United States Department of Agriculture | **Natural Resources Conservation Service** | **11 Campus Boulevard Suite 200 Newtown Square, PA 19073**

Subject: Soils – Geophysical Field Assistance **Date:** 6 October 2004

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Purpose:
The purpose of this investigation was to evaluate the performance of ground-penetrating radar (GPR) on different bedrock lithologies.

Participants:
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Activities:
All activities were completed on 29 September 2004.

Results:

1. Radar surveys were completed in the granitic terrains of the San Jacinto Mountains in southern California. Radar records collected at the *Alfisol Site* were more depth restricted than the radar record obtained at the *Entisol Site*. The bedrock at the *Alfisol Site*, which contain a larger amount of mafic minerals (5% hornblende and 20% biotite), are more attenuating to GPR than the bedrock at the *Entisol Site*, which contain a smaller amount of mafic minerals (<1% hornblende and 10% biotite).

2. A sample of the weathered bedrock was collected at each site and will be taken to the Colorado School of Mines (Golden, Colorado) for analysis of the electromagnetic properties that affect the performance of GPR.

I appreciate the opportunity to work with you and the University of California at Riverside.

With kind regards,

James A. Doolittle
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cc:

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Background:
Ground-penetrating radar (GPR) has been used to provide high-resolution information on soil and bedrock. GPR has been used to chart bedrock depths (Collins et al., 1989; Davis and Annan, 1988) and to detect geologic hazards in advance of mining operations (Grodner, 2001; Molinda et al., 1996). It has also been used to locate and characterize fracture patterns in crystalline bedrock (Holloway and Mugford, 1990; Stevens et al., 1995; and Lane et al., 2000) and cavities, sinkholes, and fractures in limestone (Barr, 1993; Pipan et al., 2000). In the absences of continuous and satisfactory outcrops or exposures, GPR is an accepted tool for imaging the regolith (Beres and Haeni, 1991; and Dagallier et al., 2000). Recently, GPR has been used to study weathered bedrock and the transition from weathered to hard bedrock (Aranha et al., 2002; Li, 1998; Volkel et al., 2001; Hubbert et al., 2001).

Although extensively used to characterize the regolith, few studies have addressed the affects of differences in the chemical and mineralogical compositions of soils and bedrock on the performance of GPR. Lithology is often a key to pedology. Granitic terrains in southern California have deeply weathered regoliths. Wahrhaftig (1965) observed that below the limits of Pleistocene glaciation in the southern Sierra Nevada Mountains of California, granitic bedrock is weathered to depths of 3 to 30 m. Differences in soils and soil properties are often related to differences in lithology. The purpose of this investigation was to compare the performance of GPR on two deeply weathered sites with different lithologies, and consequentially soils, in the San Jacinto Mountains of southern California.

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 was restricted to setting the initial pulse to time zero, color transformation, marker editing, distance normalization, and range gain adjustments.

Study Sites:
Two sites were selected in the *North Experimental Area*, which is located in the northwest foothills of the San Jacinto Mountains about 9 km south of Banning, California. The sites were used in an earlier investigation (Graham et al., 1997). The sites are at an elevation of about 1150 m. The bedrock lithology ranges from mafic tonalite to K-feldspar-poor granodiorite (Graham et al., 1997). The bedrock is 50 to 55% plagioclase, 20 to 30% quartz, 10 to 15 % biotite, 1 to 8% K-feldspar, and 0 to 5% hornblende (Hill, 1988). Mineral grains are < 10 mm in diameter (Graham et al., 1997).

The sites are on nearly level ridge tops and in areas that had been mapped as Tollhouse rocky coarse sandy loam, 8 to 50 percent slopes, eroded (Knecht, 1971). The shallow, somewhat excessively drained or excessively drained Tollhouse soil formed in material weathered from granitic rocks. Tollhouse is a member of the loamy, mixed, superactive, mesic, shallow Entic Haploxerolls family. At each site, the underlying bedrock (Cr horizon) is weathered to depths greater than 3 m, has a low clay content (<6%), and can be excavated with an auger (Graham et al., 1997). One site, known as the *Alfisol Site* is located at 33.85426^{o} N. Latitude, 116.87206^{o} W. Longitude. At this site the soils are classified as fine-loamy, mixed, mesic Typic Haploxeralfs. The other site, the *Entisol Site*, is located at 33.85342^{o} N. Latitude, 116.87624^{o} W. Longitude. At this site the soils are classified as coarse-loamy, mixed, mesic Typic Xerorthents. Graham and others (1997) observed that bedrock at the *Alfisol Site* contains a larger amount of mafic minerals (5% hornblende and 20% biotite) than the bedrock at the *Entisol Site* (<1% hornblende and 10% biotite).

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 (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. The soil was very dry at the time of this investigation. A metallic reflector was buried at a depth of 50 cm. Because of the high conductivity of the soils, the signal from the 400 MHz antenna was rapidly attenuated. As a consequence, the 400 MHz did not detect the buried metallic reflector. The metallic reflector was detected with the 200 MHz antenna. Based on the measured depth to a buried metallic reflector, the velocity of propagation through the upper part of the soil profile was an estimated 0.141 m/ns. The E_r was 4.47. With a scanning time of 70 ns and a velocity of 0.141 m/ns, equation [1] estimates that the maximum depth of penetration is about 4.9 m with the 200 MHz.

Survey Procedures:
A short traverse line was established at each site. Because of the greater clay content at the *Alfisol Site*, a traverse was also completed in the bottom of an excavated pit to evaluate the GPR performance through the weathered bedrock. Along each line, reference marks were spaced at 1-m intervals. Radar surveys were completed by pulling the 200 MHz antenna along each line. As the antenna passed a reference point, a vertical mark was impressed on the radar record.

Results:
Graham and others (1997) observed that the regolith at the *Entisol Site* is less pedogenically altered than at the *Alfisol Site*. These researchers noted that the more mafic nature of the bedrock at the *Alfisol Site* may have enhanced the rate of weathering and the formation of a fine-loamy argillic horizon. The *Entisol Site* is coarse-loamy and lacks an illuvial horizon (Graham et al., 1997).

It is hypothesized that the soils and bedrock at the *Alfisol Site*, which contain a larger amount of mafic minerals (5% hornblende and 20% biotite), are more attenuating to GPR than the soils and bedrock at the *Entisol Site*, which contain a smaller amount of mafic minerals (<1% hornblende and 10% biotite). Saarenketo (1998) showed that with increasing CEC, the relative dielectric permittivity of soils increases. Soils dominated by clay fractions with a high percentage of smectite or vermiculite have a higher CEC and are more attenuating to GPR than soils with an equivalent percentage of kaolinite. In the southern Piedmont, soils formed in residuum weathered from granitic gneiss have saprolite that contains large amounts of halloysite, gibbsite and amorphous aluminosilicate clays (Buol and Weed, 1991). Soils weathered from gabbro and metagabbro have saprolite that contains large amounts of smectite, vermiculite, and chlorite (Buol and Weed, 1991). In addition, Buol and Weed (1991) observed that argillic horizons formed over basic and/or fine-grained rock contain larger amounts of 2:1 expanding lattice clays. Subsoils developed over quartzofeldspathic rocks are not as clay rich and contain greater amounts of kaolinite and nonexpanding vermiculite clay minerals (Pavich et al., 1989). The higher cation exchange capacities of 2:1 expanding lattice clays increase attenuation and restrict penetration of radar energy. The exchange complex of these clays is low (< 10%) and the cation content is very low.

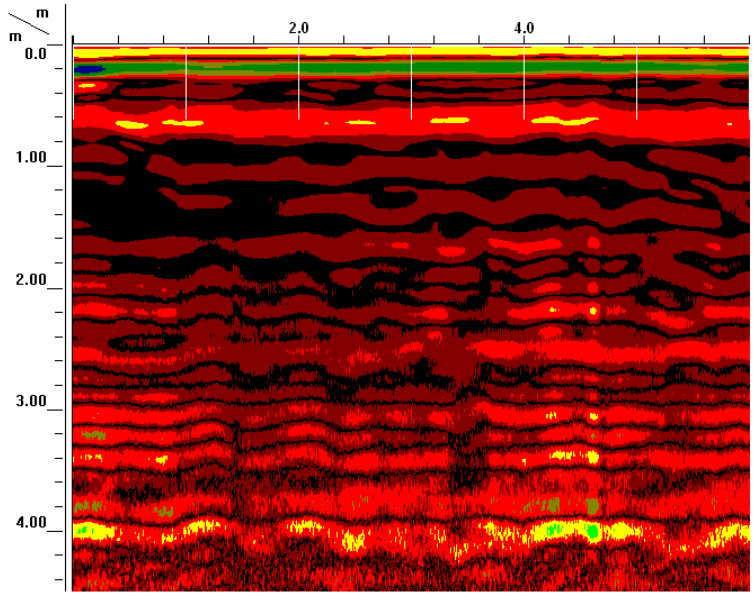

Figure 1. Radar record from the Alfisol Site shows high levels of background noise and limited depth of penetration.

Figure 1 is the radar record that was obtained with the 200 MHz antenna along a traverse line at the *Alfisol Site*. The radar traverse is 6-m long. As seen in Figure 1 meaningful information appears largely restricted to upper 1.5 meters of the soil. Below these depths, the radar energy was significantly attenuated and no clear reflections were detectable. The lower part of the radar record is plagued by parallel bands of low-frequency noise. The broad, planar, medium-amplitude (in Figure 1, colored red and yellow) reflection at a depth of about 50 cm is believed to be the argillic horizon which ranges from 20- to 60 cm in depth in the excavated trench.

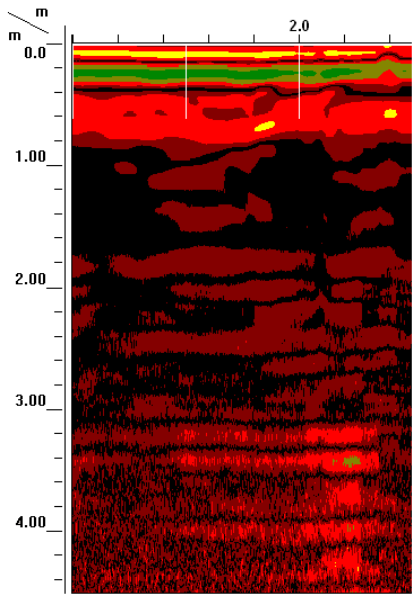

Figure 2. Radar record from the bottom of an excavated pit at the Alfisol Site shows high levels of background noise and limited depth of penetration.

It was assumed that the clays in the argillic horizon were responsible for the high attenuation rates and limit penetration of GPR. To test this hypothesis, a radar traverse was conducted along the bottom of the trench which was excavated into the weathered bedrock. The radar traverse is 3-m long and is shown in Figure 2. Even though

the radar traverse was conducted on bedrock, the depth of penetration does not appear to have improved. The radar energy has been significantly attenuated and no clear reflections were detectable in the lower part of the radar record. As on radar record that was collected over the nearby soil, the lower part of the radar record is plagued by parallel bands of low-frequency noise.

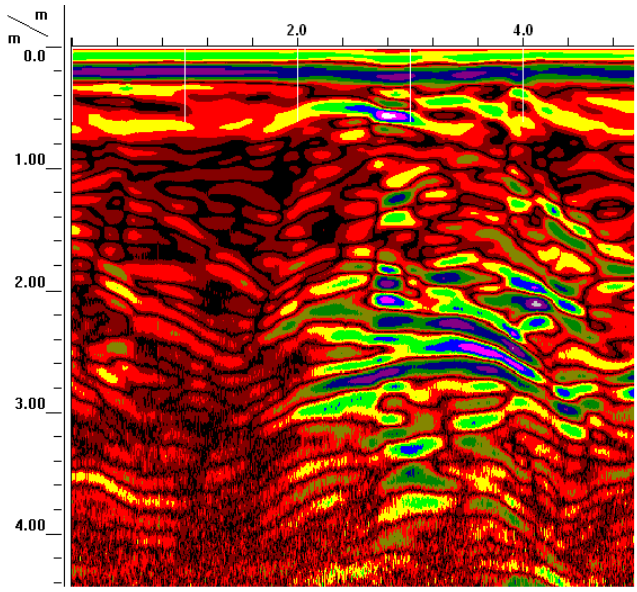

Figure 3. Radar record from the Entisol Site shows lower levels of background noise and greater depth of penetration.

Figure 3 is the radar record from the *Entisol Site*. The traverse line is 5-m long. Compare with the *Alfisol Site*, the radar signal appears less attenuated and provides greater depth of penetration at the *Entisol Site*. Depth of penetration is greater than 3.5 m. The reflectors are believed to represent foliation (mineral layering) and cleavage planes and are remnants of the original rock structure. The higher amplitude reflections within the weathered bedrock may represent more resistant boudins of quartz. Weaker amplitude reflections are believed to represent fracture or cleavage planes.

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