CHAPTER 12

TOTAL FIELD MAGNETIC EXPLORATION FOR PREHISTORIC ARCHAEOLOGICAL SITES ALONG YELLOWSTONE LAKE’S NORTHWEST SHORE

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Abstract

The Montana-.Yellowstone Archaeological Project 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 contributed about 200 hectares of archaeological survey focused on the northwest shores of Yellowstone Lake (Figure 1). In hopes of optimally placing archaeological test units, we subjected a small fraction of those 200 hectares to total field magnetic (TMI) and/or Ground Penetrating Radar (GPR) investigation. The typical archaeological features and geophysical targets in Yellowstone National Park are temporary campsites, small ephemeral surface hearths, occasional larger roasting pits, stone rings, and indeterminate artifact scatters; there are no village sites. The materials used for the campsite features were existing glacial erratics, ice-rafted dropstones, and colluvial debris. This introduces a complication in that given TMI or GPR results alone, it is not yet possible to separate rocks used for many of the above cultural processes from those occurring naturally.

Our first geophysical objective was to complete a number of detailed TMI grids occasionally followed by GPR surveys in sub-areas with a high likelihood of cultural features. To choose these small areas for investigation with magnetometry we first completed close-interval 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 m² to 2,500 m² depending on access and our interest. Our next objective was to rapidly acquire, process, and interpret sufficient, meaningful magnetic data in the time available to guide placement of test units. In some cases, sufficiently clear and flat ground conditions allowed GPR investigation as well. The GPR results can be particularly valuable by allowing one to eliminate magnetic anomalies from fluvial features from further consideration.

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. Thus, our hierarchical method of pedestrian survey and geophysical exploration followed by archaeological test units successfully contributed to delineating archaeological resources and ascertaining the cultural history of Yellowstone National Park.

Figure 1. Location of Study Area
Project Overview

The University of Montana’s (UM) 2009 and 2010 field seasons were focused on the lake developed area along the northwestern shores of Yellowstone Lake near Fishing Bridge and Lake Lodge (Figure 1). As discussed above, we conducted total field magnetic (TMI) and/or Ground Penetrating Radar (GPR) investigations at several sites in meadows and shorelines between Lake Lodge and Fishing Bridge. We do not show precise site locations to avoid artifact collection in this busy area of the park. We placed these geophysical grids in areas where standard pedestrian surveys found higher concentrations of artifact scatter suggesting a reasonable likelihood of subsurface archaeological features.

The typical archaeological features and geophysical targets in Yellowstone National Park are temporary campsites, small ephemeral surface hearths, occasional larger roasting pits, stone rings, and indeterminate artifact scatters; there are no village sites. The materials used for the campsite features were existing glacial erratics, ice-rafted dropstones, and colluvial debris. This introduces a complication in that given TMI or GPR results alone, it is not yet possible to separate rocks used for many of the above cultural processes from those occurring naturally.

The ultimate MYAP 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 this survey and evaluation, MYAP (MacDonald and Livers 2011) collected nearly 11,000 prehistoric artifacts indicating ephemeral use of the northwest lakeshore since the Late Paleoindian period (~10,000 B.P.). We include here a summary of our techniques, representative maps of processed total magnetic intensity, and examples from excavation of typical archaeological and/or geophysical targets.

Prehistoric Setting, Geophysical Targets

Pleistocene volcanic eruptions, lava flows, and associated thermal uplift formed the Yellowstone Plateau physiographic province (Pierce et al. 2007). During glacial maxima an icecap covered almost the entire Yellowstone area. The most recent icecap was virtually gone by 12,000 B.P. (Hale 2003; Licciardi and Pierce 2008), 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 up to a meter or more 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 Pierce et al. (2007) related to glacial rebound and caldera deformation range in age from 14,000 B.P. to present. These terraces provide potential living surfaces when they emerge. Thus, we expect evidence of habitation and human use of terraces shortly after their emergence.

Sagebrush and short-grass prairie as well as stands of lodgepole pine and spruce dominate the study area (Figure 2). Both the boulders and sagebrush complicate geophysical investigation and interpretation. Naturally distributed boulders yield geophysical signals similar to many human arranged features. The sagebrush, bunchgrass, and surficial erratics often rule out using GPR as those antennas must contact the ground for good electromagnetic coupling and low-noise results. Further,

Figure 2. Typical summer field conditions with tall grass, sagebrush, and lodgepole pines. Winter snowpack is meters deep when -20C temperatures are common.
the sagebrush, bunchgrass, and surficial rocks make smooth walking difficult during the acquisition of magnetic observations. The latter complication is efficiently and effectively addressed with signal processing techniques (e.g. Sheriff et al. 2010).

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 (e.g. Hale 2003). Deep 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, their temporary campsites are the typical archaeological features and geophysical targets in Yellowstone National Park, similar to the targets sought by Jones and Munson (2005). These are the features we seek with the geophysical exploration methods in this study. Camps were small and used for short-term occupations during summer months. Of the features of interest, only stone rings would have geometry and signal different than naturally occurring features.

Methods
Total Field Magnetic Investigation

About 180 km of shoreline surrounds 350 km² of Yellowstone Lake. Consequently, the archaeological survey of the areas included multiple 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 m² to 2,500 m² depending on access, our interest, and available time. 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 archaeological test units.

Once we determined an area for which we desired magnetic data, we established grids using the archaeological datum 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 (TMI) observations at 10 Hz to assure sub-decimeter sampling along traverse lines (see Figure 2). We acquire these data 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. The magnetometer software then linearly interpolates the observations along each line while assuming straight lines.

The Geometrics G858 is a total field cesium vapor magnetometer with nominal sensitivity of 0.05 nT at a 10 Hz sampling rate. While vertical gradient fluxgate (vector) magnetometer surveys are quite common in Western Europe (Aspinall et al. 2008) and to some extent in the United States (e.g. Jones and Munson 2005, De Vore 2008a, De Vore 2008b) collecting total field intensity (TMI) offers several advantages. First, collecting the vertical gradient of a magnetic anomaly is essentially applying a high pass filter, or edge detector, in the field to bias against signal from deeper sources. Modeling of appropriate causative sources shows that if such sources are buried a meter in more, their signal is severely attenuated on vertical gradient maps relative to TMI maps. Thus acquiring TMI data allows detection of deep and shallow targets which can later be isolated with common equivalent layer separation techniques (Sheriff 2010). Second, deciding on line separation to be used during magnetic surveys is a fundamental part of experimental design. One wants sufficient coverage to guarantee finding all features of interest within a specified depth and size limit. Yet, decreasing the spacing between acquisition lines adds substantially to the total time, thus cost, of a magnetic survey. Here, TMI investigations offer another advantage over acquisition of the vertical gradient. This improvement is evident upon consideration of the magnetic field over a simple...
magnetic dipole. That field strength is proportional to 1/r², where 'r' is the distance from the magnetometer to the magnetic dipole; the vertical gradient of the same dipole is proportional to 1/r³. Thus, because the vertical gradient falls off notably faster with distance than the total field, vertical gradient surveys necessarily require tighter line spacing to achieve the same detection ability as total field surveys. Finally, given the total field anomaly, calculating the vertical component and its vertical gradient, is a simple procedure (Pedersen et al. 1990). Thus, one can display the gradient of the vertical component along with other edge detection techniques to highlight shallow sources as part of the processing routine while still acquiring signal from deeper sources.

Traditionally, when designing a magnetic survey, we use standard sampling theory which requires at least two observations per the shortest wavelength of signal in any gridded or profiled data set (e.g. Blakely 1995). We then calculate the power spectrum of expected buried sources to determine the ratio of elevation above sources and spacing between lines of acquired data. Upon doing so, we find that an isolated dipole requires line or sample spacing equal to or less than the depth of the source below the sensor. Obviously, isolated theoretical dipoles are uncommon archaeological targets; hearths, boulders, or assemblages of fire cracked rock, are not point source dipoles. The sources we seek are better characterized by the equations for a magnetized half space with magnetic distribution proportional to 1/f², where f is spatial frequency; colloquially, this fractal distribution is known as red noise. This more realistic model has less stringent sampling requirements than that of an isolated magnetic dipole. Assuming a 1/f² distribution suggests maximum sample or line spacing equal to twice the depth of the layer.

We acquire TMI observations on lines spaced one meter apart after analyzing the power spectra for simulated sources which shows line spacing can be twice the separation of the source and sensor. This keeps aliasing of shorter wavelength components sufficiently small to still allow detection and accurate modeling by forward or inverse methods. Boulders and arranged cobbles are distributed sources with respect to theoretical dipole targets. Thus, though theoretical individual dipoles require half that line spacing our targets of interest are spatially broader than dipole sources and readily evident on data acquired at one meter line intervals. Our empirical comparison of occasional test grids from other projects collected at half meter intervals typically shows no additional anomalies of interest compared to data collected at one meter line intervals.

Sources of measurement noise during acquisition include slow to rapid changes in Earth’s magnetic field, positioning errors, and instrumental noise. Rough ground, substantial sagebrush, and bunchgrass in our field areas made steady, straight walking difficult. Such difficult acquisition causes regular spatial and rotational displacement of the magnetometer’s sensor as well as changes in pace which adds much noise to the acquired observations. Fortunately we can 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 magnetically quiet periods as observed by NOAA (2010) and our on-site observations. We also used a GEM Systems recording Proton Precession base station magnetometer for diurnal corrections on many larger grids. For these grids, we perform the correction for diurnal variations of the geomagnetic field by simply subtracting the time-appropriate ambient field strength at a fixed location from the observation made at the corresponding time in the grid of data being collected. Grids collected and processed without simultaneous base station observations of the ambient field will contain geomagnetic variations convolved with the desired anomalies from targets of interest. The frequency spectrum of such geomagnetic variation 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 which are much larger than the amplitude of short period magnetic field changes during our studies.

Our TMI observations, gridded by kriging with 0.4 meter spacing, include features at three dominant scales. First, there is experimental noise resulting from sensor position errors during acquisition and the effects of highly magnetic rhyolite and obsidian cobbles and historic debris on the surface. The corrugation (e.g. Sheriff et al. 2010) 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 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. This impacts the distance and orientation of the sensor relative to the ground and causes variation in pace while acquiring TMI observations at 10 Hz which manifests as linear magnetic anomalies, known as corrugation, in the direction of acquisition. These anomalies are highly correlated with acquisition lines.

We use a common technique (Urquhart 1988) for decorrigration filtering as elaborated on in Sheriff et al. (2010). Essentially, we filter the data and add short wavelength components from along acquisition lines to long wavelength components across the lines.

The second and third spatial scales of magnetic anomalies in ground based magnetic investigation are from deeper geologic sources and shallow potentially interesting sources at the archaeological and/or environmental scale. Anomalies at the latter scale also include near surface sources such as lateral or vertical changes in the soil or other local geology. We typically separate magnetic signal from these shallow and deep sources into equivalent layers using either differencing of upward continuations following (Jacobsen 1987) or matched bandpass filtering based on equivalent sources (Pedersen 1991). Upward continuation (Blakely 1995) is a process whereby the magnetic field is recalculated as if the observations were acquired at a higher level above the ground, thereby simulating a buried target. The application, subsequent choice of method and its success is largely empirical and determined by experimentation.

Employing matched bandpass filtering for anomaly separation has a long history (Nabighian et al. 2005) 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 as demonstrated by Sheriff (2010). The successive application of correcting for diurnal variation of the geomagnetic field, orthogonal wavelength filtering to remove corrugation, and then separating the TMI observations into equivalent magnetic layers yields magnetic maps ready for interpretation.

Edge detection follows filtering applied for decorrigration and equivalent layer separation. Not only does edge detection highlight anomalies of interest, done properly it centers anomalies over their causative sources as does a reduction to pole transform (e.g. Blakely 1995). For edge detection and source location, we typically compare results from calculating the analytic signal (Roest et al., 1992) and horizontal gradient (Blakely and Simpson 1986) of either the equivalent layer or the pseudogravity transformation (Baranov 1957) of that layer. For small features, such as concentrations of fire-cracked rocks, the analytic signal provides a single anomaly over the source while the horizontal gradient tends to work better for delineating edges of larger features. Calculating the vertical gradient (Pedersen et al. 1990) of the total magnetic intensity can also highlight shallow sources (e.g. Aspinall et al. 2008) so we also occasionally employ that technique along with other image enhancement and edge detecting techniques.

Typically, during the processing and interpretation steps discussed above, one tests different methods and parameters during each step. Thus, one would evaluate different filter window sizes to select the optimal size for decorrigration hoping to best decrement noise and retain anomalies of interest. Sometimes differencing upwards continuations isolates different interesting anomalies during equivalent layer separation than does matched filtering. Ultimately, comparing and considering the results of several edge detection techniques often leads to anomaly recognition missed by any individual technique. Consequently, in the following we present the final interpreted results from our magnetic exploration
Ground Penetrating Radar Investigation

In some instances we were also able to collect ground penetrating radar (GPR) data within a magnetic grid. A very large percentage of the area around Yellowstone Lake is not amenable to successful GPR investigation because a requirement for reasonable GPR results is less than 2.5 centimeters of ground clearance and roughness; GPR antennas must sit on the ground. The tall grasses, sage brush, rabbit brush, other foliage, rocky terrain, and geomorphological rugosities greatly exceed the 2.5 cm specification throughout the area limiting GPR acquisition without significant clearing of the area. In a few cases we were able to acquire GPR observations within limited areas where topography and surface conditions allowed its use.

Ground Penetrating Radar (GPR) is an active source geophysical tool in which tuned antennas, typically 250 - 500 MHz for archaeological work, transmit radar waves into the subsurface and subsequently receive radar reflections from subsurface changes in electrical properties. Antenna choice is based on the likely targets, ground conditions, and depth of interest. For this study we collected the GPR data using a Mala Ramac 500 MHz antenna system. We chose this antenna because the expected targets from the magnetic investigations appeared to be within a meter of the surface and the 500 MHz wavelengths are on the order of one quarter of a meter. With a nominal transect spacing of 0.5 meters and radar velocities appropriate for the materials in the area, the 500 MHz signal spreads enough to allow overlap and very good line-to-line interpolation of results. We collected GPR profiles with a line spacing of 0.50 meters at 20 individual radar pulses (traces) per meter along lines.

In GPR profiles (depth sections) we plot reflections from subsurface sources as the time to travel down to, and back up from, reflectors thereby mapping the depth and shape of the reflectors. When collected in a tight grid, we also make time-slice maps showing the amplitude of reflected radar waves in map view.

GPR results require substantial processing to get the most information out of the data. Typically, one analyzes and interprets numerous individual profiles and iteratively processes those with different parameters to determine the most suitable filter parameters for a given situation. Assembling the group of profiles yields a 3D volume for analysis. Next, one produces and inspects a myriad of time slices to determine the best interpolation parameters, window lengths, and starting times to bring out reflection features of potential archaeological interest. In either case (profiles or time slices) we analyze the results looking for disruptions of natural stratigraphy and subsurface geology. We interpret truncated reflections, diffraction returns, and changes in amplitude while rarely seeing definite images. Typical shapes we might find in time slices would be that of stone rings, pit houses, compacted living surfaces, grave sites, and the like.

Expectations and Examples

Temporary campsites represented by small ephemeral hearths (Figure 3), rare larger basin-shaped features (Figure 4), stone rings (tipi rings), and indeterminate artifact scatters are the typical archaeological features and geophysical targets in our Yellowstone work as they were for Jones and Munro (2005). Given these targets, strong obvious magnetic signals with characteristic, non-natural geometry are rare. And, the building materials, which are the locally derived glacial erratics common on the surface and in the

![Figure 3. Representative hearth exposed in profile due to wave erosion at 48YE380, dated to 1600 BP (MacDonald, Chapter 13, this volume).](image-url)
shallow subsurface, create substantial magnetic anomalies whether naturally or culturally distributed. Finn and Morgan (2002) report both remanence values for the volcanic rocks in the area (0.5 to 10 A/m) and their susceptibilities which range from \(1 \times 10^{-3}\) to \(5 \times 10^{-4}\). This complicates the archaeological exploration issue. Their smaller counterparts, cobbles on the surface, add point dipole signals to the observations which we treat, by filtering, as noise.

Among our expected targets were stone rings as prevalent in the northern borderlands of Yellowstone National Park (Livers 2011). Stone rings (tipi rings) if they exist in the area would be comprised of a mix of individual glacial erratics and other locally available boulders. These stones have quite variable magnetizations. To investigate the likelihood of detecting buried stone rings, we simulated buried rings by upward continuing TMI observations acquired over surface rings near Kevin, Montana (O’Boyle et al. 2011). Upward continuation (Blakely 1995) is a process whereby the magnetic field is recalculated as if the observations were acquired at a higher level above the ground, thereby simulating a buried target. Upward continuation of the total magnetic intensity of visible stone rings by up to 1.5 meters demonstrates that the radial symmetry of such features is detectable at depth with minimal filtering and edge enhancement. Jones and Munro (2005) showed similar results.

While designing experiments, 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. We designed experiments and acquired observations with these features in mind. 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.

**Representative Grids, Archaeological Results**

*Site 48YE381 (Fishing Bridge Point Site)*

Located on an S2 terrace dating to approximately 8,000 B.P., site 48YE381—the Fishing Bridge Point Site (MacDonald, this volume) is along Yellowstone Lake’s northwest shore and holds cultural features from ca. 1,500 B.P. to 6,000 B.P. (MacDonald and Livers 2011). 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 m². We sited two magnetic grids (2,500 m² and 300 m²) 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 (northern) grid which helped eliminate excavating some test units into fluvial structures.

Figure 5 shows the magnetic and radar anomalies we chose to investigate with 1x1 meter test units in the first of the two grids in 48YE381; other apparent anomalies had surface sources or lack the shape or size of interest. Although GPR time slices showed some interesting arcuate features where we also had magnetic features, the GPR profiles confirmed those were from horizontal
slices through the cross bedded fluvial sediments. Thus we refrained from excavating at those anomalies. To interpret the magnetics, 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. The sum of these steps leads to the selection of the marked test units. The discoveries in those test units (Figure 5) include:

- #1, #2, and #3 yielded only boulders. Each individual anomaly has the character of a boulder yet their concentration and alignment was promising. We placed test units to the sides of the marked anomalies to avoid dropping in on top of features. Thus, these anomalies were not directly investigated;
- #4: hearth (1,720 ± 40 B.P.) and evidence of obsidian tool manufacturing at 0.56 meters;
- #5: hearth (2,920 ± 40 B.P.) at 0.8 meters;
- #6: hearth (3,090 ± 40 B.P.) at 1.0 meters;

Figure 6, from elsewhere in site 48YE381, shows an excavated magnetic source along with an isolated set of anomalies and a subsurface model of the potential shape of the sources from the second magnetic grid in the site. A test unit on the central anomaly yielded a welded tuff boulder with its surface at 30 cm and its base at about 1.0 meter deep. The surface of the boulder was smoothed, as if used for a table or food processing area (Macdonald and Livers 2011). 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 of this feature, yielded several burned and fire cracked rocks at a depth of 0.5 meters with a conventional radiocarbon age of 2840±40 BP. Figure 6 shows a calculated shape of the subsurface sources using MAG3D (2007) employing the techniques of Li and Oldenburg (1996). There are several radially distributed magnetic highs (Figure 6) surrounding the anomaly over the furniture rock which is the central magnetic source. Although not investigated with test units, the remaining modeled sources (Figure 6) radially around the central source may represent hearths associated with additional ephemeral camps around the central furniture rock. This is likely because MacDonald and Livers (2011) report Middle Archaic features with fire cracked rock in test units within two meters of the test unit intersecting the furniture rock.

Of ten total test units placed in site 48YE381 based on magnetic anomalies, four yielded ancient cultural results. For the remainder, boulders of welded tuff were the causative source (four test units) or, test units were placed adjacent to anomalies and missed the source. An additional benefit was that we avoided placing test units in parts of the grid which showed the impact of recent (historic) cultural disruption.

Site 48YE1558 (Lake Lodge Meadows Site)
Site 48YE1558, the Lake Lodge Meadows Site, 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 (MacDonald and Livers 2011). 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 m². We sited three magnetic grids to investigate areas with the most artifact scatter in the...
southern part of the site just parallel to the old road (now a walking path).

In the southern (2,000 m$^2$) of those three 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 a historic metal artifact as a source, while the three remaining test unit sources were large rhyolitic boulders.

In the second (1,000 m$^2$) of the magnetic grids, about 125 meters north of the first, 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 (Figure 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.

The third and northern most magnetic grid (2,400 m$^2$) in 48YE1558 showed several high amplitude, short wavelength anomalies characteristic of near-surface metallic sources as well as numerous similar but smaller anomalies from similar sources or magnetic cobbles at or near the surface as labeled on Figure 8. We investigated only three of those anomalies with test units (19-21) placed at the marked anomalies g, k, and b, respectively (Figure 8); none yielded cultural features confirming this interpretation. The anomaly labeled ‘M’ has promising character but further observation showed significant recent surface disturbance which likely is the source of that anomaly and rendered it unlikely to contain prehistoric materials. We placed an additional test unit (TU22) in the grid on a spot without a magnetic anomaly but with a concentration of lithic scatter on the surface. MacDonald and Livers (2011) note that this excavation yielded a ‘possible feature’, a circular dark black soil stain with a few fire cracked rocks at a depth of about 60 cm. Magnetic anomalies from such sources would likely yield signals too small for detection within the background noise.

Figure 7. 48YE1558_TU9: Concentration of fire-cracked rocks (2,130 B.P.) 10-12 cm thick and the associated magnetic anomaly; horizontal dimensions are meters; magnetic field in nT.
Within site 48YE1558, as in others, while the results from magnetic exploration are positive they definitely demonstrate the difficulty of having a mix of glacial erratics, drop stones, and fluvial material in the subsurface. These same materials are used for building ancient cultural features and containing ephemeral campfires. All magnetic anomalies have sources, but it remains difficult to separate natural and cultural sources in these conditions. As noted by MacDonald and Livers (2011), in this site the magnetometry work produced a feature-identification rate of 37.5% when only ancient cultural results are considered as positive. From an exploration and anomaly identification standpoint, isolating the signature of any subsurface source can be considered positive as well. Throughout 48YE1558, ten test units were placed outside of magnetic grids or within a grid but not on an anomaly. Only one of these, TU13, between the northern and central magnetic grids yielded a feature (MacDonald and Livers 2011). This success rate of 37.5% is consistent with our results in other sites around Yellowstone Lake.

Site 48YE380 (Lake Pump Station Site)

Site 48YE380, also known as the Lake Pump Station Site (Hoffman 1961), is approximately 150 m east of Lake Lodge on a small point along the lakeshore. It sits on an S1 terrace dating to about 7,000 B.P. (Pierce et al. 2007). Numerous studies have excavated hearths and other features, all of which span the Late Archaic period between 3,000 and 1,500 years ago (see MacDonald and Livers 2011). Many of the previously excavated features, as well as some recently exposed features, are along the lake edge and most of the site is within a small grove of lodgepole pines along the lake shore. Therefore, we only
collected magnetic data on one small (250 m²) grid (Figure 9). The filtered anomalies from this grid are readily apparent and consistent in that they form a strong linear trend from southwest to northeast and clearly mark historic construction as the trend points directly at the historic location of the pump house. The anomaly marked by the 'X' is characteristic of a reversely magnetized metal post or pipe. Given this historic disruption we did not excavate within this magnetic grid.

Site 48YE1556

This site shares a characteristic with the previous (48YE380) in that 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. Such disruption can lead one to exclude a site from further consideration for listing on the United States National Register of Historic Places.

At Site 48YE1556 we collected about 1,250 m² of total field magnetics (Figure 10) on an S6 terrace (~14,000 B.P.) which only revealed the existence of historic disruption due to old sewer lines and probable septic drain fields. Thus these results are negative in the sense of locating prehistoric features but positive in that they characterize the subsurface and still guide excavation. We chose not to put test units in the historically disrupted areas marked by the rectangles in Figure 10. Rather, we placed five test units in the eastern (right) ten meters of the grid where there are no meaningful anomalies; those test units yielded no features.

On Figure 10 the marked rectangles around rectilinear anomalies highlight relatively deep-sources; the source beneath the dashed rectangle, with its lower gradient and amplitude anomaly, is probably deeper than that beneath the solid rectangle. The solid line marks a probable trench leading to those rectilinear sources. Debris piled during excavation of the trench probably caused the large magnetic highs symmetrically across the line towards the western (left) edge of the grid.

The relatively shallow and deep sources beneath the rectangles marked on Figure 10 provide a convenient example regarding the benefits of total field magnetics versus collecting the gradient of the vertical component as discussed earlier in this paper. Typically in magnetic exploration we seek buried sources and hope to delineate the edges of those sources and their depths. Calculating and comparing the analytic signal (Roest et al. 1992) and/or horizontal gradient (Blakely and Simpson 1986) of TMI or the pseudogravity transformation.

![Figure 9. Total magnetic intensity from grid near the Lake Pump Station site; contour interval is 2.5 nT.](image-url)
(Baranov 1957) of TMI typically provides good edge detection for source location. For shallow sources, in-the-field edge detection using the vertical gradient of TMI is also common and valuable (e.g. Aspinall et al. 2008). That is among the reasons that vertical gradient magnetometers are often used in archaeological surveys.

To demonstrate the loss of resolving power for deeper sources when measuring the vertical gradient rather than the total field anomaly, we calculated (Pedersen et al. 1990) the vertical component of magnetization for two upward continuations (Blakely 1995) of the TMI to 0.25 meters and 0.75 meters above the observation surface, respectively. This calculation simulates the common setup of a vertical gradient magnetometer (e.g. Aspinall et al. 2008). Differentiating those vertical components yields the vertical gradient (Figure 11) expressed in nT/m. The vertical gradient (Figure 11) clearly helps delineate the trajectory of the trench going into the rectilinear area. The cost of that delineation is the degradation of resolution of the shallower rectilinear source shown by the solid rectangle on Figure 10 and the near total loss of signal from the deep source marked by the dashed rectangle on Figure 10. Normal sedimentation and turf buildup suggests that ancient cultural sources buried deeply in the older terraces would be missed with a vertical gradient magnetometer survey.

Summary

This study was one of exploration rather than an attempt to provide total field magnetic data for 100% of the area. Thus, we sought valuable results within timing and funding constraints that would improve the productivity of archaeological test units. The approach proved successful.

The targets in mind while designing our geophysical surveys along the northwest shore of Yellowstone Lake included temporary campsites, small ephemeral surface hearths, larger roasting pits, stone rings (tipi rings), and the like. We used a hierarchical approach, starting with close-interval (ca. 2-3 meter) pedestrian surveys followed by more detailed observation, and then siting limited grids for the acquisition of total field magnetic observations. In one case we also had sufficiently open ground to cover part of the magnetic grid with GPR observations.

The resultant seven magnetic grids in four sites were quite positive in locating anomalies for excavation and yielding cultural or natural sources. Note that while many test units recovered lithic fragments, sometimes in high
concentration, those would rarely create detectable anomalies. In 48YE380 the magnetic grid showed a historic trench (no longer apparent on the surface) trending to the sewer pump house; we avoided excavation in this grid. In 48YE381 in two magnetic grids, four of ten test units sited on magnetic anomalies revealed hearths, four yielded subsurface boulders (one of which showed cultural use), and two test units were placed adjacent to anomalies. In 48YE1556 the magnetic grid revealed the location of historic disruption from historic septic facilities; we avoided excavation in this area. However, we did site five test units in the grid north of the disruption. These lacked magnetic anomalies and revealed no cultural features. The northern grid in 48YE1558 lacked any archaeologically compelling anomalies; test units confirmed that interpretation. However the southern two grids in 48YE1558 revealed cultural features, mainly hearths, in four of ten test units sited on magnetic anomalies. Four of the remaining tested anomalies revealed naturally distributed subsurface rocks, while two were placed adjacent to anomalies and revealed no additional sources. Throughout the magnetic grids, we found no buried stone rings nor roasting pits, though some rock concentrations may result from their construction. Perhaps stone ring material is commonly recycled forward in time and upward in stratigraphy.

Our hierarchical method, comprised of pedestrian survey, then siting geophysical grids in areas of high surface scatter, followed by excavation of archaeological test units successfully contributed to delineating archaeological resources and ascertaining the cultural history of Yellowstone National Park (MacDonald and Livers 2011). 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. Other results rejected sites or excavation due to historic disruption. Of course, all magnetic 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 buried glacial erratic with a magnetic anomaly characteristic of such a source proved to be a nice lakeside seat for flaking and other camp chores.

The general magnetic exploration and processing protocol we use is adapted from common techniques.
used during aeromagnetic exploration for energy and minerals (e.g. Reeves 2005). We acquire TMI data at 10 Hz while walking bidirectional transects separated by one meter. These data are then decorrugated and separated into shallow and deep equivalent magnetic layers (Sheriff 2010). Following separation, the analytic signal (total gradient), horizontal gradient, and vertical gradient all contribute good edge detection and further insight into the source characteristics. At times, those results are suitable for depth estimate or inversion for the shape of the subsurface source. We base final decisions on placing test units on the sum of the results and visualizations.

Acknowledgements
This work was completed in conjunction with efforts and contributions from Doug MacDonald and Michael Livers. The National Park Service provided funding to Yellowstone National Park, with subsequent Rocky Mountains Cooperative Ecosystem Study Unit agreement H120009004.

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