SCANNING 3-AXIS MAGNETOMETRY CAN DETECT ANCIENT MARTIAN LIGHTNING STRIKES: FIELD TRIALS ON A NATIVE AMERICAN LIGHTNING PETROGLYPH.

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Introduction: The central scientific objective of the NASA Mars 2020 Mission is to assess the hability of ancient Martian environments [1]. Core goals of the mission include the *in situ* identification of chemical and physical proxies for past conditions suitable for life and the caching of samples, especially ones containing potential biomarkers, for return to Earth.

The proposed Mars Compass instrument [2] consists of a pair of rover-borne, dual-function magnetometer/gradiometers. Mars Compass will contribute to the overarching objective of habitability assessment in several ways including the characterization of ancient Martian magnetic field strengths and dating of rock formations via magnetostatigraphy [2].

An additional key capability of Mars Compass is the detection and characterization of paleolightning strikes in Martian material. The electrical current associated with terrestrial cloud-to-surface lightning induces strong magnetic fields of greater than 100 mT [3]. Such fields are capable of imparting a strong isothermal remanent magnetization (IRM) on Martian crustal material [4]. Once acquired, an IRM in Martian rocks may be retained for >4.5 Gy at Martian temperatures without significant decay [5]. This permanent magnetization in turn produces a characterstic magnetic field anomaly that can be readily detected by the Mars Compass instrument.

In this abstract, we first summarize the scientific implications of paleolightning detection on Mars. We then present results of field trials with a similar scanning magnetometer to show that lightning magnetism is readily characterized. Our high-resolution magnetic mapping shows a close correspondence between the magnetic anomaly and an ancient lightning petroglyph, supporting Native American knowledge and measurement of magnetism.

Paleo-lightning detection will constrain early Mars conditions and aid in biomarker sample selection: The atmophere of early Mars may have been substantially denser than that of the present day and have harbored an Earth-like hydrological cycle [e.g., 6, 7]. The collisions of water and ice particles in a cloud layer lead to the build-up of negative charge at its base, which may be released to the ground as lightning if the electric potential exceeds a threshold.

The existence of lightning on early Mars would therefore suggest that water and ice particles were pervasively suspended in the early Martian atmophere. Such conditions imply the existence of precipitation and an active hydrological cycle on early Mars. Furthermore, the threshold voltage required for lightning increases with atmospheric pressure [8]. Since the intensity of the magnetic anomaly varies with the threshold voltage, measuring the strength of lightning IRM in Martian rocks will constrain the atmospheric pressure of early Mars, which is currently uncertain to more than an order of magnitude [9].

Finally, lightning can locally heat rocks to up to 1,800 K [10]. Even a small fraction of this excursion would destroy organic biomarkers. Therefore, the identification of lightning locations is fundamental to the caching of viable biomarker samples.

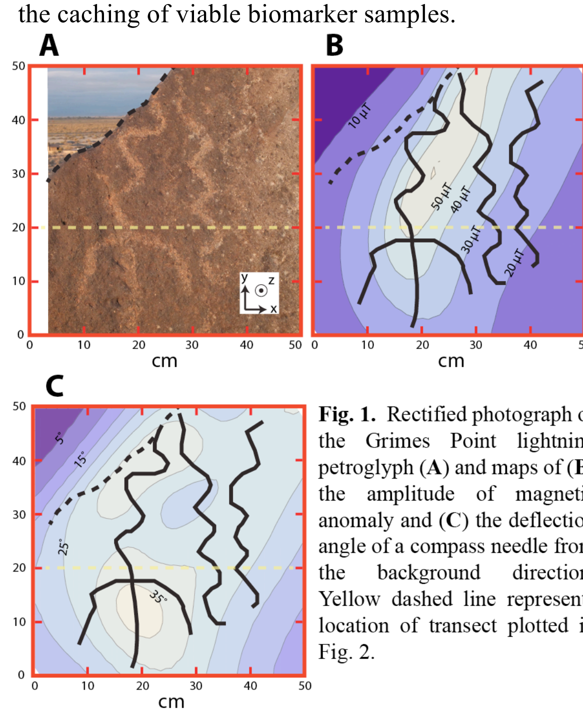

Fig. 1. Rectified photograph of the Grimes Point lightning petroglyph (**A**) and maps of (**B**) the amplitude of magnetic anomaly and (**C**) the deflection angle of a compass needle from the background direction. Yellow dashed line represents location of transect plotted in Fig. 2.

Field trials confirm that paleolightning is readily identified via magnetic mapping: Electrical currents associated with lightning strikes display characteristic geometries [3, 11]. Also, magnetic fields due to lightning-struck rock are generally more than one order of magnitude stronger than those from unremagnetized material. These unique properties of lightning induced magnetic anomalies permit their identification.

To show that *in situ* measurements of magnetic field can unambiguously identify and characterize ancient lightning strikes, we mapped magnetic fields on the surface of a lightning-struck, basaltic terrestrial outcrop. We constructed a motorized stage capable of scanning a fluxgate magnetometer sensor with ~1 nT sensitivity across a 0.7×0.7 m area with <1 cm precision. The fluxgate sensor is maintained less than 4 cm above the surface of the outcrop.

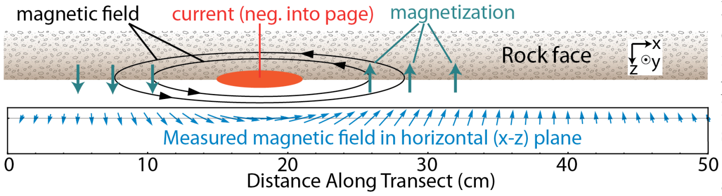

Fig. 2. Birds eye view of Grimes Point outcrop comparing measured magnetic fields in the horizontal plane and expected field directions due to a lightning-induced current. Coordinate system and transect position as in Fig. 1. Z component of magnetic field exagerrated by 4x to show morphology.

For our field site, we selected a lightning-struck basaltic outcrop at the Grimes Point archaeological site in Nevada. Grimes Point may hold the highest concentration of paleo-Indian petroglyphs in the United States [12]. The selected outcrop is a boulder ~1 m in diameter and height and bears a petroglyph depicting a lightning strike on a vertical face (Fig. 1A).

After subtracting the background magnetic field measured >20 cm from the outcrop, the residual magnetic field anomaly shows a clear channel of high intensity that traces the path of the current that flowed from the location of the lightning strike at the top of the outcrop to the ground (Fig. 1B). The strength of the anomalous magnetic field is similar in magnitude to that of the Earth's magnetic field (~50 μT), making it ~500,000 times stronger than the noise level of the Mars Compass instrument [2].

The geometry of the magnetic anomaly confirms its origin in a cloud-to-ground lightning strike. Since cloud-to-ground lightning consists of negative current that travels downward into the ground, the induced magnetic field near a current passing down a rock surface would be out of the rock (+z in Figs. 1 and 2) to the left (–x) of the current path and into the rock to the right. This field geometry is readily observed in the vicinity of the Grimes Point lightning strike (Fig. 2).

These observations further indicate that the lightning-struck boulder has not undergone significant rotation since the lightning event. Finally, the currents expected from water/ice-bearing and dust clouds have opposing polarities [8]. Therefore, mapping of lightning-induced magnetic fields can constrain the physical origin of the lightning electric potential and provide further evidence for an early hydrosphere on Mars.

Native Americans may have detected magnetic anomalies using a suspended lodestone: High-resolution magnetic mapping as performed by the Mars Compass instrument and our field magnetometer permits analysis of any relationship between magnetic anomalies and other outcrop features.

For the Grime Point scanning location, the close correspondence between the lightning petroglyphs and the regions of maximum deflection in the local magnetic field suggests that the placement of the petroglyphs is not coincidental. Native Americans may have measured the magnetic field deflection angle using a lodestone suspended from a string. An alternative hypothesis is that Native Americans saw the lightning strike on the boulder and later carved the petroglyphs. However, the passage of an electric current on a basaltic surface leaves no visible trace, and, given the ~3 m circumference of the outcrop, the co-location of the lightning anomaly and petroglyphs to better than 10 cm accuracy is very unlikely (P~0.03) to have occurred without measurement of the magnetic field.

The discovery of a hematite-rich, compass needle-like artifact in southern Mexico demonstrated that early Meso-American cultures were aware of magnetism before 1000 BCE [13]. Furthermore, the presence of strong magnetic anomalies on specific regions of pre-Olmec "pot belly" statues suggests that early Americans were able to accurately locate magnetic anomalies in basaltic rocks [14]. Our observation implies that Great Basin native groups were aware of the ability of electricity (e.g., lightning) to induce magnetism, an observation commonly attributed to Hans Christian Ørsted in 1820.

Linguistic evidence suggests that Native American groups in the Great Basin region migrated from Meso-America beginning in the 13th century [15]. Given that the Grimes Point petroglyphs were continuously made as late as the 16th century, northward migration of Meso-American groups in the preceding centuries may have brought with them knowledge of magnetic materials required for the construction and usage of a suspended lodestone.

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