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Northeast NTC
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Subject: GPR Field Assistance to the San Juan National Forest, Durango, Colorado; June 4 - 12, 1988

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Purpose:

To evaluate the effectiveness of ground-penetrating radar (GPR) techniques for detecting and mapping Anasazi artifacts within the San Juan National Forest.

Principal Participants:

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Activities:

The GPR unit travelled from Manhattan, Kansas, to Durango, Colorado, on 4 and 5 June 1988. Field studies were conducted adjacent to the Mancos Ranger Station on 6 June; at the House Creek Site, an exposed gravel pit, and along the Glade Camp Road on 7 June; adjacent to the Mancos Ranger Station and at the Glade Lake Site on 8 June; and at Chimney Rock Ruins on 9 June. The GPR unit returned to Chester, Pennsylvania on 10-12 June 1988.

Results:

The following are brief summaries of the results obtained with the GPR at selected archaeological sites:

Mancos Ranger Station - Archeological Site at, 5MT7244(SJNF#: 05-59)

Archaeological investigations were conducted in a pasture adjacent to the Mancos Ranger Station. This area was composed of fine textured soils which were highly attenuating to the radar signals. The 120 MHz with a scanning time of 40 nanoseconds (ns) provided the best imagery of the surface layers and the upper part of the subsoil. Maximum depth of consistent profiling with the 80 or 120 MHz antennas was 0.5 to 0.7 meters. High levels of background noise and signal reverberation masked desired signals.

A "wildcat survey" with the GPR identified an area having high levels of suspected "cultural noise." Archaeologists confirmed that the area identified by the GPR was the most probably site for discovering buried artifacts. A detailed grid having a two meter interval was established on this area. A detailed GPR survey was conducted. On the basis of the radar imagery, subsurface anomalies appeared to be few in number, dispersed, and poorly expressed. Six observation pits were partially excavated to confirm the interpretations. Images which were interpreted as foundation walls, charcoal layers, or natural soil horizons were confirmed at four of the six pits. The other two pits failed to disclose any artifacts.

House Creek Site - 5MT2320 (No SJNF number assigned)

This site is located north of Dolores, Colorado. The House Creek Site had been extensively excavated, recorded, and back-filled prior to the radar survey. Soils at this site are medium textured and calcareous. Two preliminary traverses were conducted across the area with the 120 MHz antenna. The scanning time was set at 40 ns. Although the soils at this site contained less clay than soils at the Mancos Site, the maximum depth of consistent profiling remained 0.5 to 0.7 meters. Other than the presence of soil horizons and bedrock, few subsurface anomalies were observed on the radar profiles. It is probable that the radar traverses failed to cross buried artifacts. High levels of background noise (caused by high gain settings necessary to amplify weak subsurface signals) were evident on these profiles.

Later, a GPR survey was conducted over an area of the House Creek Site having known buried artifacts. The 80 MHz antenna provided slightly better definition of subsurface images than the 120 MHz antenna. Levels of background noise were high. Excavated areas and buried structural features were evident on these profiles. Time did not permit the complete excavation and identification of these buried features.

Glade Camp Road - Site: 5DL474(SJNF#: 02-64). Area of Artifact Concentrations 5 & 6 as mapped by Wharton, 10/13/77; see SJNF CRR File 13-47, Durango, CO.

A wildcat survey was conducted across an area of exposed bedrock and soils along the Glade Camp Road. Though undocumented the site was believed to contain buried artifacts. The soils are medium textured and shallow over bedrock. The 120 MHz antenna provided the clearest imagery and definition of the soil/bedrock contact, but failed to detect artifacts. It is very probably that this area lacks sufficient and sizeable artifacts. Also, the radar's traverses could have failed to cross buried artifacts.

Glade Lake Site - Site: 5DL474(SJNF#:02-64).Area of Artifact Concentrations 7 & 8 as mapped by Wharton, 10/13/77; see SJNF CRR File 13-47, Durango, CO.

Two sites were selected for radar survey along the eastern shore of Glade Lake. Site selection was made by archaeologists and based on the "most probable" sites for former occupation.

Grids were laid out to provide a 10 percent coverage of each area. Radar traverses were conducted with the 120 MHz antenna. At this site, observed levels of background noise were minimal and the clarity and definition of subsurface features were good. However, interpretations were hindered by the large number of coarse fragments in the soil and the irregular bedrock surface.

Two subsurface anomalies believed to be an ash layer and a pit were identified on the radar imagery. These sites were investigated to confirm these interpretations. The ash layer was a buried, flat rock; the identify of pit remained uncertain. Generally the occupation of this site was too brief and the artifacts are too small and scattered to be detected with the GPR.

* Chimney Rock Site- Site: 5AA87(SJNF#: 06-378) Mound 1 (unexcavated).

A survey was conducted at the Chimney Rock Site to determine whether the GPR could detect large, buried Anasazi structures. The site is underlain by sandstone and the soils are moderately-coarse textured. High rates of signal attenuation and limited profiling depths were attributed to the high concentration of soluble salts in these soils. Radar imagery from this site was of poor quality. However, major structural features were observed on the radar profiles. The GPR disclosed general areas but not specific features within structure.

An EM (electromagnetic) survey was conducted at this site by James Allen. All participants were encouraged at this site to become familiar with and to operate the GPR.

Conclusions:

The performance of the GPR is highly site specific and interpreter dependent. Generally, the soils of southwestern Colorado are very attenuating and depth restricting to ground-penetrating radar because of high concentrations of soluble salts and montmorillonitic clays. However, for many archaeological investigation, depth of penetration is not a concern. Unfortunately, many artifacts of the Anasazi are similar to and do not contrast strongly with their enclosing soil mediums and, therefore, are difficult to discern. High levels of background noise were experienced at most sites. High levels of background noise masked the presence of some subsurface features. Signal processing did not significantly improve the radar images.

In general, compared with European artifacts, Anasazi artifacts are more widely dispersed (often without a patterned arrangement), smaller in size, and fewer in number. This complicates radar survey designs and interpretations. The more dispersed or fewer in number the artifacts, the larger the survey grid that is required to properly assess a suspected area. Small subsurface features require more closely spaced grid intervals to insure their detection and to minimize the errors of omission (features missed). Large grids with narrow grid intervals may be prohibitive in terms of available resources.

The use of ground-penetrating radar for archaeological investigations is in an active stage of growth and development. This trend has been accelerated by the recent growth in its commercialization and by a growing familiarity with its potential uses. However, the use of GPR techniques has been limited because of (i) initial purchase costs, (ii) limited knowledge of performance in various media and geographic locations, (iii) rapid signal attenuation and depth restrictions in certain media, and (iv) results which are often dependent upon the skills and experience of the operator.

Results obtained with the GPR in the San Juan National Forest are generally of poor quality. Within the San Juan National Forest, the nature (size, concentration, and electromagnetic characteristics) of many buried artifacts reduces the potential for routine use of ground-penetrating radar techniques for archaeological purposes. Compared with results from other areas of the United States, the radar imagery is depth restricted, poorly resolved, and has high levels of background noise. However ground-penetrating radar can be used successfully to develop pre-excavation strategies, reconnoiter or assess a site for major structural features, pinpoint the location of some artifacts, or help substantiate site evaluations made by archaeologists.

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* Most rewarding result was obtained at this site. Original site record by P.M. Heberling, 6/26/70, shows only 1 room for Mound 1 at 5AA87. Simple eye evaluation of the mound today still shows this to be a safe assumption. However, GPR assessment shows a similar signatur pattern to the east of and adjacent to this "known" room. Tentative conclusion is that Mound 1 probably contains at least two rooms rather than the assumed one. This should be tested by clearing the surface of the GPR "hit" to confirm or refute this result. If the suspected new room exists tops of walls should be evident and observed quickly below the present ground surface.

Additional Comment. To parrot Doolittle's findings, use of GPR on the San Juan N.F. appears marginal but does hold promise for assessing many of our sites -- especially may be helpful in determing if sub-surface features (hearths, etc.) exist on many of our "lithic scatters." Our next test of this equipment should be in the form of an intensive test at probably just one lithic scatter type site. With assessment of essentially all hits to determine if a distinctive signature pattern for cultural anomalies can be discerne Even though use of GPR on the San Juan appears limited it may be very useful on other Fores in R-2 where soils are less rocky and better developed (Nebraska N.F.?). Robert York, August 4, 1988

Discussion of GPR Techniques

Archaeologists are becoming increasingly aware of the advantages of using geophysical techniques for reconnaissance and pre-excavation surveys. These techniques are being used to facilitate excavation strategies, decrease field time and costs, and pinpoint the location of buried artifacts. Geophysical techniques compliment conventional methods of archaeological investigation. Compared with conventional methods, geophysical techniques are faster, provide greater areal coverage per unit time and cost, and are non-destructive. These techniques help to minimize the number of unsuccessful exploratory excavations and to reduce unnecessary or unproductive expenditures of time and effort.

Geophysical techniques used by archaeologists include electromagnetic (EM), ground-penetrating radar (GPR), magnetometer, and resistivity. Ground-penetrating radar (GPR) techniques have been used to locate buried artifacts in various areas of the world (Batey, 1987; Berg and Bruch, 1982; Bevan, 1977, 1984a and 1984b; Bevan and Kenyon, 1975; Bevan et al., 1984; Grossman, 1979; Kenyon, 1977; Parrington, 1979; Vaughan, 1986; Vickers and Dolphin, 1975; Vickers et al., 1976; and Weymouth and Bevan, 1983). These studies document the nondestructive efficiency of using GPR methods to pinpoint buried artifacts, facilitate excavation planning, and aid site interpretations.

The GPR field studies within the San Juan National Forest, Colorado, provided a unique opportunity to familiarize archaeologists with GPR techniques, improve field procedures, and develop search strategies and interpretative skills in areas having dispersed, often small and poorly defined artifacts.

Ground-Penetrating Radar

Principles of Operation

Ground-penetrating radar is a broad band, impulse radar system that has been designed to penetrate earthen materials. Relatively high frequency (10 to 1000 MHZ), short-duration pulses of electromagnetic energy are radiated into the ground from an antenna. When a pulse encounters an interface separating layers of differing dielectric properties, a portion of the pulse's energy is reflected back to the antenna. The radar's receiving unit samples and amplifies the reflected energy and converts it into the audio frequency range. The processed reflected signals are displayed on a graphic recorder or recorded and stored on magnetic tape.

A continuous profile of the subsurface is developed on the graphic recorder as the antenna is towed along the ground surface. As electrosensitive paper moves under the revolving styli of the graphic recorder, images of subsurface features and conditions are "burned" onto the paper to create a graphic profile. Each scan of a stylus draws a line across the paper in the direction of increasing signal travel time (depth). The intensity of the image printed is dependent upon the amplitude of the reflected signal.

Ground-penetrating Radar System

The GPR used in this study is the SIR (Subsurface Interface Radar) System-8 manufactured by Geophysical Survey Systems, Inc.1. The SIR System-8 consists of a control unit, a graphic recorder, a digital tape recorder, and a program control unit (microprocessor). During this field study, the microprocessor did not significantly improve interpretations and was used with limited success. The system was powered by a 12-volt vehicular battery. A 10 or 30 meter transmission cable was used to connect the control unit with the antenna. The antenna was towed along survey lines at an average speed of 2.0 km h-1. Detailed techniques for using GPR in the field have been described by Morey (1974), and Shih and Doolittle (1984).

In this field study, the 80, 120, 250, and 300 MHz antennas were used. The profiled soils rapidly attenuated the energy radiated from the 500 and 300 MHz antennas and restricted penetration to the surface layers. After limited field trials, use of the 500 and 300 MHz antennas was discontinued. The experimental 250 MHz antenna malfunctioned. Generally, the 80 MHz antenna provided coarser resolution of subsurface features but comparable profiling depths as the 120 MHz antenna. The 120 MHz antenna was preferred as it provided the best balance of probing depth and resolution of subsurface features.

At each site, several preliminary scans were made with the radar to select the proper antennas and to calibrate the control and recorder settings. This procedure optimized the systems configuration and provided the best balance of probing depth and resolution.

Factors Affecting the Radar's Performance

The performance of the GPR is highly site specific and soil dependent. The GPR does not perform equally well in all soils.

The maximum probing depth of the GPR is, to a large degree, determined by the electrical conductivity of soils. Soils having high conductivities rapidly dissipate the radar's energy and restrict its probing depth. The principal factors influencing the conductivity of soils are: (i) degree of water saturation, (ii) amount and type of salts in solution, and (iii) amount and type of clays.

Moisture content is the primary determiner of conductivity. Electromagnetic conductivity is essentially an electrolytic process that takes place through moisture filled pores. The surveyed areas receives 12 to 18 inches of annual precipitation. The survey was conducted during the month of July and the soils were dry. It has been observed that even small amounts of moisture can significantly increase the conductivity of soils and substantially increase signal attenuation (Vickers et al., 1976). Signal attenuation is significantly increased in some soils when the moisture content is changed from as low as 5 to 10 percent (Jesch, 1978).

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1. Trade names have been used to provide specific information. Their mention does not constitute endorsement.

Electrical conductivity is directly related to the concentration of dissolved salts in the soil solution. In unirrigated areas, the concentration of dissolved salts in the soil profile and the probing depth of the GPR are influenced by parent material and climatic parameters. Soils formed in sediments weathered from shale, limestone, and sandstone (as at the study sites) generally contain more salts in solution than soils developed in felsic crystalline rocks. In general, most soluble salts are leached rapidly from soil profiles in humid regions. However, in semi-arid and arid regions, soluble salts of potassium and sodium and less soluble carbonates of calcium and magnesium accumulate in the soil profile; the depth of accumulation being a function of precipitation. Most soils within the San Juan National Forest contain large concentrations of soluble salts in their profiles.

The electrical properties of many soils are strongly influenced by the amount and type of clay minerals present. Ions absorbed on clay particles can undergo exchange reaction with ions in the soil solution and thereby contribute to the electrical conductivity of soils. The concentration of ions in the soil solution is dependent upon the clay minerals present, the pH of the soil solution, the degree of water filled porosity, the nature of the ions in solution, and the relative proportion of ions on exchange sites. Smectitic and vermiculitic clays have higher cation exchange capacity (CEC) than kaolinitic and oxidic clays, and under similar soil moisture conditions, are more conductive. Within the studied areas, moderately-fine (18-34 percent clay) and fine (>35 percent clay) textured soils with high proportions of montmorillonite clays predominate.

Within most areas of the San Juan National Forest, the unfavorable electromagnetic characteristics of soils limit the radar's probing depth. The moderately-fine and fine textured, calcareous soils rapidly attenuated the radar energy and limited the penetration of the 120 MHz antenna to depths of 0.5 to 0.7 meters in most areas. In areas of shallow soils (<50 cm) overlying bedrock, attenuation is less severe and depths of 1 to 4 meters can be achieved.

The depth of penetration is also limited by buried artifacts. Buried artifacts cause partial absorption, reflection, and scattering of the electromagnetic energy. The high clay content of mud brick walls, high salt contents of sedimentary rocks, and the calcareous nature of debris and fill materials absorbed and dissipated some of the radiated energy. Successive, closely spaced layers of fill, debris, and rubble cause partial reflection and scattering of the energy, thereby, further restricting the profiling depth.

In spite of these limitations, the GPR detected artifacts at some sites within the San Juan National Forest. These artifacts are not deeply buried and occur within the effective profiling depth of the GPR. In most areas, the GPR provided sufficient resolution and penetration to detect artifacts within depths of 0.5 to 0.7 meters.

Interpreting the Graphic Profiles

Reliable interpretations are developed through experience. Interpretation of radar imagery is best accomplished in the field, through a joint effort of radar technicians and archaeologists, with adequate ground-truth observations to verify the data.

All areas surveyed with the GPR were selected by field archaeologists. Archaeologists familiar with the subsurface stratigraphy and history of the site provide invaluable assistance concerning the distribution and identity of subsurface images. Field archaeologists directed the excavation of all ground truth observation sites used to verify the graphic imagery.

It is generally assumed that linear features, such as buried wall foundations, are easily detect by conducting several parallel traverses with the GPR. According to Bevan (1984), reliable detection of a buried structure requires similar imagery on three to six transects. However, others (Vickers et al., 1976) have noted a "natural tendency" to assume the occurrence of a linear object whenever radar images appear to align. Indian foundation walls are not necessarily linear.

Interpretations require a limited number of ground truth observations to correlate the radar imagery with observed features and to determine what features were and were not detected. During the course of this study, nine exploratory pits were excavated to confirm the presence of buried artifacts and to improve interpretations. Buried artifacts were exposed in five of these nine pits. Natural features, such as soil horizons, bedrock or rock fragments, were found within the other four pits.

While the GPR detects subsurface anomalies, it does not identify subsurface features. Without sufficient ground-truth observations, few images can be correctly identified with a high degree of confidence on radar profiles. With experience and sufficient ground truth observations many subsurface features can be identified by their unique graphic signatures.

Survey Procedures

One of the primary objectives of this study was to evaluate survey procedures for charting the location of buried Indian artifacts. The most accepted and perhaps efficient method to chart the location of buried artifacts with the GPR is to establish a grid on the area to be surveyed. Generally, rectangular grids are preferred, though Bevan (1977), in a study of subsurface remanents of earthworks, describes traverses radiating outwards like spokes of a wheel from a fort. In addition, "wildcat" surveys have been used by some authors (Berg and Burch, 1982) to quickly locate small areas having large concentrations of buried artifacts within a larger area. Wildcat and grid surveys were used at the investigated sites.

Grid spacing is dependent upon the purpose of the survey, available time, features being identified, local ground conditions, and desired detection probability. Bevan (1984b) has described three levels of surveying intensities based on the purpose of the investigation. These levels include: (1) locating an archaeological site, (2) defining site boundaries, and (3) charting internal features within a delineated site.

Grid spacing is a compromise between detection probability and available time. Generally, several grids of varying patterns and spacings are constructed within a defined area during the course of a survey. Often, in preliminary or pre-excavation reconnaissance surveys a large grid spacing is used to define the broad or general location of subsurface anomalies. Once the general location of anomalies has been defined, a smaller grid spacing is used. A smaller grid spacing provides more observation points and greater coverage. However, unless antenna positioning and position referencing are more rigidly maintained, smaller grid spacings do not necessarily insure greater precision. Closely spaced grid patterns help to pinpoint the location, define the spatial extent, and resolve the identity of the subsurface anomalies.

The anticipated size of the buried artifacts being defined or located will dictate grid spacing. In relatively detailed surveys, grid spacings of 1 meter were used to detect grave sites (Vaughan, 1986), 1.5 to 3 meters to locate buried foundation walls (Bevan, 1979; Bevan et al.,1984; and Grossman, 1979), and 5 meters to define the general location of buried Indian ruins (Vickers et al., 1977). The 5 meter spacing, while satisfactory for defining buried kivas and foundation walls, or areas with high concentrations of subsurface anomalies, is too coarse for small or disperse artifacts. Even a 2 meter grid interval is too coarse for many detailed within site investigations.

At many sites within the San Juan National Forest, local ground conditions dictated the survey area as well as the grid spacing. Excessive slope, dense vegetation, irregular rock outcrops, and structures hinder or restrict GPR surveys. Abrupt and precipitous slope breaks or excavation walls often defined the limits of the radar survey. Areas of trees or dense undergrowth were generally avoided as these features impeded the movement of the radar antenna, ensnared the transmission cable, and introduced unwanted background noise.

A grid spacing of 1 meter may proved to be too wide for charting the internal features of many sites. The presence of rock fragments and debris, which produced undesired point reflections on the radar profiles, complicated the tracing of cultural features within the excavation sites with the grid spacing used. In most areas, a closer, overlapping grid spacing would be desired to accurately anticipate the location of buried foundation walls.

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