Total Field Magnetics and Exploration for Paleoindian to Plains-Culture Targets; Yellowstone National Park, USA

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I. INTRODUCTION

The Montana-Yellowstone Archaeological Project (MYAP) is a joint archaeological project of the University of Montana's Department of Anthropology and Yellowstone National Park's Center for Resources. Our 2009 and 2010 field seasons focused on the shores of Yellowstone Lake (Fig. 1). The ultimate goal is to inventory all archaeological sites around the lake and evaluate their eligibility for listing on the United States National Register of Historic Places. During the survey and evaluations, MYAP collected nearly 11,000 prehistoric artifacts indicating ephemeral use of the northwest lakeshore since the Late Paleoindian period (~10,000 B.P.). The currently completed survey area includes about 200 hectares, a limited portion of which was subject to total field magnetic (TMI) and/or Ground Penetrating Radar (GPR) investigation. We include here a summary of our techniques, representative maps of processed total magnetic intensity, and examples from excavation of typical archaeological/geophysical targets.

II. PREHISTORIC SETTING, GEOPHYSICAL TARGETS

Pleistocene volcanic eruptions, lava flows, and associated thermal uplift formed the Yellowstone Plateau physiographic province. During glacial maxima an icecap covered almost the entire Yellowstone area. The most recent icecap was virtually gone by 12,000 B.P. [1], more recent than the oldest archaeological sites in North America. The resulting glacial deposits are poorly to moderately sorted boulder-rich gravels and sand, including gneiss, rhyolite, welded-tuff, and basalt boulders greater than a meter in diameter. These boulders are present along the current lakeshore and in the shallow subsurface. The magnetic susceptibility and remanent magnetization of these boulders varies dramatically. A series of lakeshore terraces, named S2-S6 by [2] related to glacial rebound and caldera deformation range in age from 14,000 B.P. to present. These provided potential living surfaces when they emerged. Sagebrush and short-grass prairie as well as stands of lodgepole pine and spruce dominate the area near Yellowstone Lake (Fig. 2). Both the boulders and sagebrush complicate magnetic acquisition and interpretation for this magnetic exploration project.

The 2,380-meter elevation of the project area yields a deep snowpack and extremely low winter temperatures that drive animal migration to lower elevations generally beginning in October. The heavy snow and paucity of game renders the area uninhabitable during winter assuring that habitation of the upper portions of the Yellowstone Plateau, including Yellowstone Lake, by prehistoric peoples would have been seasonal. People followed migrating herds and sought seasonal flora. Thus, temporary campsites, small ephemeral surface

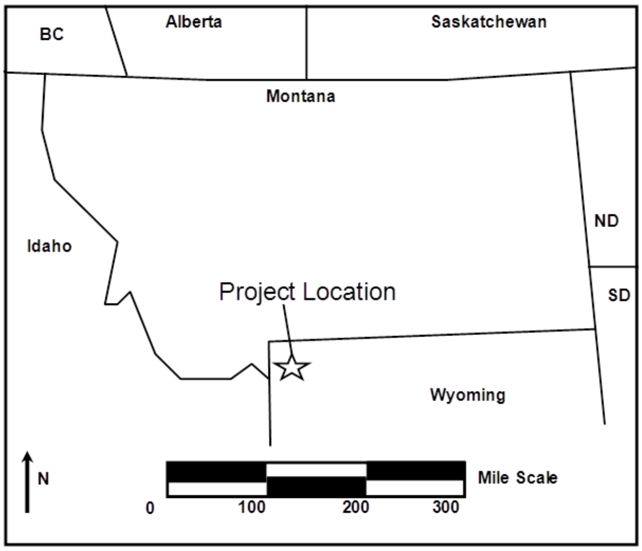

Figure 1. Yellowstone National Park occupies northwestern Wyoming and nearby Montana in the northern Rocky Mountains, USA.

Figure 2. Typical summer field conditions in sagebrush and lodgepole pines. Winter snowpack is meters deep when -20C temperatures are common.

hearths (Fig. 3), occasional larger roasting pits, stone rings (tipi rings), and indeterminate artifact scatters are the typical archaeological features and geophysical targets in Yellowstone National Park. There are no village sites. Camps were small and used for short-term occupations during summer months. This introduces a further complication: given magnetic results alone, it is not possible to separate rocks used for many of the above cultural processes from those occurring naturally; stone rings are the exception.

III. METHODS

About 180 km of shoreline surrounds 350 km^2 of Yellowstone Lake. Consequently, our archaeological survey will include several field seasons and, lacking infinite funding, some expedience in site surveying, discovery, and limited excavation is necessary. In siting small areas for investigation with magnetometry, we first completed close-interval (ca. 2-3 meter) pedestrian surveys to map visible artifact density on the surface over large areas. Following discovery of high counts of surface artifacts or other indications of potential sites, we employed detailed surface surveys and then sited test grids for magnetic exploration. Those magnetic grids range from 100 m^2 to 2,500 m^2 depending on access and our interest. Thus, we employed a hierarchical method hoping to exploit magnetometry to locate excavation test units likely to discover small subsurface features left from ephemeral occupation in the Yellowstone Lake area. Our principal objective was to rapidly acquire, process, and interpret sufficient, meaningful magnetic data in the time available to guide placement of test units.

Once we determined an area for which we desired magnetic data, we established grids with tape measures and corner stakes or by using a total station when available. Following establishment of a grid, we acquired total field magnetic intensity observations at 10 Hz while walking bidirectional transects spaced one meter apart using a Geometrics G858 Cesium vapor magnetometer holding the sensor roughly 30 cm off the ground. We guided those transects with observers at each end of the line. For longer transects we used rope on transect lines for additional guidance and included a reference mark at the grid center. We use one-meter line spacing because analyzing the power spectra for the total magnetic intensity (TMI) of a randomly magnetized layer shows line spacing can be twice the separation of the source and sensor while keeping aliasing of shorter wavelength components sufficiently small to still allow accurate modeling and inversion. Dipole targets require half that line spacing but our targets of interest are spatially broader than dipole sources.

Figure 4. Typical hearth exposed in profile due to wave erosion; minimum of 2,000 BP. These were lightly used features.

Although the presence of substantial sagebrush in the field areas added much noise to our magnetic acquisition, we filter the vast majority of that noise with techniques typical for aeromagnetic and ground magnetic data acquired in the energy and minerals exploration industry. We collected our TMI data during a magnetically quiet period as observed by NOAA [4] and our on-site observations. We also used a GEM Systems recording Proton Precession base station magnetometer for diurnal corrections on many larger grids. On grids collected without a recording base station, geomagnetic variations will be present in the data. The frequency spectrum of such geomagnetic variance can be broad. Low frequency components have periods similar to the acquisition time of several transects and longer. High frequency components have periods ranging from the time for acquiring a few observations to that for acquiring a few transects. In the filtering described below, we deal with the possibility of long period geomagnetic variation in combination with that for regional and deeper geologic sources. We treat the potential effects of high frequency variance with filtering techniques adapted from the energy and mining industry. This proved successful as is demonstrated by the final maps whether diurnally corrected or not; the results are comparable. The ultimate anomalies of interest have amplitudes of nanoteslas to 10’s of nanoteslas.

Our TMI observations, usually gridded by kriging with 0.4 meter spacing, include features at three dominant scales. First, there is experimental noise resulting from acquisition and the effects of highly magnetic rhyolite and obsidian cobbles and historic debris on the surface. The corrugation from acquisition can be significant and is typical in ground and airborne magnetic surveys where one acquires observations at relatively high spatial frequency along more widely spaced transects. Yet, this approach requires less surveying and grid setup and

Figure 3. Late Archaic (1570±40 BP) hearth that shows the physical similarity of constructed hearths and glacial erratics or dropstones.

allows acquisition at walking speed as compared to surveying each acquisition point. Despite the usual efforts to keep the sensor a constant distance from the ground and walk at a consistent pace, sage, bunch grass, rough surfaces, rocks and wind combine to interfere with the operator and impact the distance of the sensor from the ground and vary rates of walking while acquiring TMI observations at 10 Hz. This manifests as linear magnetic anomalies in the direction of acquisition. We use a common technique [4] for decorrugation filtering as elaborated on in [5]. The second and third scales of magnetic anomalies in this type of study are deeper geologic sources and shallow, potentially interesting sources at the archaeological and/or environmental scale. We typically separate these sources into equivalent layers using either differencing of upward continuations following [6] or matched bandpass filtering based on equivalent sources [7]. Employing matched bandpass filtering for anomaly separation has a long history [8] in the application of aeromagnetic data to tectonics, structure, and resource exploration, but not in archaeology. Yet, it works quite well in many archaeological situations [9]. The successive application of correcting for diurnal variation of the geomagnetic field, filtering to remove corrugation, and then separating the TMI observations into equivalent layers yields magnetic maps ready for interpretation. For edge detection and source location, we typically compare results from calculating the analytic signal [10] and horizontal gradient [11] of either the equivalent layer or the pseudogravity transformation [12] of that layer. Calculating the vertical gradient [13] of the total magnetic intensity can also highlight shallow sources [e.g. 14] so we also employ that technique.

IV. Examples of Our Magnetic Investigations

Temporary campsites represented by small ephemeral surface hearths, rare larger roasting pits, stone rings (tipi rings), and indeterminate artifact scatters are the typical archaeological features and geophysical targets in our study. Thus, strong obvious signals with characteristic, non-natural geometry are rare. Remanence values for the volcanic rocks in the area range from 0.5 to 10 A/m [15] and complicate the issue. Additionally, their susceptibilities range from $1x10^{-3}$ to $5x10^{-4}$ [15]. Thus, many of the locally derived glacial erratics which are common on the surface and in the shallow subsurface create substantial magnetic anomalies. Their smaller counterparts, cobbles on the surface, add point dipole signals to the observations. Stone rings (tipi rings) if they exist in the area are comprised of a mix of the glacial erratics; such stones have quite variable magnetizations. Regardless, upward continuation of the total magnetic intensity of visible stone rings by a meter demonstrates that the radial symmetry of such features is detectable at depth with minimal filtering and edge enhancement. Consequently, our expectation was for subtle anomalies that, in the case of hearths, look quite similar to signal from natural sources. Of course, in the case of stone rings there would be a benefit from their diagnostic radial symmetry. Most of our magnetic grids were successful in locating productive test units. Other grids were successful in delineating historic disruption which rendered potential sites ineligible for inclusion in the National Register of Historic Places.

A. *Representative Grids, Archaeological Results*

Site 48YE381, located on an S2 terrace dating to approximately 8,000 B.P., is along Yellowstone Lakes' northwest shore and holds cultural features from 1,720 B.P. to 3,090 B.P. Low, hummocky wetlands mark the southern and western limits. On-site vegetation consists of lodgepole pine and open meadow consisting of sagebrush, marsh/alpine meadow flowers, various alpine grasses and shrubs along the terrace. A substantial amount of obsidian and lesser chert flaking debris is scattered throughout the pine stand and the sagebrush open area along the lakeshore. Artifact densities fall-off significantly on the far western and southern limits of the site near a wetlands and hummocks. The whole area of diffuse to more concentrated artifact scatter covers about 32,500 m^2. We sited two magnetic grids (2,500 m^2 and 300 m^2) to cover the areas with the most artifact scatter. We were also able to collect Ground Penetrating Radar (GPR) data on a relatively open portion of the smaller grid which helped eliminate excavating some test units into fluvial structures.

Fig. 5 shows the anomalies we chose to investigate with 1x1 meter test units. The image is of a shallow equivalent layer, after removal of deeper source effects by matched bandpass filtering. We used the analytic signal and horizontal gradient maxima of the TMI for edge and source detection. We combined those results along with recognition, in the field, of a decades old road in the northeast corner of the grid lead to the selection of the marked test units. The discoveries in those test units (Fig. 5) include:

- #1: hearth (1,720 +/-40 B.P.) and evidence of obsidian tool manufacturing at 0.56 meters
- #2, 3, and 4 yielded only boulders. Each individual anomaly has the character of a boulder yet their concentration and alignment was promising
- #5: hearth (2,920 +/- 40 B.P.) at 0.8 meters
- #6: hearth (3,090 +/- 40 B.P.) at 1.0 meters

Fig. 6 shows an isolated set of anomalies from a second magnetic grid in site 48YE381. A test unit on the central anomaly yielded an obsidian boulder with its base at about 1.0 meter deep. Extensive flakes around the base of that boulder indicated its long-term use as a seat or "furniture rock" for production of arrowheads, scrapers, and spear points. Test unit 12, two meters north, yielded several burned and fire cracked

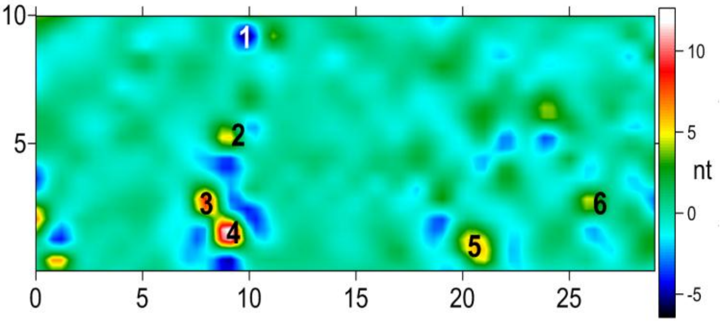

Figure 5. Filtered TMI for a shallow equivalent layer separated by matched filtering. Numbers mark test units; three of these test units revealed hearths and three revealed boulders. Horizontal dimensions are meters.

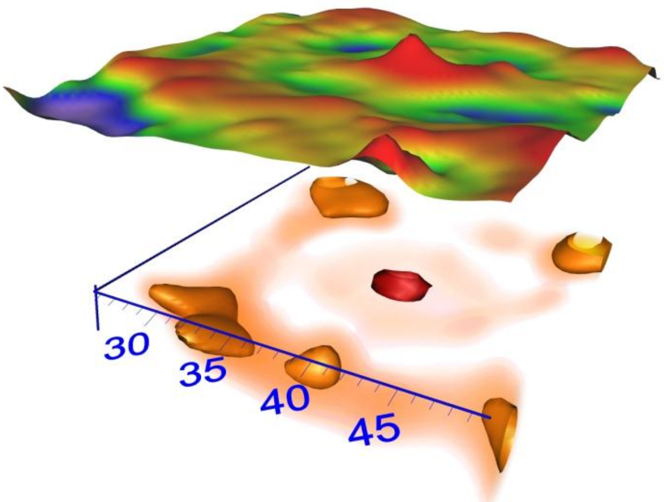

Figure 7. Upper image is filtered TMI, lower is source distribution (probably hearths) from inversions of TMI. Horizontal dimensions are meters.

rocks at a depth of 0.5 meters with a conventional radiocarbon age of 2840±40 BP. There are several radially distributed magnetic highs (Fig. 6) surrounding the anomaly over the furniture rock which is the central magnetic source. The remaining modeled sources (Fig. 6) likely represent features resulting from ephemeral camps around the central furniture rock.

Site 48YE1558, located on an S4 terrace dating to approximately 10,700 B.P. is roughly 250 meters inland from the northwest shore of the lake and holds evidence of Paleoindian (c. 9,000 B.P.) occupation. This is an area of a few lone pines, sagebrush, marsh/alpine meadow flowers, various alpine grasses and shrubs along the terrace. Low natural hummocky wetlands bound the site on its southwest and for most of its eastern limits. As delineated by surface artifact distributions, the site covers about 120,000 m^2. We sited two magnetic grids to investigate areas with the most artifact scatter in the southern part of the site.

In the first (2,000 m^2) of those two grids we excavated five 1x1 meter test units during the 2009 field season. One of the test units recovered a Late Archaic fire feature (1,470±60 B.P.) at 0.8 meters. Given its thinness (<5 cm) and amorphous shape, the feature likely was a very short-term fire during a camping episode on the S4 terrace at the end of the Late Archaic period. Another test unit had historic metal artifact as a source, while the three remaining test unit sources were large rhyolitic boulders.

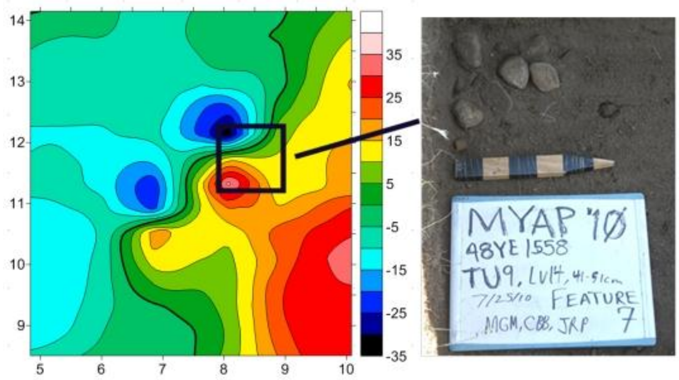

Figure 6. 48YE1558_TU9: Concentration of fire-cracked rocks (2,130 B.P.) 10-12 cm thick and the associated magnetic anomaly; horizontal dimensions are meters.

In the second (1,000 m^2) of the magnetic grids we excavated three test units based on magnetic results. One contained two stratified prehistoric features, the other two failed to yield features, probably due to mislocations. The excavated features (Fig. 7) were both small burn features at depths of 45 and 70 cm below datum with ages of approximately 2,130 and 2,310 B.P, respectively.

Not all of our magnetic investigations provided direct positive results with respect to archaeological excavation. Rather, some results were positive in the sense that they provided evidence of significant historical disruption. Thus, we were able to exclude these sites from further consideration for listing on the United States National Register of Historic Places. Two such sites, 48YE380 and 48YE1556, where we collected about 2,000 m^2 of total field magnetic revealed the existence of historic disruption due to old sewer lines and probable septic drain fields. As an example for site 48YE1556, on Fig. 8 the marked rectangles around rectilinear anomalies highlight relatively deep-sources; the solid line marks a probable trench leading to those rectilinear sources. Construction of the trench probably caused the large magnetic highs symmetrically across the line.

Calculating and comparing the analytic signal [10] and/or horizontal gradient [11] of TMI or the pseudogravity transformation [12] of TMI typically provides good edge detection for source location. For shallow sources, the vertical gradient of TMI is also common and valuable [e.g. 14]. To compare methods and to highlight the shorter wavelength anomalies in Fig. 8, we calculated [13] the vertical component of magnetization for two upward continuations of the TMI to 0.25 meters and 0.75 meters, respectively. Differencing those vertical components yields the vertical gradient (Fig. 9) and contoured it in the common grey-scale format. The vertical gradient (Fig. 9) clearly helps delineate the trajectory of the trench going into the rectilinear area. The cost of that delineation is the loss of some resolution of the deeper, rectilinear sources. For this grid and most others, we compared separation of equivalent source layers by both differencing upward continuations and by employing matched bandpass

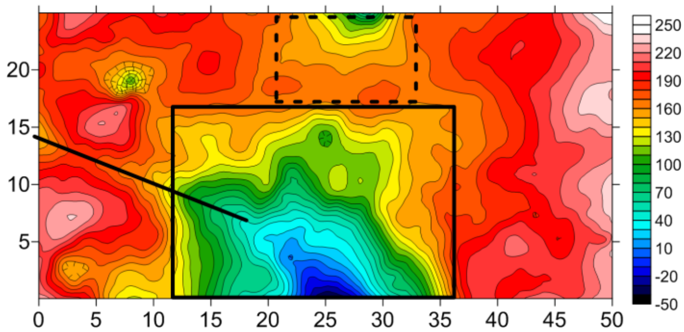

Figure 8. 48YE1556 ,TMI after filtering. The solid line marks an old trench/pipe leading to a probable septic drain field. The rectangles surround suspiciously rectilinear anomalies that we interpret as historic features.

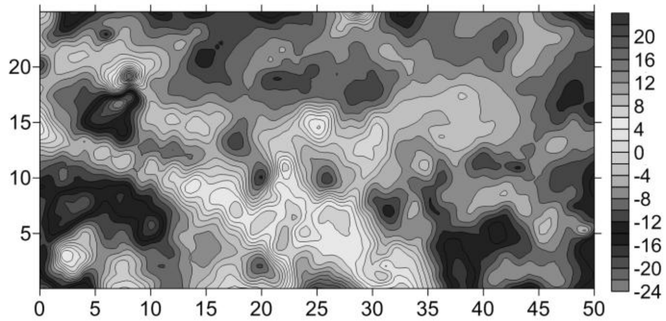

Figure 9. Vertical gradient of TMI from fig. 8; contours are nT/m. Note that the range of signal is much reduced with respect to TMI (Fig. 8).

filtering. Here, both methods yield comparable separation of shallow and deep sources but such is not always the case; sometimes one result is more distinct than the other. Following separation, the analytic signal (total gradient), horizontal gradient, and vertical gradient all contributed good edge detection and further insight into the source characteristics.

V. Summary

Our hierarchical approach includes starting with close-interval (ca. 2-3 meter) pedestrian surveys followed by more detailed observation, and then siting of limited grids for the acquisition of total field magnetic observations. That hierarchical method, followed by archaeological test units, has successfully contributed to delineating archaeological resources and ascertaining the cultural history of Yellowstone National Park [16]. After excavating test units at selected magnetic anomalies about 40% of those excavations yielded cultural material with most of the remaining sources being glacial erratics or occasional historic ferromagnetic materials. Of course, all anomalies have sources; the glacial erratics around Yellowstone Lake produce anomalies similar to those of the ephemeral hearths we seek. In the case of the feature we call "furniture rock" a glacial erratic proved to be a nice lakeside seat for flaking and other camp chores.

Acknowledgments

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