

Ground Penetrating Radar Studies at Mammoth Hot Springs

by Marvin Speece and
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Introduction

The Fort Yellowstone-Mammoth Hot Springs Historic District has long been an area of development within Yellowstone National Park. The park's second superintendent, Philetus W. Norris, selected Mammoth as the permanent park headquarters in 1878 because of "its nearness and accessibility throughout the year, through one of the...main entrances to the park to the nearest permanent settlements of whites and a military post, [because of its] remoteness from routes inviting Indian raids, and [its position as] a proper site for defense therefrom, and [because it provided] for ourselves [and our] saddle and other animals, good pasturage, water, and timber, as well as accessibility to the other prominent points of interest in the Park."¹

In retrospect, Mammoth has in some ways proved to be an unfortunate choice for park headquarters. For example, the surface rock in the area is a variety of layered limestone called travertine. Because travertine is highly porous and susceptible to dissolution, subsurface cavities are present throughout the area. Collapse features that form when subsurface

water weakens overlying travertine are commonly seen at the surface. Moreover, the horizontal travertine beds are cut by numerous steeply dipping fractures. The area features active hot springs with new hot springs forming and some old hot springs becoming inactive. As a result, the area is unstable, and historic buildings are occasionally threatened by the inconstant thermal features and subsidence. For instance, the historic 1907 H.W. Child's Residence, also known as the Executive House, is threatened by the encroachment of the relatively young Opal Terrace hot spring feature.

Throughout Yellowstone National Park's history, the area's unique cultural and natural resources have generated a great deal of research activity by both park and outside researchers. This has resulted in substantial collections of natural resource specimens and cultural resource artifacts being stored in overcrowded facilities and a lack of researcher workspace. Current storage conditions do not meet professional standards, and deficiencies include inadequate environmental controls, security, fire protection, and pest management.

To best serve researchers and the re-

source collections, the park needs a consolidated research and preservation facility for storage and exhibition of cultural and natural resource collections. The proposed facility, the "Yellowstone Heritage and Research Center," will be approximately 35,000 square feet in size and include storage and exhibit areas, wet and dry laboratories, and researcher workspaces. Mammoth Hot Springs has been targeted as the preferred location so that the facility will be accessible year-round to park staff and visiting researchers.

Given the unstable geology of the area, park staff are concerned about finding a secure site for this facility. Noninvasive subsurface investigations commonly employing one or more geophysical techniques were considered as a preliminary step in surveying potential construction sites at Mammoth Hot Springs. Geophysical techniques can provide images of the subsurface with a minimum of surface

Montana Tech students conduct GPR survey near the Mail Carrier's Cabin. Students pull a sled containing radar antennas. Photos courtesy Marvin A. Speece.

disturbance. In the best case, these images can give sufficient detail to locate subsurface cavities and large-scale fractures or faults. Such information may also help the park staff manage conflicts posed when ever-changing thermal features threaten cultural resources.

The need for geophysical site characterization at Mammoth provided a unique opportunity for a cooperative study involving students and faculty at Montana Tech of the University of Montana, working with the National Park Service.

How Ground Penetrating Radar Works

Of the commonly used geophysical techniques, ground-penetrating radar (GPR) has the greatest resolution. In ideal situations objects in the subsurface with contrasting electrical properties that are separated by only a few centimeters can be distinguished from one another. GPR is the geophysical method of choice whenever sufficient electrical property contrasts exist and high resolution is desired. Moreover, GPR profiles can be quickly

displayed and interpreted in the field. Most other geophysical techniques require elaborate post-processing or modeling that can take additional time and thereby delay gratification and increase costs.

In practice, GPR measurements are made by moving transmitting and receiving antennas (1 MHz to 1 GHz) along the ground surface. At a particular position along the surface, the transmitter emits an electromagnetic wave into the ground. When this wave encounters a boundary between materials of differing electrical properties, some of the incident wave energy is reflected back to the surface. The energy returning to the surface is, in turn, recorded at the receiving antenna. The information recorded at one ground position is called a trace. Reflected energy on the trace is observed as an increase in the signal amplitude that occurs at a particular time along the trace.

As the GPR system is moved along the ground surface, traces are recorded at regular intervals. When these traces are displayed side-by-side as a cross section, the size, shape, and depth of a reflecting object can often be determined. Some common features that cause reflections in the subsurface include: 1) changes in rock type, 2) cavities, 3) plastic and metal containers, 4) pipes, 5) changes in porosity, 6) the water table, 7) hydrocarbon plumes, and 8) building foundations.

Unfortunately, the electrical conductivity of the subsurface limits the use of GPR. As conductivity increases, the depth of penetration decreases. In highly conductive, clay-rich soils, the effective depth of penetration of the electromagnetic waves may be less than a meter. Water can also limit the use of GPR. As the salinity or total dissolved solids in water increases, the conductivity of the water increases and severely limits the ground-penetrating capabilities of radar. Local geologic conditions govern which geophysical methods can be used at a given site.

In the Mammoth Hot Springs area, the surface rock is predominantly a hydrothermal variety of layered, porous limestone known as travertine. Limestone typically has low conductivity, making it ideal for radar use. On the other hand, when highly mineralized ground water is

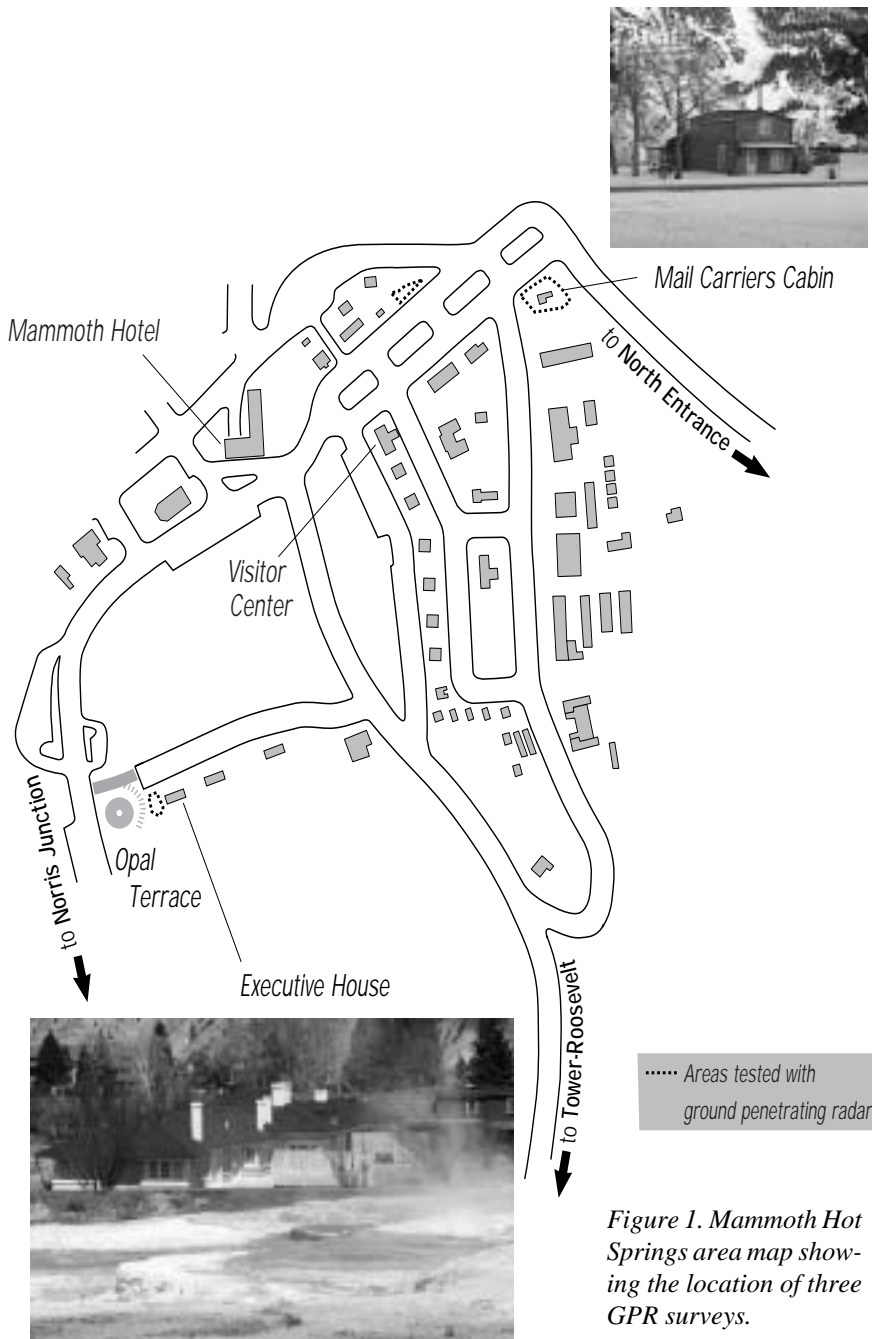


Figure 1. Mammoth Hot Springs area map showing the location of three GPR surveys.

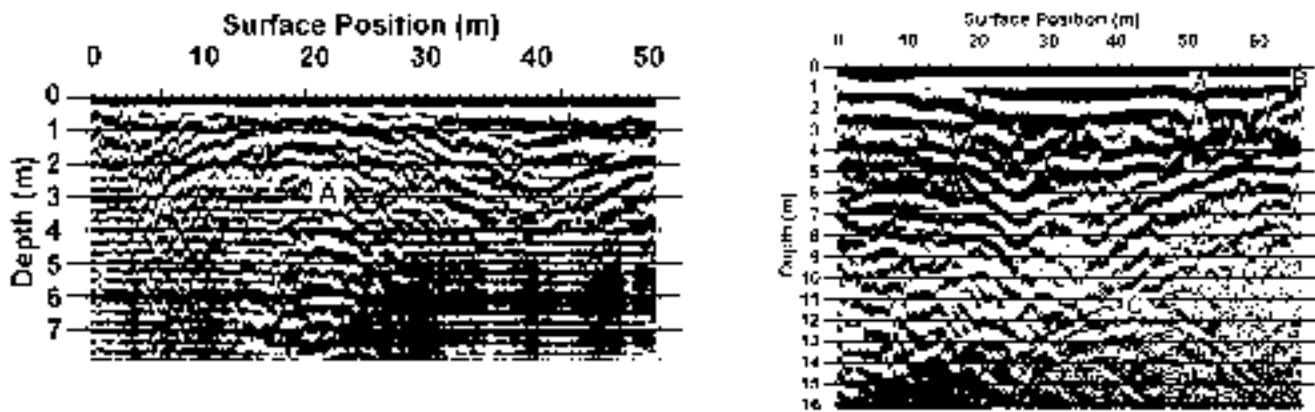


Figure 2 (left). GPR profile collected between Opal Terrace and the Executive House using 200 MHz antennas. The profile direction is approximately south to north and parallel to the earthen retaining wall built to stop the encroachment of the terrace. Depths are approximate and are based on a subsurface wave speed of 160 m/micros that was estimated for travertine. Point A near the center of the figure identifies the top of a suspected cavity. Figure 3 (right). GPR profile collected near the 1895 Mail Carrier's Cabin using 100 MHz antennas. The profile direction is south to north. Depths are approximate and are based on a subsurface wave speed of 160 m/micros that was estimated for travertine. Labeled points A and B are at the top of buried pipes. Point C is a the top of a large arcing reflection caused by an overhead transmission line.

present in the travertine pore space, radar penetration would decrease significantly.

GPR Tests at Mammoth Hot Springs

In May 1997, we conducted GPR tests at several locations in Mammoth: 1) near the 1895 Mail Carrier's Cabin, 2) near the Ice House, and 3) Opal Terrace (Figure 1.) The first two sites were considered as possible locations for the Yellowstone Heritage and Research Center, while the third site was investigated because of concerns about the encroachment of Opal Terrace on the Executive House. These tests consisted of short GPR profiles that were gathered to determine if reasonable penetration depths could be obtained in the area, as well as to see if sufficient electrical property contrasts existed in the subsurface to produce observable reflections. These initial tests showed that penetration depths of over 15 meters were possible, and numerous reflections were observed in the data.

Figure 2 shows a radar profile collected near the base of Opal Terrace between the terrace and the Executive House. The top of a possible subsurface cavity is labeled near the center of the figure. Cavities typically produce strong reverberations in GPR profiles, as demonstrated by the series of reflections that

continue until the bottom of the profile (seen beneath the labeled point). Also, note the bowl-shaped feature centered along the top of the profile. This feature may be a former channel that was subsequently filled by layered travertine. This subsurface information will be extremely useful to guide the creation of realistic subsurface models of geology and ground water flow. In turn, the models could be used to help develop contingency plans for protecting the Executive House from continued growth and overflow of the travertine terrace.

The Montana Tech Students' Summer Experience

Field studies are often an integral part of geoscience curricula. At Montana Tech, much of the field experience is gained in a six-week-long summer field camp in which students are exposed to both geological and geophysical field methods. This camp is a required course for both geophysical and geological engineering majors at Montana Tech. Group projects are typically utilized to give students the experience of working with others. Furthermore, projects that combine elements of service to the community with academic learning are sought to enrich the field camp experience.

After the preliminary GPR tests, Yellowstone National Park staff made arrangements to have students in the 1997 Montana Tech summer field course perform a geophysical site assessment of one of the sites under consideration for the Yellowstone Heritage and Research Center, the 1895 Mail Carrier's Cabin. The students had to provide a professional quality report to the park detailing the results of the survey at the end of the field course

In the field, students were organized into task groups that variously surveyed profile lines, collected GPR profiles, and collected background information at the Yellowstone National Park research library. After field data were collected, student teams prepared a report for the



Marvin Speece collects GPR data in the parade grounds near the Ice House, which can be seen in the background.

park. Team tasks needed to prepare the final report included map preparation, profile preparation, survey-data reduction, and narrative writing. Individual tasks were changed at intervals to provide the students with a variety of experiences.

In all, Montana Tech students gathered 35 separate GPR profiles near the Mail Carrier's Cabin. One of these profiles, displayed in Figure 3, shows a wedge of relatively continuous, layered travertine that thins to the north along the profile. The lack of reflections at the base of the layered travertine package could be caused by the boundary between travertine and less reflective volcanic or sedimentary rocks that are likely found underneath the travertine in the area. Alternatively, the lack of reflections could be due to mineralized water. This water has relatively high electrical conductivity which would cause rapid loss in signal strength with depth. Several cultural features—buried pipes and overhead transmission lines—are identified in the figure. No large subsurface cavities are seen in the profile.

The GPR survey at the Mail Carrier's Cabin site detected numerous cultural features such as buried wires and pipes but did not show any large cavities that would preclude building at the site. The study, however, indicated that numerous fractures and small faults are present throughout the site. These fractures may be related to historic subsidence. Partly on the basis of this study, alternate sites

are being considered for the proposed facility. A follow-up GPR test near the Ice House indicated that it would be a more secure building site.

Conclusions

Student evaluations of this project were overwhelmingly supportive. Students enjoyed the visit to Yellowstone National Park as well as the opportunity to contribute to a professional quality report that was going to be put to real use. They welcomed the opportunity to practice their public relation skills while interacting with park personnel and visitors. This study provided Yellowstone National Park personnel with information that proved useful for planning purposes for the siting of the proposed facility. Cooperative projects such as this one can provide important learning opportunities for college students while at the same time perform a useful service for the community.

GPR successfully imaged travertine layers in the Mammoth Hot Springs area and detected a possible subsurface cavity near the historic Executive House. GPR is high resolution, easy to use, and noninvasive. Furthermore, it costs much less than a detailed drilling programs. Cooperative studies involving students, faculty, park staff, and the use of GPR are a cost-effective way to evaluate the subsurface and understand the changing thermal features of Yellowstone. *



Laura Joss, Marvin Speece, and Stuart Coleman conducting GPR tests. The Mail Carrier's Cabin is in the background.

Further Reading

A detailed description of the geology of Mammoth Hot Springs can be found in: Keith E. Barger, 1978, *Geology and Thermal history of Mammoth Hot Springs, Yellowstone National Park, Wyoming*, Geological Survey Bulletin 1444. A copy of the student report, Margaret H. Allen et al., 1997, *Ground-Penetrating Radar Study of the Mail Carrier's Cabin Area, Mammoth Hot Springs, Yellowstone National Park*, is at the Yellowstone National Park research library.

¹ *Fifth Annual Report of the Superintendent of the Yellowstone National Park, to the Secretary of the Interior*, Washington, D.C., Government Printing Office, 1881, 23.

Marvin A. Speece is associate professor of geophysical engineering at Montana Tech of the University of Montana in Butte. He first visited Yellowstone National Park in 1981 during his undergraduate summer geology field camp. During that visit, Marvin most recalls a long, forced march to the top of Specimen Ridge to look at fossilized tree stumps. He began research in Yellowstone in 1995 with a geophysical study of the Soda Butte Creek drainage, and hopes to keep visiting Yellowstone for research—and pleasure—for many years to come.

Laura E. Joss is Chief of the Branch of Cultural Resources for the park. She received a B.A. in anthropology from Indiana University and an M.A. in museum studies from the Cooperstown graduate program at the State University of New York College at Oneonta. Previously, she was the NPS Rocky Mountain regional curator, and also worked at Glen Canyon National Recreation Area and Mesa Verde National Park. At Yellowstone, Laura enjoys the opportunity to create partnerships between cultural resource management and research disciplines for the mutual benefit of both.