Magnetic Surveys to Probe the Lunar Subsurface

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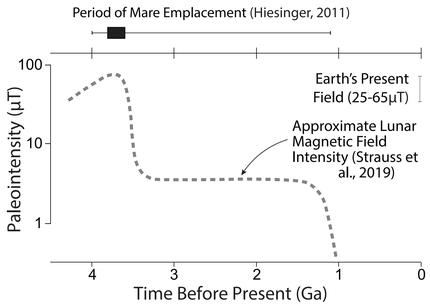
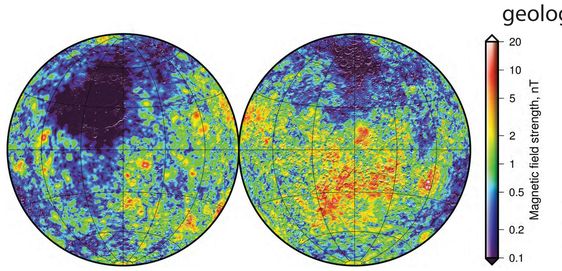
Background and Motivation

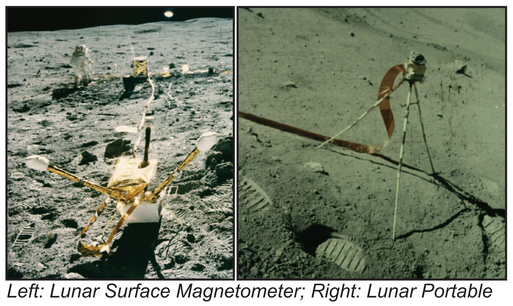
Samples retrieved from the Moon's surface during the Apollo missions hold records of an ancient lunar dynamo field at least as strong as that of the present-day Earth. The igneous rock population at the surface of the Moon spans nearly the entire history of the satellite and mare volcanism was primarily emplaced between 3-4 Ga, overlapping in time with a strong ~78 μT lunar dynamo field (~3.9-3.6 Ga) and a transition to a weaker (~5 μT by 3 Ga) dynamo (Strauss et al, 2019; Weiss & Tikoo, 2014).
Mapping magnetized rocks on the lunar surface can help prospect for exploration enabling resources (ore deposits and void spaces) and clarify the emplacement history of igneous rocks based on magnetic anomalies from buried geologic units.





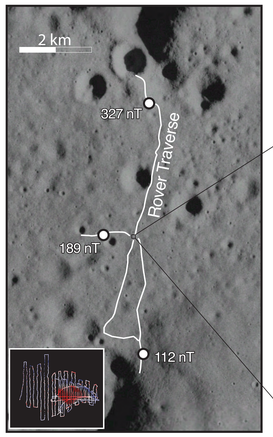
Magnetic field strength of the lunar surface colored with a log-scale (Wieczorek, 2018).

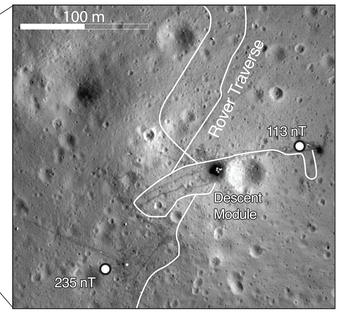
Magnetic Investigations at the Moon



Left: Lunar Surface Magnetometer; Right: Lunar Portable Magnetometer at Apollo 16.

The **Lunar Surface Magnetometer** was included as part of the Apollo Lunar Surface Experiments Package (ALSEP) and the **Lunar Portable Magnetometer** was a part of Apollo 14 and 16. All landing sites had a measureable magnetic field between 3-327 nT. Magnetic readings were taken at five places at the Apollo 16 landing site in the Decartes Highlands, with strengths from 112±5 nT to 327±7 nT. This variation suggests that field-scale magnetic anomalies are present at the Moon.

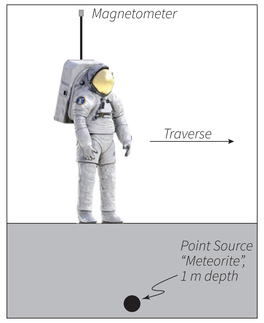


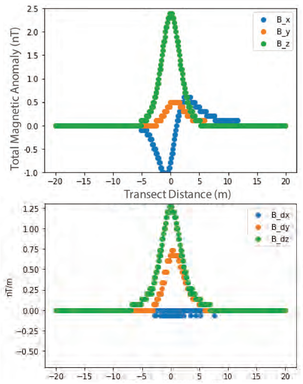


Left: The Apollo 16 landing site with recorded magnetic field strengths. Inset is a terrestrial magnetic survey of a volcano (see right panel) at the same scale as the larger map.
Right: Detailed view of the Apollo 16 landing site. ALSEP was setup in the lower right of this image.

Image Credit: LROC

Magnetized Features of Interest on the Moon





Decimeter-radius meteorites in the shallow lunar subsurface can produce magnetic anomalies of a few nT, as measured from a magnetometer 3 meters from the metallic object. We model the magnetic field generated by the **Natural Remanent Magnetism (NRM)** of a buried meteorite. By modeling the field in three dimensions at different locations, we simulate an astronaut traverse over the object.

Meteorite Properties

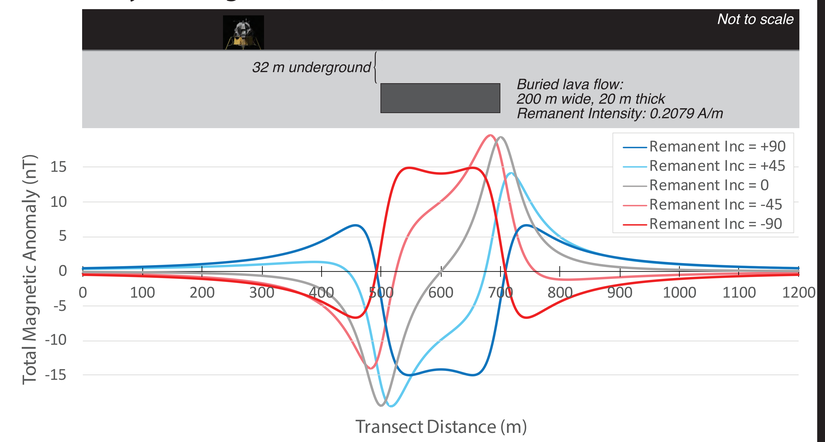
Depth, 1 m
Raw NRM, 10^{-2} A m^2 kg^{-1}
Mass, 10 kg
Magnetometer Position, 2.5 m above the ground.

Top: An Astronaut with a back-mounted magnetometer walks over a buried meteorite.
Middle: The strength of the magnetic field at the magnetometer along the transect, split into three vector components
Bottom: The vector components of the gradient of the magnetic field at the magnetometer.

Iron-rich igneous rocks (lava flows and impact melts) will retain remnant magnetism as they form and cool if they are in the presence of a strong magnetic field. We use Apollo 17 data to construct magnetic anomalies from a potential lava flow with different magnetic inclinations. Remanent inclination is a product of the magnetizing field direction and can help us understand the direction of an ancient lunar magnetic field.

Lava Flow Properties

Depth, 32 m *(Watkins & Kovach, 1973)*
Dimensions, 200 m wide, 20 m thick
Raw NRM, 6.6x10^{-5} A m^2 kg^{-1} *(Apollo Sample 70017; Cournede et al., 2012)*
Bulk Density, 3150 kg/m^{-3} *(Kiefer et al., 2012)*



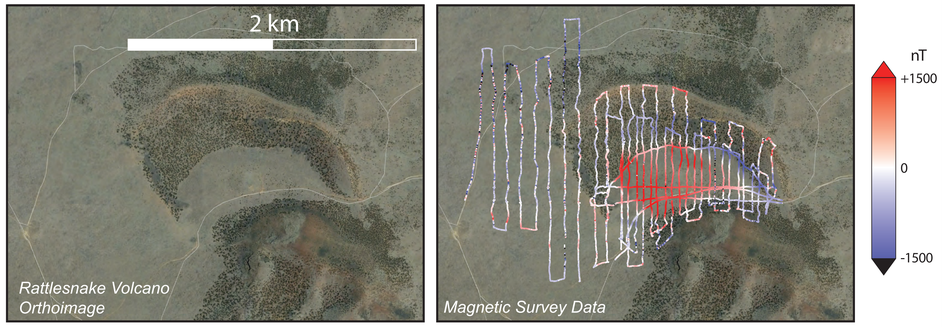
Terrestrial Analog Magnetic Investigations

Top: Nick Schmerr carries a terrestrial field magnetometer and GPS system on a lava flow. Jared Espley for scale.

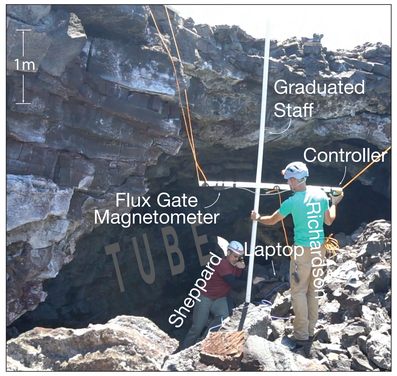
On Earth, magnetometers are generally suspended from aircraft, a ship, or above operator on a boom. The boom length provides near constant survey altitude and distances mag from electronics. **Traverses are generally grid patterns to produce magnetic anomaly maps**. Similar surveys can be performed with rovers or astronauts on the lunar surface with a mountable magnetometer.

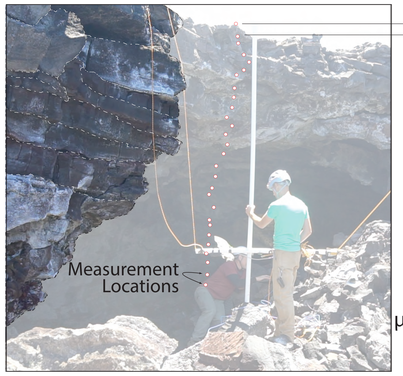
Magnetic Surveys of Volcanic Terrains

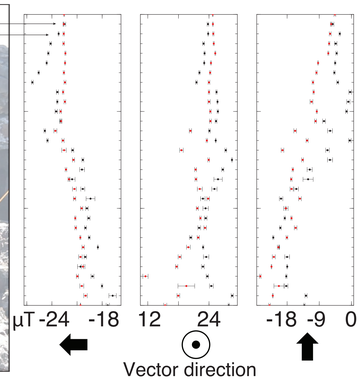
This "traditional" magnetic survey was created by performing north and south traverses 50 or 100 m apart from each other. Data was collected at 1 Hz. This survey helped identify buried lavas at the Rattlesnake Crater Volcano (Flagstaff, Arizona; Marshall et al., 2015). Mapped magnetic anomalies here are likely 10-100x stronger than similar anomalies on the Moon (see above example).



Below: A fluxgate magnetometer was attached to a PVC boom to perform vertical surveys 85cm (black symbols to the right) and 150 cm (red symbols) away from the layered wall to the left.







Vertical Magnetic Surveys

We performed a magnetic survey with a commerically available fluxgate magnetometer along a vertical outcrop at the entrance of a lava tube (Mauna Loa, Hawaii). We found the total field strength increased monotonically by 3000 nT during descent into the pit. Structure that can be connected to layers of lava is seen with the three vector components of the field.

Acknowledgements

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Related Papers

Kiefer, W. S., et al. (2012). GRL 39(7).
Marshall et al. (2015) JVGR, 304, 253-264.
Wieczorek, M. A. (2018) JGR: Planets, 123(1), 291-316.
Watkins, J. S., & Kovach, R. L. (1973). LPSC IV, p 2561.
Cournède, C. et al. (2012). EPSL, 331, 31-42.
Weiss, B.P. and Tikoo, S.M. (2014) Science, 346, 1346753
Heisinger H. (2011) GSA Spec. Paper 477, 1-51
Strauss B. E. et al. (2019) LPSC L, Abstract #3135
Dyal P. et al. (1974) Rev. Geophys. & Space Phys., 12(4), 568-591
Bell, E. Jr. et al. (2020) LPSC LI, Abstract #2294.
Bell, E. et al. (2020) NESF (this meeting)
George, O. et al. (2015) Stat. in Volc. 1, 1-23.