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Use of magnetometry for detecting and documenting multi-species Pleistocene megafauna tracks at White Sands National Monument, New Mexico, U.S.A

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A B S T R A C T

Tracks and trackways of a range of Pleistocene megafauna can be found in White Sands National Monument, New Mexico, U.S.A. These tracks occur is several forms, not all of which are visible and some of which are only intermittently visible depending on lighting and moisture conditions. Here we present the result of a successful test of cesium vapor magnetometry to detect a known Columbian mammoth trackway. This initial test found that not only the known mammoth tracks were easily detected by the method, but that the tracks of additional species, though not visible to the eye, were detected in the vicinity of the mammoth tracks, including likely giant sloth tracks. Our initial results indicate that resolution may be suitable to distinguish between the tracks of various species, including possibly humans which are known archaeologically to have overlapped temporally with these species in the southwestern U.S. This preliminary result has immediate implications for the detection and documentation of Pleistocene track sites, and further refinement of the procedure is planned in the coming months.

1. Introduction

White Sands National Monument (WHSA) in New Mexico is home to one of the largest concentrations of Cenozoic trackways in North America (Lucas et al., 2007; Santucci et al., 2015). Within the area a number of extinct Pleistocene species trackways can be found from representative species including Columbian mammoth (*M. Columbi*), ground sloth (Bustos et al. 2018) as well as various camelid, felid, canid, and ungulates (Morgan and Lucas, 2002). The presence of multiple track-bearing surfaces is suspected and their detailed chronology awaits further work. The tracks in question here appear on playa deposits of ancient Lake Otero (Fig. 1). Preservation is of two types, either as upstanding dolomite-rich pedestals, or as true tracks (depressed). The depressed tracks are described colloquially as ‘ghost-tracks’ since they are only visible given specific environmental moisture conditions and are invisible for parts of the year due to a surface crust of dry salt (Fig. 2). The depressed tracks can be successfully excavated, with sufficient textural contrast between the infill and plantar morphology of the track becoming evident; however, excavation is a destructive process since erosion and deflation follows. Cross-sections through mammoth tracks show a compressed bowl infilled by detrital gypsum-rich sands and silts (Fig. 2).

In light of the poor preservation potential of these tracks, their frequency and crucially their elusive nature in terms of surface visibility, they are ideal candidates to explore the potential for non-destructive geophysical prospection. If successful, this would greatly increase the ability of the Resource Manager of the Monument to document and conserve the tracks present at the site which are threatened by environmental change and periodically by human activities. Emerging from discussions at the WHSA January

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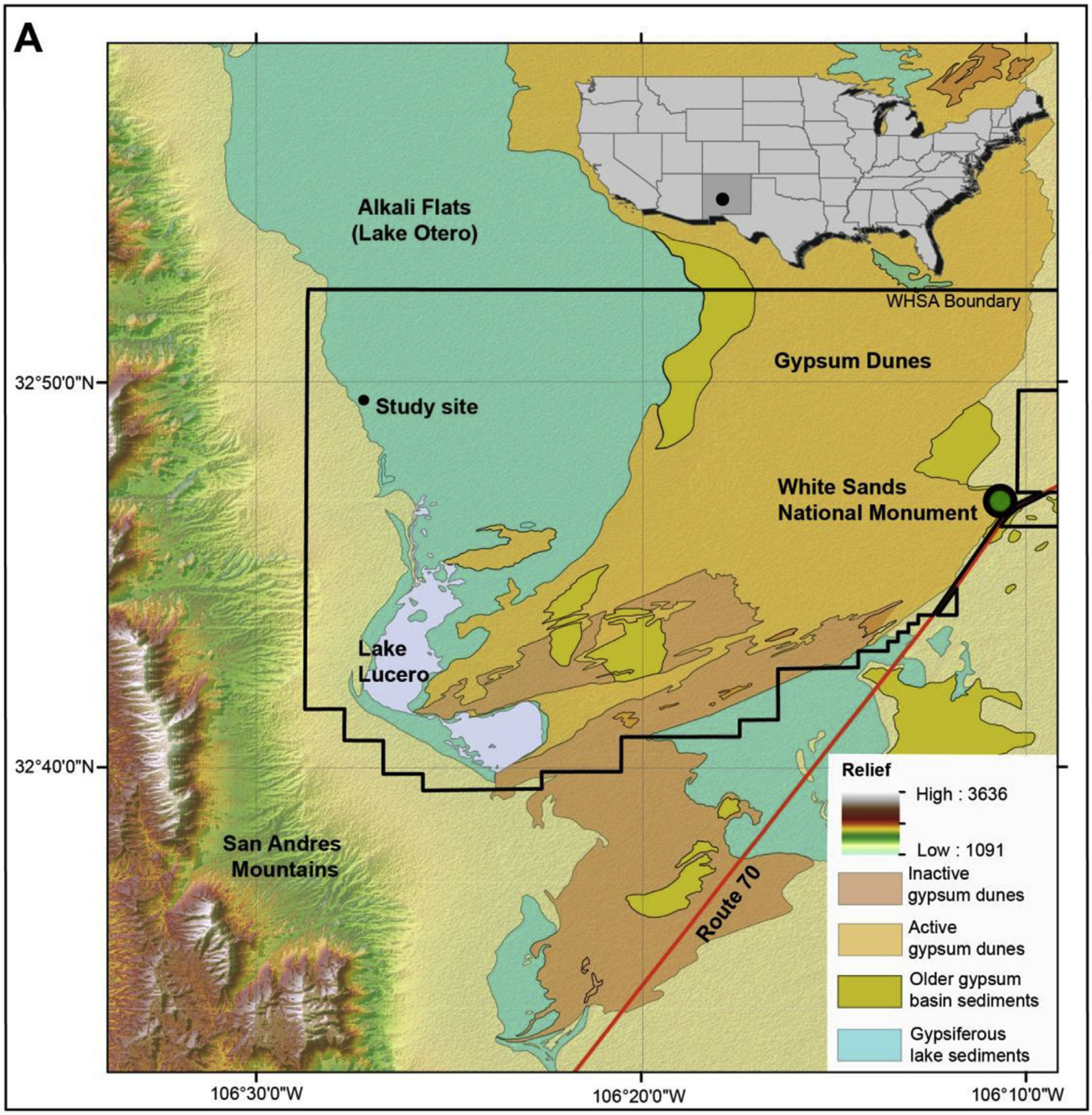

Fig. 1. Location map of White Sands National Monument. Digital elevation model is based on a 1 arc SRTM (Shuttle Radar Topography Mission) dataset.

2017 Workshop, a plan was made to test a magnetic sensor for detecting the tracks. We report the results of this initial test here.

2. Method

A magnetic survey was conducted at Alkali Flats within the monument over four previously known Columbian mammoth tracks in succession along a larger trackway with a cesium-vapor magnetometer. A single magnetic sensor was deployed on a 3 m aluminum boom in order to collect magnetic data without the need for walking across the delicate trackway surface, with data collection perpendicular to the mammoth's path. This approach strictly limited transect length that could be undertaken without walking across the tracks, and was altered for later follow-up surveys as the method was refined in more recent visits (see post-script).

A close transect spacing was used to ensure that spatial density of collected data was sufficient to image the mammoth track in good detail. Additionally, because any disparity in magnetic properties between the tracks and surrounding substrate was expected to be very small, the sensor was deployed very close to the ground surface in order to maximize sensitivity to subtle variations. An on-site stationary magnetic base-station was used to remove the diurnal trend from the gridded data. Initial processing was undertaken with Geometrics MagMap2000 software, and final figures produce with Surfer 13 by Golden Software. The survey and instrument parameters are listed in Table 1.

3. Result

The magnetic survey successfully detected the four known mammoth tracks targeted in the test (Figs. 3 and 4a). In addition, a number of details not visible at the time of the survey appear to have been detected by the magnetometer, including what are likely additional tracks. This was not entirely surprising since the tracks of multiple species, including humans, are present in the general area (Fig. 4b). In particular, the two central mammoth tracks appear to be crossed by bipedal trackways that run perpendicular to the

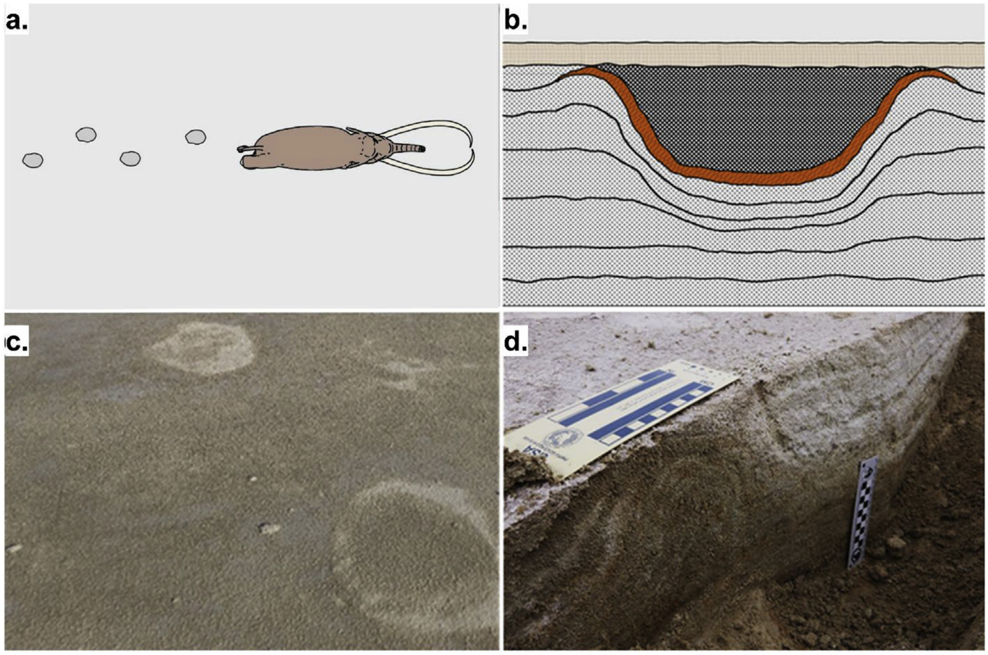

Fig. 2. Mammoth track formation at White Sands. (a.) Illustration of depressed mammoth track formation (b.) Illustration of depressed mammoth track cross-section showing iron rich layer caused by algal mats. (c.) visible mammoth tracks during appropriate moisture conditions (d.) excavated cross-section of mammoth track.

Table 1
Survey and instrument set up.

Instrument: Geometrics G-858 total-field, optically-pumped cesium-vapor magnetometer
Cycle time: 0.1 s (spatially approximately 0.02 m in-line per sample)
Cylinder orientation: perpendicular to surface
Instrument configuration: total field (single sensor)
Survey set up: Unidirectional, north to south
Sensor height from survey surface: 0.1 m
Transect spacing: 0.2 m
Interpolation: Kriging

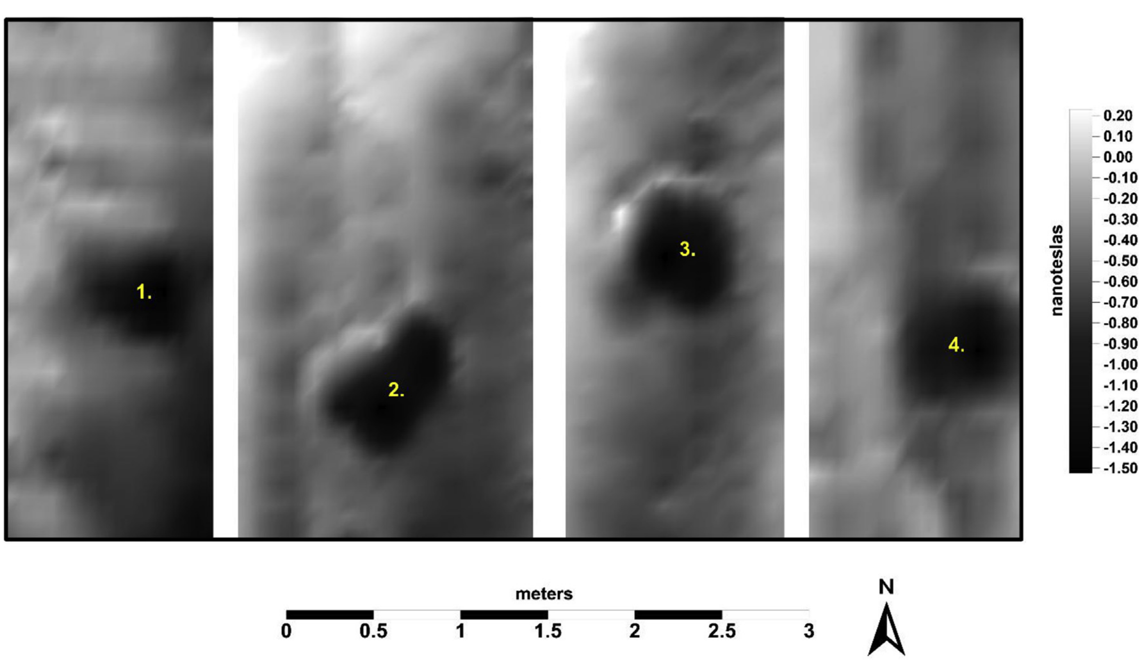

Fig. 3. Magnetic test results. The visible mammoth track were clearly detected, as were other apparent tracks that were not visible at the time of the survey.

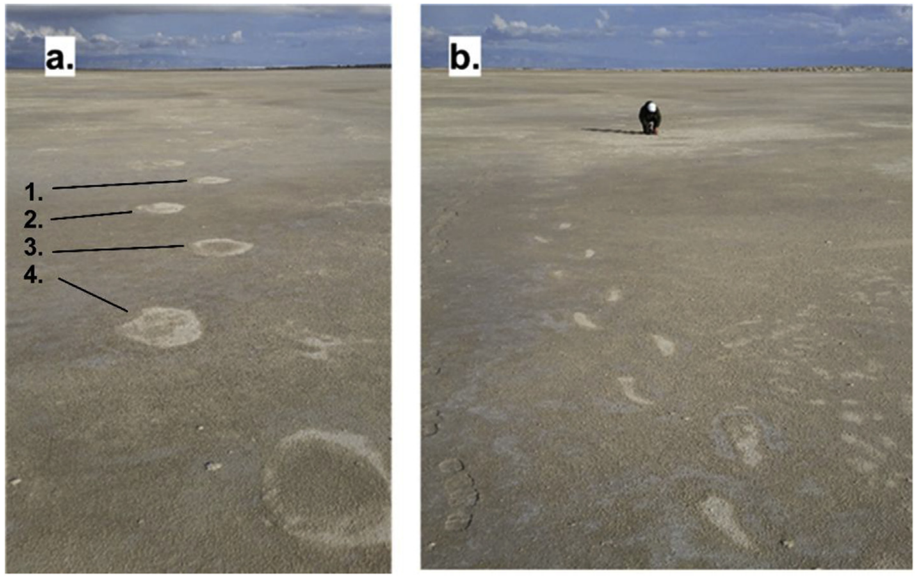

Fig. 4. Visible mammoth trackway (a.), the last four visible prints of the mammoth trackway were surveyed and shown in Fig. 3 above. The numbered mammoth print shown in panel a. Correspond to the numbered prints in Fig. 3. Visible prehistoric sloth and human tracks (b.) as well as other species also occur in the general area.

mammoth's trajectory (Fig. 5). Some of these apparent track anomalies exhibit a distinct shape notably associated with the rear feet of giant ground sloths, and possibly a second, smaller mammoth (Fig. 5). Sloth tracks, though very rare generally, are known to be present in the general vicinity of the survey (Bustos et al. 2018), though the visibility of such tracks may vary with environmental conditions (Fig. 6).

4. Analysis and further development

4.1. Low sensor elevation is critical

The upward continuation, a potential-field transformation sometimes applied to magnetic data, was used to evaluate the need for a very low sensor height. The upward continuation calculates a would-be observational plane of the magnetic sensor, above that of the actual field observation, allowing evaluation of sensor detection capability at various elevations above the survey surface. The procedure for a level-surface to level-surface continuation is described in detail by Blakely (1995: 315–319), and has been applied to magnetic data sets to relax noise prior to the application of other transformation procedures (Urban et al., 2014), or to simply suppress noise in order to better qualitatively evaluate broader trends that are obscured by smaller magnetic anomalies (e.g., Wolff and Urban, 2013). Continued fields were calculated from the original survey data for 0.25 m, 0.5 m, and 1.0 m above the survey surface (the original data set was collected at 0.1 m). It was clear from the result of this procedure that the sensor must be very close to the surface in order to detect most of fine details required for interpreting tracks (Fig. 7). At 1.0 m, no track anomalies are detectable. At 0.5 m the mammoth track is detectable, but poorly resolved. Even at 0.25 m, only the mammoth track appears to be detectable, but other tracks and many details seen in the original (0.1 m) data are clearly absent.

4.2. Spatial resolution

While the in-line sample density, averaging 50 samples per meter, would be difficult to improve upon, the transect spacing of 0.2 m (selected as being sufficient relative to the size of the mammoth tracks) could be reduced in order to improve spatial resolution. This is very clear when the in-line data are down-sampled to 5 samples per meter (i.e. the equivalent of the 0.2 m transect spacing; Fig. 8). In the down-sampled example shown below, the mammoth track is still visible, but nearly all of the finer grained details are lost.

5. Discussion

From the results of the initial magnetometry test presented here, it is clear that the magnetic imaging of trackways at WHSA is possible, however, some questions remain about the method. Why are the tracks detectable with a magnetometer? The detected mammoth tracks appear as “lows” in the magnetic total field data, with narrow halo perimeters of magnetic “highs” relative to the general background (Fig. 3). While the explanation for this is not entirely certain, the most likely scenario on the basis of field observations from excavated mammoth tracks at WHSA is that the tracks impressed into a more magnetic substrate layer, pushing it up around the perimeter, with the bowl being subsequently infilled by less magnetic wind-blown material.

Algal mats are recognized as an important part of track preservation and infilling (Marty et al., 2009). Excavation of tracks undertaken by Bustos et al. (2018) show evidence of iron staining and salt concentration at the base of many of the tracks which we attribute to the algal mats and an alternating wet-dry environment. Subsequent infilling of less iron rich material leads to the observed magnetic anomalies associated with the prints. Close to the perimeter of the print, the more magnetic, iron rich-substrate is slight closer to the observational plane of the magnetic sensor, but further away from the sensor in the center of the track. As a results we observe the “high” to “low” magnetic readings between the perimeter and bowl of each print. The much smaller bipedal tracks are less deep than the mammoth tracks, so exhibit a more variable (though still detectable) magnetic response.

Is it possible to say that all tracks present are contemporary on the basis of the magnetic data? We do not believe that such a claim can be

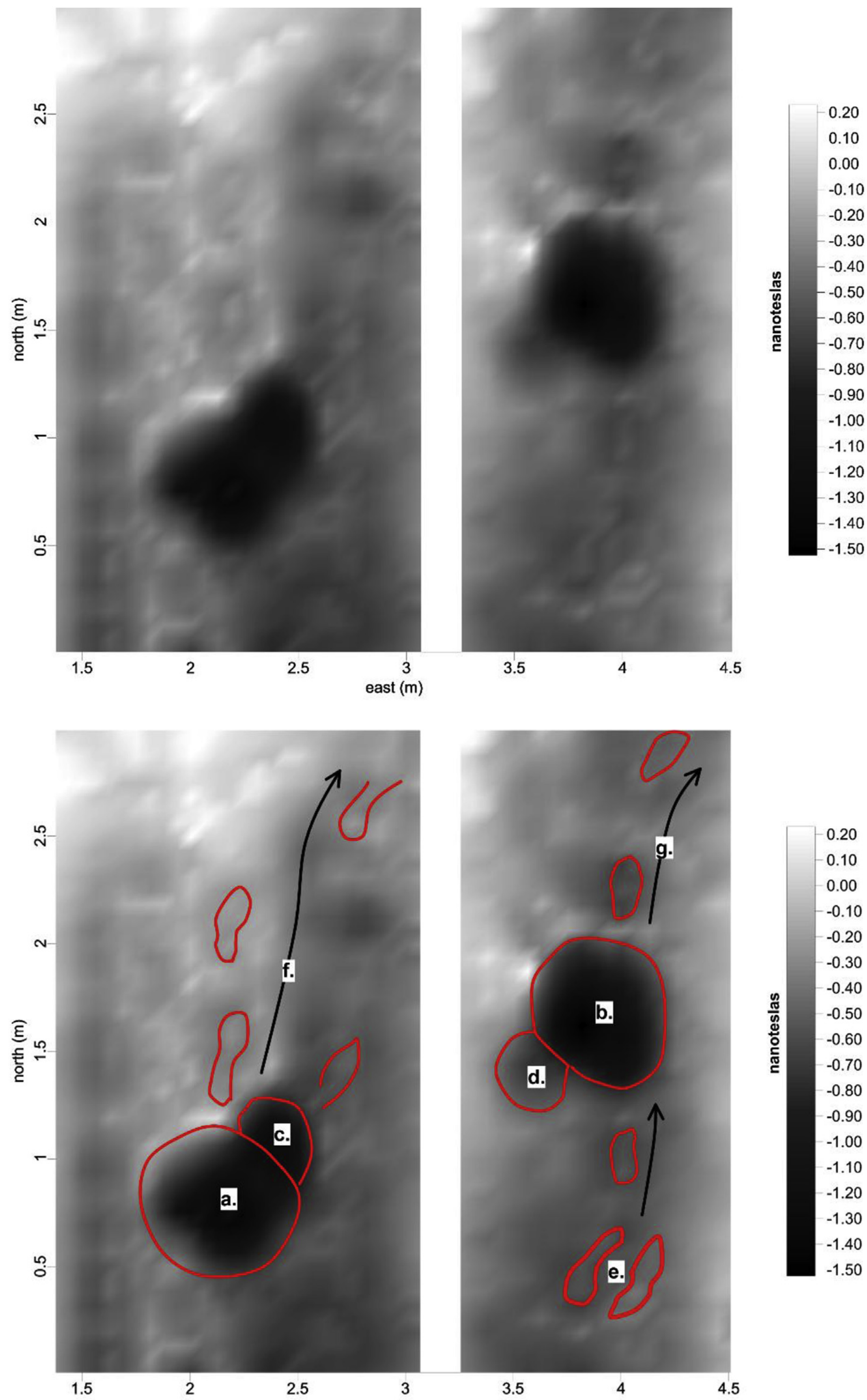

Fig. 5. Interpretation: The test was clearly successful in detecting the known adult mammoth tracks targeted by the survey (a. and b.), but three of the four tracks exhibited closely associated anomalies that may suggest a younger mammoth walking the same trajectory (c. and d.), or some other overlapping prints or slippage from a single animal. Other tracks, though not visible in the survey area were also clearly detected, such as (e.), which resembles the prints seen in a nearby sloth trackway, The two track trajectories indicated above (f. and g.) may be unseen sloth or human trackways.

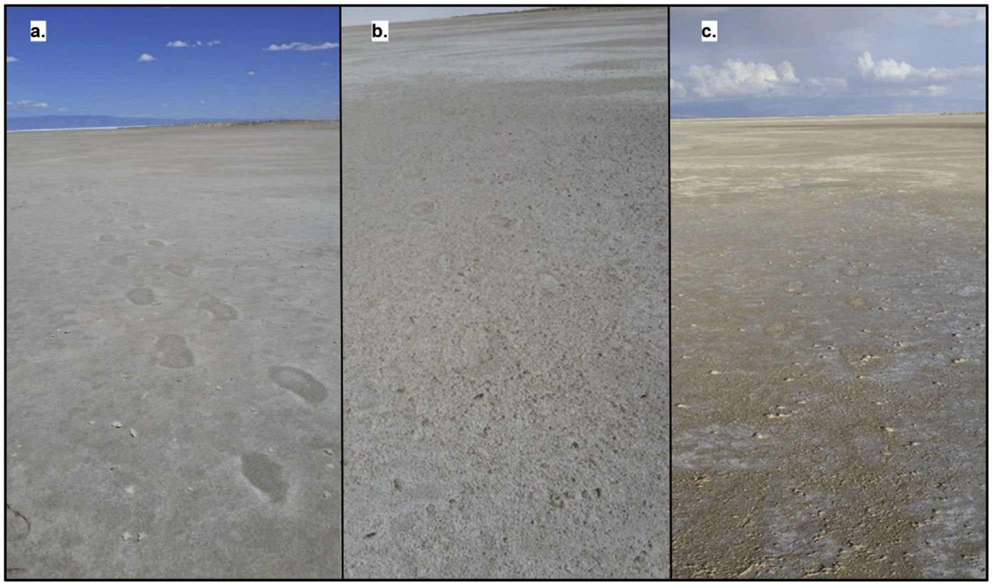

Fig. 6. Visible sloth tracks at White Sands under moderate moisture conditions (a.) dry conditions (b.), and very wet conditions (c).

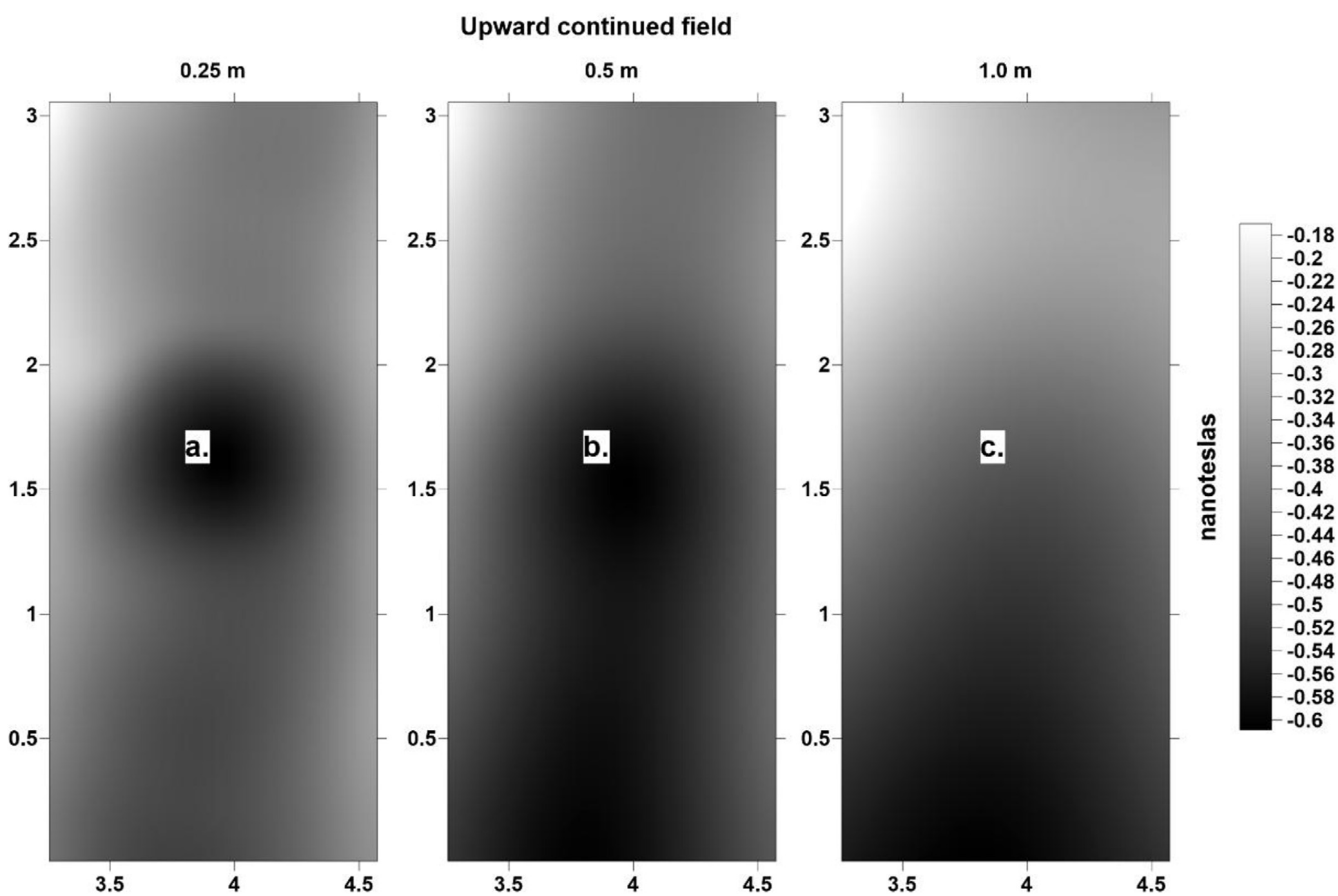

Fig. 7. Upward continued magnetic data from Track 3 showing the synthetic result for various sensor elevations. (a.) At a sensor height of 0.25 m the mammoth track is still detectable but all other detail is lost. (b.) At 0.5 m the mammoth track becomes difficult to distinguish. (c.) At 1.0 m even the mammoth track is no longer detectable.

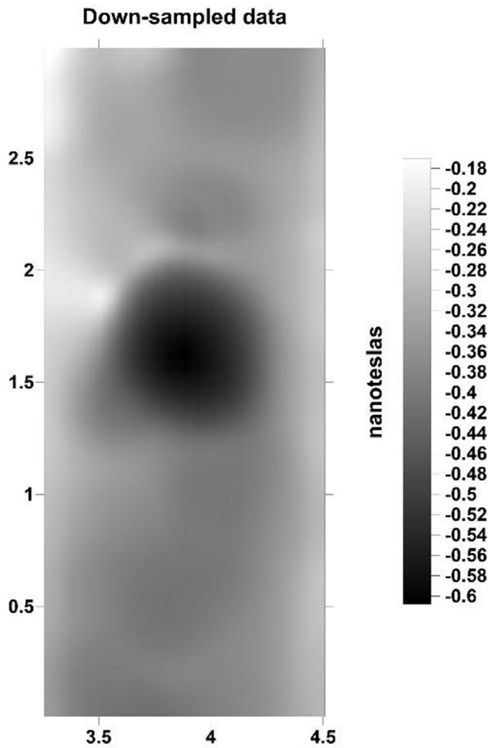

Fig. 8. In the down-sampled data set from Track 3 it is obvious that ultra-dense in-line sampling strategy (ca. 0.02 m along the Y axis) was crucial to detecting smaller tracks and other fine details. The data above were degraded along the Y axis (i.e. in-line data) to match the spatial sampling of the X axis (i.e. transect interval). The result demonstrates that a closer transect interval (e.g. 0.1 rather than 0.2 m) could significantly improve spatial resolution of tracks.

made solely on the basis of magnetic survey data. We have, however, demonstrated with excavation that human and other megafauna tracks in this setting are contemporary (Bustos et al. 2018). Invasive methods may always be necessary to address questions of contemporaneity, however, magnetic survey methods are still useful for detecting tracks that are not visible, allowing researchers to target more specific areas for excavation. In other words, while track visibility is intermittent, being tied closely to soil moisture, these "ghost" tracks are still detectable on the basis of magnetic differences regardless of whether they are visible to the human eye.

6. Conclusions

The magnetic test survey of a mammoth trackway at White Sands National Monument demonstrated not only that magnetic methods are capable of detecting large, visible tracks in good resolution, but that it is also possible to detect much smaller tracks and tracks that are not visible. Of the detected tracks that were not visible at the time of the survey, it appears likely that many of these can be attributed to Pleistocene ground sloths that were known to have been active in the area (Bustos et al. 2018). Known trackways of ground sloth species are exceedingly rare. The detection of smaller bipedal (likely sloth) tracks also illustrates the potential for detecting the tracks of Pleistocene human hunters in the area. Analysis of the test data using upward continued and down-sampled data indicates that having the magnetic sensors very close to the survey surface is crucial to detecting both smaller and unseen tracks, and that reducing transect spacing is likely to increase spatial resolution, particularly of smaller tracks.

The wider significance of this work lies in its potential to assist in locating and documenting animal and perhaps hominid tracks and traces. There is perhaps a misconception as to how rare such traces are within the geological record. The phrase 'unique acts of geological preservation' has sometimes been applied. What has become apparent, however, in recent years through the discovery of new track sites (see Bennett and Morse, 2014 and references therein) is that this is not necessarily the case. Fine-grained depositional environments are common and rich in other archaeological/anthropological evidence and they are ideal for track preservation. It is perhaps more the failure of excavators to recognize the presence of tracks. A case in point is the work of Altamura et al. (2017) where well preserved hippopotamus tracks have been recently documented but almost certainly other examples have been destroyed in the past, prior to recognition, by excavation. Improved geophysical prospection has a major contribution to make in identifying potential tracks sites.

6.1. Post-script

In several subsequent iterations of magnetic surveying at WHSA, our team covered the track surface with foam mats in orders to deploy the magnetic sensors on a wheeled cart without damaging the tracks-ways. This also allowed us to draw a grid directly on the

Fig. 9. The initial test of total field magnetic data collection on a long aluminum boom with a single sensor. T. Urban shown, photo by D. Bustos.

foam, making for more efficient data collection. The cart, by offering greater control of the sensors, allowed us to collect data 0.05 m transect spacing (as opposed to the 0.2 m used in this paper). We also added a second magnetic sensor to the set-up in order to collect gradient data to reduce random interference and eliminate the need for diurnal trend removal with base stations (See Fig. 9).

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.quascirev.2018.07.012.

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