United States Department of Agriculture
Natural Resources Conservation Service
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Subject: Soils – Geophysical Field Assistance **Date:** 8 October 2004

To: David Smith
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Purpose:
The purpose of this investigation was to provide training of the operation of the SIR-3000 radar unit and to evaluate the use of ground-penetrating radar (GPR) to assist archaeological investigations in Tulare County.

Participants:
Eric Crook, Soil Conservationist, USDA-NRCS, Visalia, CA
Frank Deitz, Archaeologist, USDA-NRCS, Davis, CA
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
Chris Hildebrandt, Biologist, Ducks Unlimited, Fresno, CA
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Elizabeth Palmer, Soil Conservationist, USDA-NRCS, Visalia, CA
Ed Russell, Soil Scientist, USDA-NRCS, Fresno, CA
Brian Zielger, Public Affairs Specialist, USDA-NRCS, Fresno, CA

Activities:
All activities were completed on 30 September 2004.

Results:

1) Training was provided to Frank Dietz on the operation of the SIR-3000 radar unit and the interpretation of radar data. A practical GPR field survey was completed of a small grid area within a suspected archaeological site.

2) In an area of inhospitable (to GPR) Houser and Gepford soils, depth of penetration was less than 100 cm on radar records collected with the 200 MHz antenna. The 400 MHz antenna suffered high rates of signal attenuation and could not detect a know reflector that had been buried at a depth of 35 cm. The high clay and soluble salts contents of these soils makes them generally unsuited to GPR.

3) Though the soils are considered unsuited to GPR, advanced data processing and imaging techniques were used to effectively image a buried feature of suspected cultural origins with the grid area.

4) The NRCS staff in California has purchased a SIR-3000 unit. The National Soil Survey Center, upon request, will provide technical assistance and training on the operation of GPR and the interpretation and processing of radar data.

I appreciate the opportunity to work in California and with Frank Dietz.

With kind regards,

James A. Doolittle
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Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR System-3000), manufactured by Geophysical Survey Systems, Inc.[1] The SIR System-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR System-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, this system requires two people to operate. The use and operation of GPR are discussed by Daniels (2004). The 200 and 400 MHz antennas were used during this investigation.

Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program (Geophysical Survey Systems, Inc, 2003).[1] Processing included setting the initial pulse to time zero, color transformation, marker editing, distance normalization, signal stacking, background removal, and range gain adjustments.

Ground-penetrating radar (GPR):
A favorable feature of GPR for archaeological investigations is its ability to detect disturbances and the intrusion of foreign materials in soils. In many soils, GPR is a useful tool for locating buried cultural features. However, results vary with soil conditions. In some soils, rates of signal attenuation are so severe that GPR cannot profile to the required depths. Even with favorable site conditions (i.e. dry, coarse-textured soils) the detection of buried artifacts is never assured with GPR. Detection is affected by (i) the electromagnetic gradient existing between the feature and the soil, (ii) the size and shape of the buried feature, and (iii) the presence of scattering bodies within the soil (Vickers et al., 1976).

The amount of energy reflected back to an antenna by a buried object is a function of the contrast in dielectric properties that exists between an object and the surrounding soil matrix. The greater and more abrupt the difference in dielectric properties, the greater the amount of energy that is reflected back to an antenna, and the more intense will be the amplitude of the reflected signals on the radar record. At first, many buried objects will contrast with the surrounding soil matrix. However, with the passage of time, buried objects decay or weather and become less electrically contrasting with the soil matrix.

The size and depth of the buried artifact affect detection. Large objects reflect more energy and are easier to detect than small objects. The reflective power of a buried object decreases with the fourth power of the distance to the object (Bevan and Kenyon, 1975). .

Buried artifacts are often difficult to distinguish in soils having rock fragments, tree roots, animal burrows, modern cultural features, or highly stratified and segmented soil layers. These scattering bodies produce undesired subsurface reflections, which complicate radar records and mask the presence of the *desired*, buried cultural features. Under such conditions, "*desired*" cultural features can be indistinguishable from the background clutter. In soils having numerous scattering bodies, GPR often provides little meaningful information to supplement traditional sampling methods (Bruzewicz et al., 1986).

On radar records, the depth, shape, size, and location of subsurface object can be used to identify buried cultural features. In the past, reflections could only be identified and correlated on two-dimensional radar records. Often, in soils with complex stratigraphic layers or high amounts of background noise, low or moderate amplitudes reflections from buried features are difficult to detect on two-dimensional radar records. The development of sophisticated signal-processing software has enabled signal enhancement and improved pattern-recognition on radar records. Recently, three-dimensional (3-D) imaging techniques have been used to identify potential targets, distinguish and reduce noise components, and reduce interpretation uncertainties (Pipan et al., 1999). Three-dimensional interpretations of GPR data have being used to identify burials, middens, and other cultural features (Conyers and Goodman, 1997; Whiting et. al, 2000; Goodman et al., 2004).

In recent years, a sophisticated type of GPR data manipulation has been used in archaeological investigations. Known as amplitude slice-map analysis (Conyers and Goodman, 1997), horizontal maps of reflected wave amplitude differences can be created from a set of closely spaced radar records. In order to be interpreted, amplitude differences within the 3-D image are analyzed in "time-slices" that examine changes within specific depths intervals (Conyers and Goodman, 1997).

Archaeological Site, Tulare County:
Six hundred twenty-one acres in Tulare County are being set aside as part Wetland Reserve Project. The acreage has been intensely farmed and leveled. Soils are principally Houser - Gepford silty clay, 0 to 1 percent slopes. The very deep, somewhat poorly drained Houser and poorly drained Gepford soils formed in mixed stratified alluvium on basin floors. These soils have high clay, moisture, and soluble salt contents and are considered poorly suited to GPR. The textural control sections of these soils contain 50 to 60 percent clay. Salinity ranges from 1 to 16 deciSiemens per meter in the surface and 4 to 30 deciSiemens per meter in the lower part of the profile. Houser soil is typically saline-sodic below the A horizon. Gepford soil has sodium adsorption ratio is 2 to 30 in the surface layer and 8 to 50 in the subsoil. Houser is a member of the fine, smectitic, calcareous, thermic Vertic Fluvaquents family. Gepford is a member of the fine, smectitic, thermic Typic Natraquerts family.

All Federal ground disturbance projects come under the National Historic Preservation Act. The consulting firm of Tremaine & Associates, Inc., (Dixon, California) conducted intensive pedestrian surveys of several sites within the Wetland Reserve Project's acreage. In the course of these surveys, three prehistoric granitic groundstone fragments, two complete handstones, and a plummet charmstone were found. These few and scattered, small artifacts are believed to belong to the Yokuts tribe. Similar artifacts are generally considered too small to be detected with GPR in these conductive soils. As the size of the area was too large to be satisfactorily surveyed in the allotted time, a detailed GPR survey of a 5 x 6 meter grid area was conducted for training purposes.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, stratigraphic layer) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (D), two-way pulse travel time (T), and velocity of propagation (V) are described in the following equation (after Daniels, 2004):

$$V = 2D/T \qquad [1]$$

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to the equation (after Daniels, 2004):

$$E_r = (C/V)^2 \qquad [2]$$

Where C is the velocity of propagation in a vacuum (about 0.3 m/nanosecond). Velocity is expressed in meters per nanosecond (m/ns). The amount and physical state (temperature dependent) of water have the greatest effect on the E_r of earthen materials and therefore the velocity of propagation.

Calibration trials were conducted with both the 200 and 400 MHz antennas. A metallic reflector was buried in the soil at a depth of 36 cm. Because of the high conductivity of the soil, the signal from the 400 MHz antenna was attenuated within very shallow depths. As a consequence, the 400 MHz could not detect the buried metallic reflector. The metallic reflector was detected with the 200 MHz antenna. Based on the measured depth to this reflector, the velocity of propagation through the upper part of the soil profile was an estimated 0.16 m/ns. The E_r was 3.47. With a scanning time of 50 ns and a velocity of 0.16 m/ns, equation [1] estimates that the maximum depth of signal penetration is about 1.5 m with the 200 MHz. While radar signals may penetrate to depths of 1.5 m with the 200 MHz antenna, depths of meaningful data were restricted to less that 1 m in these soils. At the time of this investigation, soils were dry.

Survey Procedures:
A rectangular grid, consisting of 6, 6-m survey lines was laid out across a suspected area. The dimensions of the grid were 5- by 6-m. The x-axis extended north-south toward a farm road that was orientated orthogonal to the x-axis. Survey lines were 6-m long, orientated in a north-south direction, and spaced 1-m apart. Along each line, reference marks were spaced at 1-m intervals. Pulling the 200 MHz antenna in a back and forth manner along the 6

equally spaced (1-m) survey lines completed the GPR survey. Along each line, as the antenna passed a reference point, a vertical mark was impressed on the radar record.

Results:

Figure 1 is a three-dimensional block diagram of the 5 x 6 m grid area. Three-dimensional displays permit the viewing of the composite radar data at one time. Three-dimensional displays have proven useful in studies that require the identification of linear features. In order to generate a 3D display, data between the radar traverse lines are interpolated to produce a solid cube. In general, the quality and level of detail improves as the number of traverse lines increase and the spacing between these parallel lines decrease. In Figure 1, a 4- by 4.5- by 0.5-m portion of the block diagram has been removed.

In Figure 1, the origin is located in the southeast corner of the grid area, and the X-axis (in foreground) extends in a north-south direction. All units of measurement are expressed in meters. The depth scale is based on an estimated propagation velocity of 0.16m/ns through the upper part of the soil.

In Figure 1, a high amplitude (colored white, pink, and blue) linear reflector is exposed at a depth of about 50 cm near the center of the grid. This high-amplitude linear feature is slightly more than 2-m long and about 1-m wide. Linear features are considered artificial; variations in soil and geologic materials appear more irregular and smoothed (see features in lower left and left-hand portion of cube).

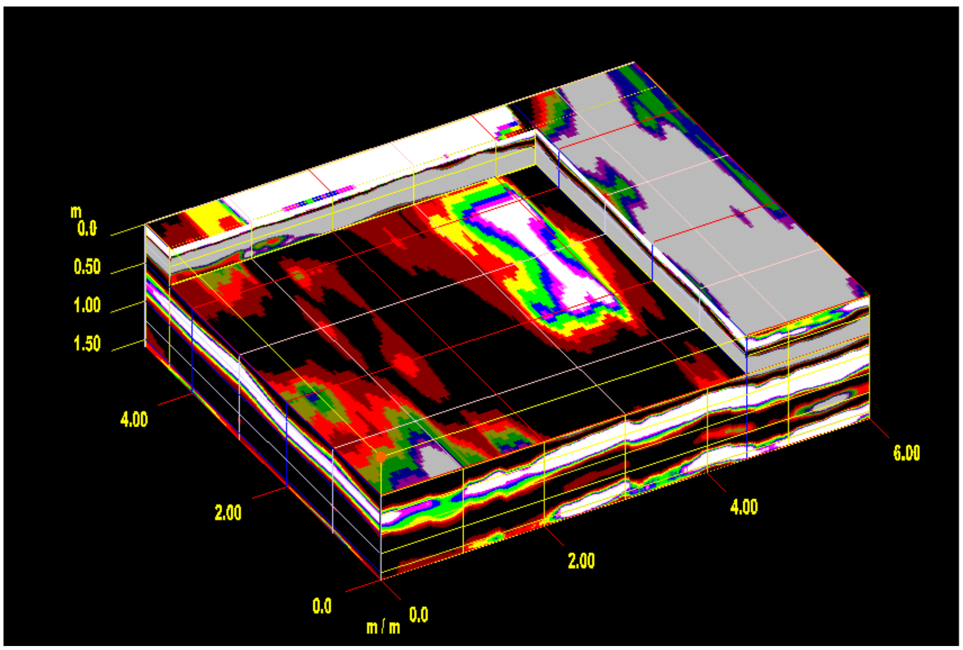

Figure 1. Three-dimensional block diagram formed from the composite radar records of the grid area with a 4 x 4.5 x 0.5 cube removed.

Figure 2 is a *time-sliced image* of the grid area. In Figure 2, we are looking down from overhead the grid area and the material above a depth of 45 cm has been removed through a process known as *time slicing*. Time slice data were created using spatially averaged amplitudes. In this *time-sliced image*, the reflected energy was averaged horizontally between each closely spaced radar records and in 3.2 ns vertical time windows to create the *time-sliced image*. The *time-sliced image* shows the spatial patterns of reflected wave amplitudes, which are indicative of changes in sediments, soils, and buried features. In Figure 2, a horizontal slice has been made across the grid and only the reflectors at a depth of 45 cm are evident. This *time-sliced image* shows a high-amplitude feature that has a distinct rectangular appearance. The linearity of this feature implies a cultural feature; the dimensions (1 by 2 m) of this feature suggest a burial.

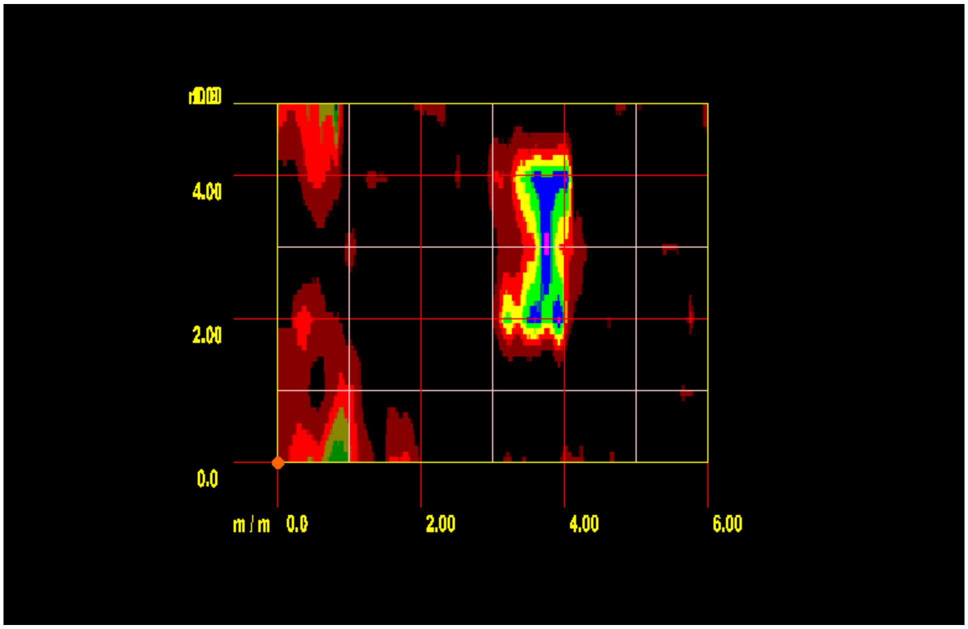

Figure 2. Time- slice image of the grid are that shows the position of the high-amplitude linear reflector. The horizontal slice was taken at a depth of 45 cm.

Figure 3 provides an alternative view of the grid area as seen in a *time-sliced image*.

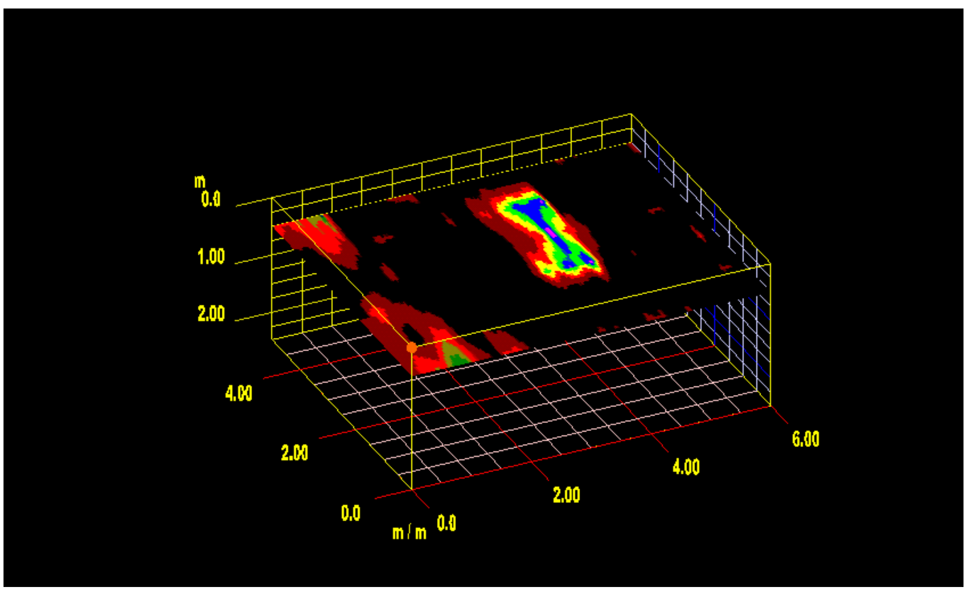

Figure 3. Horizontal or z-axis slice of the 3D radar image of the grid area. Horizontal slice has been made at a depth of 45 cm.

It must be noted that geophysical interpretations are considered preliminary estimates of site conditions. The results of geophysical site investigations are interpretive and do not substitute for direct ground-truth observations (soil borings and other excavations). The use of geophysical methods can reduce the number of coring observations, direct their placement, and supplement their interpretations. Interpretations contained in this report should be verified by ground-truth observations.

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