectives of the Mars 2020 rover mission [2]. Mars Compass will:
(1) serve as a magnetostratigraphy field tool, placing relative age constraints on rocks and enabling geologic correlations between distant stratigraphic layers;
(2) constrain geologic structures and tectonics and establish if rocks are in place bedrock or float;
(3) remotely sense buried rocks;
(4) identify paleo-lightning strikes [3], indicators of a paleoenvironment with a moist atmosphere and a formation mechanism for prebiotic organics;
(5) screen for lighting-struck rocks that may not have retained potential biosignatures (PBS);
(6) constrain the thermal and aqueous alteration history of rocks, further enabling the discrimination of samples that may not have retained PBS;
(7) constrain the history of the dynamo and test the hypothesis that the its decline was a major causative factor in atmospheric loss and climate change (Fig. 1);
(8) begin to test the hypotheses that Mars experienced ancient plate tectonics and true polar wander;
(9) optimize the selection of cache samples for paleomagnetic analysis on Earth;
(10) constrain the size of the Martian core using magnetic sounding.

Relationship to previous missions. The magnetic exploration of the solar system has thus far been mainly accomplished by magnetometers on orbiters and flyby spacecraft [4]. These instruments have flown on dozens of planetary and Earth orbiters and their fundamental components are now mature, space-hardened technology. However, only five past landed missions (Apollo 12, 14-16, and the Near-Earth Asteroid Rendezvous mission) [5, 6], and one planned Mars lander (InSight) have carried/will carry stationary magnetometers. Only once has a magnetometer on a robotic platform made continuous field measurements across a planetary surface (Lunokhod 2 rover) [7]. Never has a mobile magnetometer been deployed with the goal of detailed paleomagnetic measurements on the surface of another body. Furthermore, with the exception of Apollo, never has there also been the possibility of later making laboratory measurements on returned samples from a well-characterized spacecraft landing site. The dearth of mobile surface magnetometers has limited our knowledge of planetary and, in particular, Martian magnetism, in three major interrelated ways:

Spatial resolution and geologic context: There is an almost total absence of knowledge about the fine-

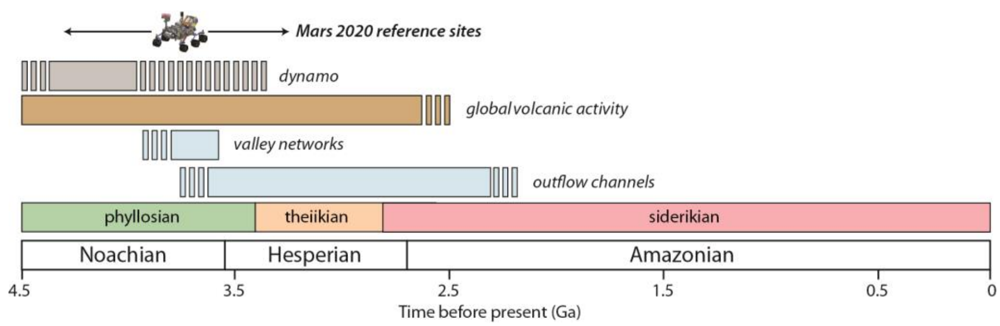

Fig. 1. Mars geologic timescale (bottom) showing simplified history of major geomorphologic (blue) and volcanic events (brown). Also shown are the three weathering epochs of ref. [11] (green, orange red). The uncertainty on the end of the Martian dynamo currently overlaps the Noachian-Hesperian and phyllosian-theiikian boundaries. The seven Mars 2020 SDT reference sites explore Noachian and Hesperian terranes. After refs. [12-16].

scale (cm to tens of km) structure of planetary crustal fields. Such data are essential for constraining the true fine-scale intensity and orientation of these fields and thereby their magnetization source regions and origin. Meteorites, while analyzable at very high spatial resolution in the laboratory, are from unknown locations and geologic structures. This missing geologic context—structural, lithostratigraphic, chemostratigraphic, sedimentological—is nevertheless critical for constraining the source of the NRM and its implications for geological events.

Uniqueness: With the exception of analyses of returned Apollo samples, direct measurements of the magnetization of individual, isolated rocks have been restricted to meteorites whose geologic context is all but unknown. Paleomagnetic data on isolated rocks like boulders and drilled cores on the Martian surface are critical because they can uniquely determine (or at least tightly constrain) the net magnetic moment of the samples. Magnetization (or its volume-integrated equivalent, magnetic moment), the quantity of interest for studies of magnetic history and rock properties, must be extracted from these field data using a highly non-unique inversion process (e.g., [8]).

NRM direction: Paleomagnetic studies of Martian meteorites are limited by the fact that the original orientations of the meteorites are unknown. As a result, all studies of Martian meteorites have only been able to estimate NRM intensity but not its absolute direction in Mars geographic coordinates (e.g., [9, 10]). Although orbital measurements are referenced to Martian geographic coordinates, their inability to resolve NRM at the stratigraphic bedrock scale makes retrieving NRM direction and correlating to discrete geologic events highly challenging.

Mars 2020: An unprecedented opportunity for magnetic studies. Mars Compass addresses the above three deficiencies by acquiring high resolution paleomagnetic measurements of surface samples with known orientations and geologic context. *This will enable NRM to be correlated directly with discrete lithologies and bedrock structures, providing unprecedented geologic context and the first unambiguous constraints on the absolute orientation of Martian magnetization. Combined with possibility of ultra-high fidelity measurements in Earth laboratories of returned samples, Mars 2020 presents a historic opportunity for magnetic studies on another body.* Finally, although not required for our objectives, Mars Compass could be active at the same time as the InSight magnetometer, the Mars Atmosphere and Volatile EvolutioN (MAVEN) orbiter mission, and/or as yet unforeseen international missions, enabling a powerful distributed magnetic sounding network.

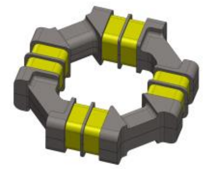

Fig. 2. The Mars Compass magnetometer/gradiometer sensor proposed for the Mars 2020 rover. The paired sense coils of the can be summed to give the field or be differenced to return the gradient of the field.

Instrument: Mars Compass is nearly a clone of the magnetometer now being built for the InSight Mars lander (Fig. 2). It incorporates the latest miniaturized technologies developed over four decades of space magnetometry and recently supported by NASA Planetary Instrument Definition and Development and Keck Institute for Space Studies funding. Mars Compass has a technology readiness level (TRL) of ~7 with most of its electronics and sensor components at essentially TRL 9, has a total mass <500 g and requires <2.5 W of power. It is composed of two identical high-sensitivity (5 pT/Hz$^{1/2}$ at 1 Hz) magnetic field sensors located on the spacecraft chassis. This dual sensor configuration both provides redundancy and enables meter-scale gradiometry measurements during traverses. Each sensor can be operated as either a magnetometer or as a centimeter-scale magnetic gradiometer and could sense the NRM of drill core samples. Its gradiometer configurations enable the rejection of rover-generated fields such that there are no magnetic cleanliness requirements for the rover.

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