United States Department of Agriculture	**Natural Resources Conservation Service**	**100 Campus Boulevard Suite 200 Newtown Square, PA 19087-4585**

Subject: Soils -- Geophysical Assistance **Date:** 6 October 2008

To: Jeff Burwell
State Conservationist
9173 West Barnes Drive
Suite C
Boise, ID 83709

Purpose:
Ground-penetrating radar (GPR) was used to help characterize the depth to rhyolite bedrock in areas of Parkally-Parkally, moist-Hagenbarth complex, 2 to 35 % slopes, in northern Clarke County. In addition, the depth to basalt bedrock was estimated in an area of Juniperbute-Rock outcrop complex, 1 to 30 % slopes, in Fremont County.

Principal Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Glenn Hoffman, MLRA Project Leader, USDA-NRCS, Idaho Falls, ID
Bill Heitt, Soil Scientist, USDA-NRCS, Idaho Falls, ID
Paul Pedone, Geologist, USDA-NRCS, Portland, OR

Activities:
All field work discussed in this report was completed on 15 and 16 September 2008.

Summary:
Ground-penetrating radar and the global positioning system (GPS) were merged to provide a novel approach for mapping the depth to bedrock and confirming the composition of soil map units (by soil depth criteria) in Clark and Fremont Counties. The merger of these technologies resulted in a most remarkable number of soil depth interpretations. In most traversed areas, the soil/bedrock interface produced a conspicuous subsurface reflection and consequentially interpretations could be made with a high degree of confidence. These interpretations were made in soils that contain a large number of coarse fragments, where the depth to bedrock is difficult to determine with conventional soil survey tools.

An Excel spreadsheet containing the results of this field investigation has been given to Bill Heitt.

It was my pleasure to work in Idaho and to be of assistance to you and your staff.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
B. Ahrens, Director, National Soil Survey Center, USDA-NRCS, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866
M. Golden, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
G. Hoffman, MLRA Soil Project Leader, USDA-NRCS, 1120 E Lincoln Road, Idaho Falls, ID 83401-2122
D. Hoover, State Soil Scientist, USDA-NRCS, 9173 West Barnes Drive, Suite C, Boise, ID 83709-1574
C. McGrath, MLRA Office Leader, USDA-NRCS, 1201 NE Lloyd Blvd., Suite 900, Portland, OR 97232
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room G08, 207 West Main Street, Wilkesboro, NC 28697
L. West, National Leader, Soil Investigation Staff, National Soil Survey Center, USDA-NRCS, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[1] The SIR-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-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Daniels (2004) discusses the use and operation of GPR. An antenna with a center frequency of 200 MHz was used in this study.

The RADAN for Windows (version 6.6) software program (GSSI; Salem, NH) was used to process the radar records.[1] Processing included: GPS option, header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, migration, and high-pass filtration (see Daniels (2004) for a discussion of these techniques).

The SIR-3000 system provides a setup for the simultaneous use of a GPS receiver and serial data recorder (SDR). With this setup, each scan on radar records can be georeferenced (position/time matched). A Trimble AG114 GPS receiver was used to collect position data. Position data were recorded at a rate of one measurement/sec with the AG114 GPS receiver. In RADAN, the position of each radar scan is proportionally adjusted according to the time stamp of the two nearest positions recorded with the GPS receiver. In this study, on the GPR control unit, the scanning rate was set to 82 scans per second. As each scan of the radar is georeferenced, the integration of GPS with GPR results in incredibly large data sets. Using the *Interactive Interpretation* module of the RADAN processing software, depths to the bedrock were quickly, automatically, and reasonably accurately picked and outputted to a worksheet (X, Y, Z format; containing latitude, longitude, bedrock depths, and other useful data).

Study Sites:
<u>Parkally-Parkally, moist-Hagenbarth complex, 2 to 35 % slopes (map unit PHD):</u>
Sites are located in northern Clark County (essentially between 44.3669 N. Latitude, 111.9609 W. Longitude; and 44. 3628 N. Latitude, 111.9787 W. Longitude) (see Figure 4). All sites are located in rangeland. Soils associated with this map unit include Parkalley, Hagenbarth, Latigo, and Povey soils. These deep or very deep, well drained soils formed in mixed loess, residuum, colluvium, and slope alluvium weathered from rhyolite. The taxonomic classifications of these soils are listed in Table 1.

Table 1. Taxonomic Classification of soils commonly encountered in areas of Parkally-Parkally, moist-Hagenbarth complex, 2 to 35 % slopes

Soil Series	Taxonomic Classification
Hagenbarth	Fine-loamy, mixed, superactive Pachic Argicryolls
Latigo	Loamy-skeletal, mixed, superactive Calcic Argicryolls
Parkalley	Loamy-skeletal, mixed, superactive Pachic Argicryolls
Povey	Loamy-skeletal, mixed, superactive Pachic Haplocryolls

<u>Juniperbute Rock outcrop complex, 1 to 30 % slopes (map unit 44):</u>
This rangeland site is located near St Anthony in Fremont County (44.0771 N. Latitude 111.8760 W. Longitude). The very deep, excessively drained Juniperbute soils formed in eolian deposits from mixed sources on basalt plains. Juniperbute is a member of the mixed, frigid Typic Xeropsamments taxonomic family.

Survey Procedures:
Random GPR traverses were conducted across each site. The 200 MHz antenna was pulled across representative areas of several delineations of map unit PHD (see Figure 1) and one area of map unit 44 in Clark

[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

and Fremont Counties, respectively. In these rangeland settings, the 200 MHz antenna provides a fairly stable platform, which largely remained closely coupled to the ground surface. This helped to reduce unwanted background noise caused by uncoupling of the antenna from the soil surface. However, rangeland vegetation and larger coarse fragments did cause some jarring and uncoupling of the antenna, which produced some spurious reflections on radar records. Each radar traverse was stored as a separate file. Radar records were reviewed in the field and the soil/bedrock interface identified.

Figure 1. Bill Heitt and Jim Doolittle conducting radar survey in an area of Parkalley soils.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., bedrock, 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 equation [1] (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 equation [2] (after Daniels, 2004):

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

Where C is the velocity of propagation in a vacuum (0.298 m/ns). Velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and *v*. At the time of this investigation, soils were very dry.

Based on the measured depth and the two-way pulse travel time to a known subsurface reflector (metal plate buried at 50 cm), the velocity of propagation and the relative dielectric permittivity through the upper part of soil profiles were estimated using equations [1] and [2]. In an area of Parkalley soil, an estimated E_r of 4.07 resulted in a *v* of 0.1477 m/ns. In areas of the Parkally-Parkally, moist-Hagenbarth complex, using a constant *v* of 0.1477 m/ns, a range of 50 ns, and equation [1], the 200 MHz antenna was set to penetrate the subsurface to a depth of about 3.7 m. In an area of Juniperbute soil, an estimated E_r of 2.4 resulted in a *v* of 0.1923 m/ns. In areas of the Juniperbute Rock outcrop complex, using a constant *v* of 0.1923 m/ns, a range of 100 ns, and equation [1], the 200 MHz antenna was set to penetrate the subsurface to a depth of about 9.6 m.

Results:

Parkally-Parkally, moist-Hagenbarth complex, 2 to 35 % slopes (map unit PHD):

The medium textured (average clay in control section ranges from18 to 35 %) Parkalley, Hagenbarth, Latigo, and Povey soils are considered to have moderate potential for GPR (http://soils.usda.gov/survey/geography/maps/GPR/index.html). The *moderate* clay contents and the *superactive* cation activity of these soils contributed to the comparatively high rates of signal attenuation, reduced penetration depths, and lower resolution of subsurface features. In addition, large numbers of rock fragments in these soils produced unwanted scattering losses, which further restricted penetration depths and obscured the soil/bedrock interface, which confounded interpretations of the soil/bedrock interface on portions of the collected radar records. However, in the traversed delineations, the suitability of GPR to map the soil/bedrock interface was better than initial expectations.

On radar records collected within this map unit, the soil/bedrock interface was interpreted based on reflection signal amplitude, patterns, and continuity. Figure 2 is a representative portion of a radar record from a delineation of Parkally-Parkally, moist-Hagenbarth complex on 2 to 35 % slopes. On this radar record, the interpreted depth to the soil/bedrock interface has been highlighted with a segmented, green-colored line. The bedrock interface was identified by higher-amplitude (white and gray colored), more continuous linear reflectors. On this radar record, the overlying soil materials appear to be relatively free of coarse fragments and radar reflections. Some moderate to high amplitude reflections are evident in the materials overlying the soil/bedrock interface, but these reflections are either of weaker amplitude, discontinuous, or appear as point anomalies (interpreted as large rock fragments rather than the parent rock surface).

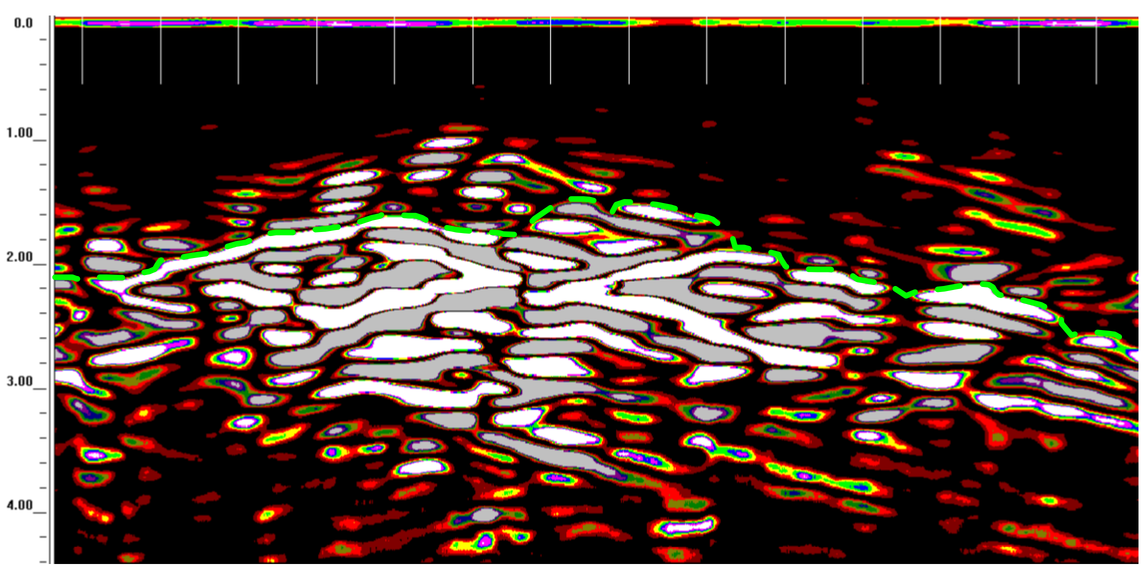

Figure 2. On this radar record from an area of Parkally-Parkally, moist-Hagenbarth complex on 2 to 35 % slopes, the interpreted soil/bedrock interface has been highlighted with a segmented, green-colored line.

The soil/bedrock interface was more difficult to confidently interpret in soils with larger amounts of coarse fragments and/or calcium carbonates either dispersed or concentrated in Bk horizons. Figure 3 provides examples of these situations. This radar record was collected on a shoulder slope in an area of the Parkally-Parkally, moist-Hagenbarth complex. In the left-hand portion of this radar record, soils contained a large amount of coarse fragments, which weakened and obscured the soil/bedrock interface. In the right-hand portion of this radar record, soils contained more noticeable concentrations of calcium carbonates. Here, higher rates of signal attenuation restricted penetration depths and weaken reflections from the soil/bedrock interface. These conditions precluded accurate picking of the soil/bedrock interface.

Eight radar traverses of varying lengths were conducted across separate delineations of the Parkally-Parkally, moist-Hagenbarth complex on 2 to 35 % slopes. Figure 4 is a Google Earth image of the area traversed with GPR. The locations of these traverse lines as well as the soil depths interpreted along these lines are shown in Figure 4. Although the scale is small and it is difficult to see all the depth intervals, it is obvious that very deep and deep soils (colored white and green, respectively) dominate the traversed areas.

Tables 2 and 3 summarize the results of these surveys. The techniques used in these surveys are novel (GPR and GPS), and the number of observations is beyond a soil scientist's past levels of reasoning (we probably set the Idaho record for number of soil observations in one day). Table 2 lists the number of observations made of the depth to bedrock for each traverse according to soil depth classes.

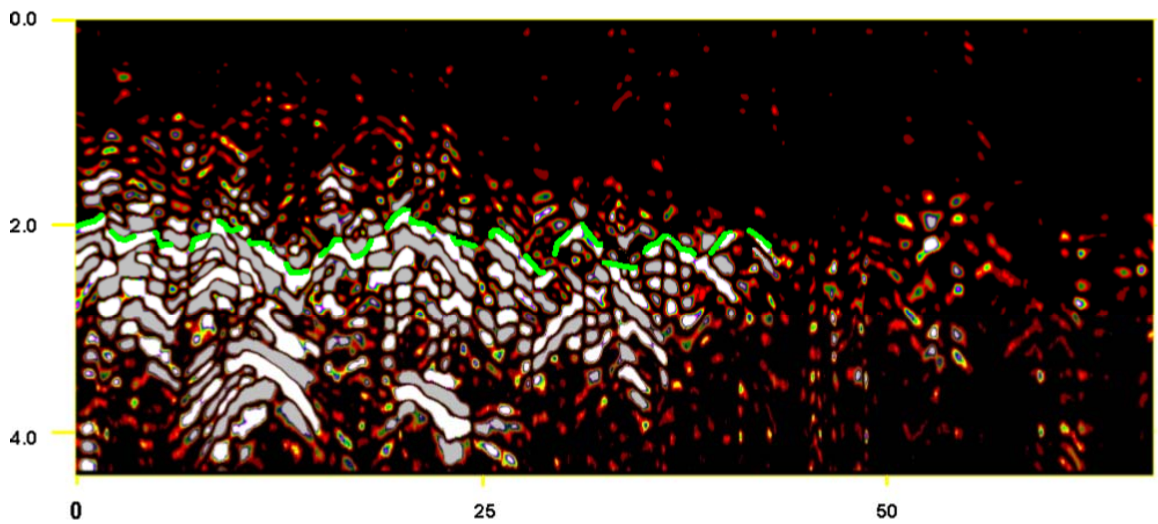

Figure 3. *On this radar record from an area of Parkally-Parkally, moist-Hagenbarth complex on 2 to 35 % slopes, greater amounts of rock fragments (left-hand portion) and concentrations of calcium carbonates (right-hand portion) reduce confidence in interpretations.*

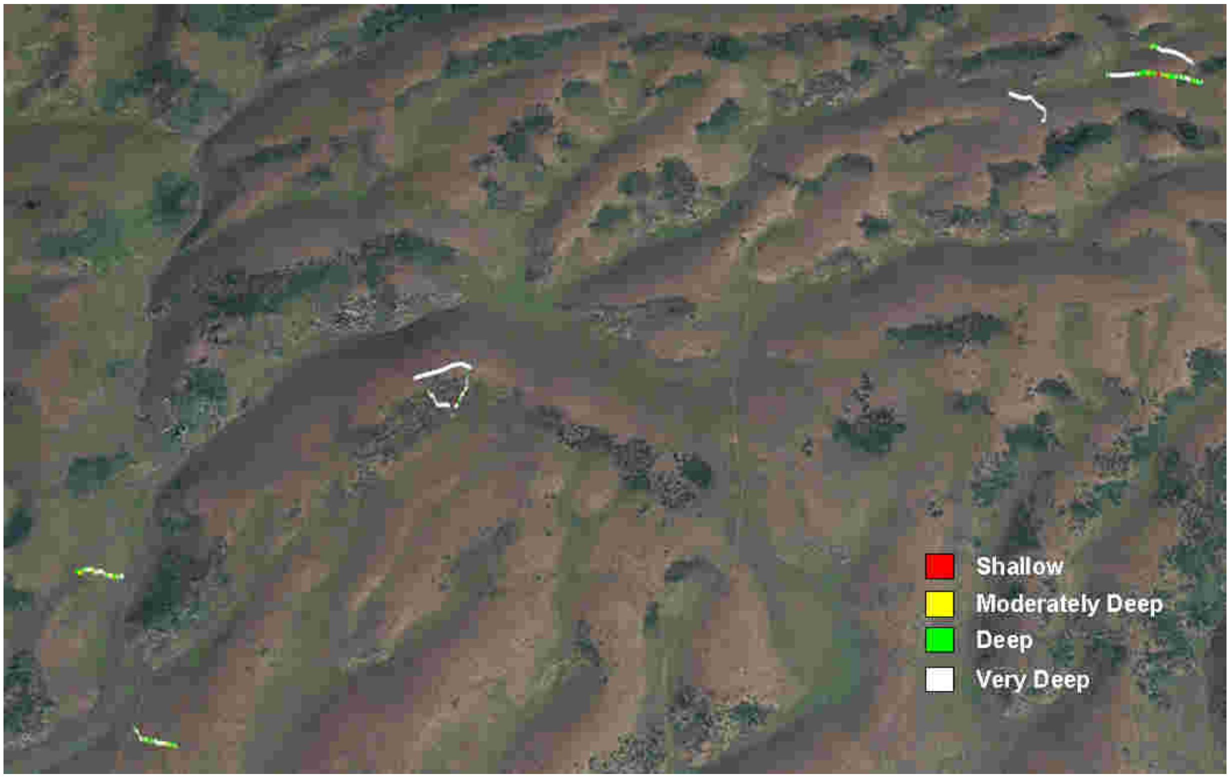

Figure 4. This Google Earth image shows the locations of the GPR traverses conducted in areas of Parkally-Parkally, moist-Hagenbarth complex, 2 to 35 % slopes, in Clark County. Different colors have been used to identify soils by soil depth classes along each traverse line.

Table 2. The number of observations recorded in each soil depths class for the 8 radar traverses made in separate areas of the Parkally-Parkally, moist-Hagenbarth complex on 2 to 35 %.

Depth Class	GPR1	GPR2	GPR3	GPR4	GPR5	GPR6A	GPR6B	GPR6C	Sum
shallow	695	52	0	0	0	0	1176	398	**2321**
mod deep	3804	1691	0	0	131	0	2934	275	**8835**
deep	4219	5359	8	2467	2571	0	9578	713	**24915**
very deep	8039	11736	17905	13833	14201	22104	11941	9724	**109483**
sum	**16757**	**18838**	**17913**	**16300**	**16903**	**22104**	**25629**	**11110**	**145554**

Table 3. *The frequency distribution of observations recorded in each soil depths class for the 8 radar traverses made in separate areas of the Parkally-Parkally, moist-Hagenbarth complex on 2 to 35 %.*

Depth Class	GPR1	GPR2	GPR3	GPR4	GPR5	GPR6A	GPR6B	GPR6C	Average
shallow	0.04	0.00	0.00	0.00	0.00	0.00	0.05	0.04	**0.02**
mod deep	0.23	0.09	0.00	0.00	0.01	0.00	0.11	0.02	**0.06**
deep	0.25	0.28	0.00	0.15	0.15	0.00	0.37	0.06	**0.16**
very deep	0.48	0.62	1.00	0.85	0.84	1.00	0.47	0.88	**0.77**
	1.00	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

<u>Juniperbute Rock outcrop complex, 1 to 30 % slopes:</u>
The 200 MHz antenna provided adequate penetration depth and good resolution of the contact separating the

eolian mantle from the underlying Bk horizon or basalt bedrock. A traverse was conducted across a delineation of this map unit. Figure 5 is the radar record from this map unit. Depths are expressed in meters. Coordinates are expressed in UTM.

In Figure 5, interface "A" defines the base of the sandy eolian mantle. This interface can be traced laterally across this record with a high degree of confidence. On this radar record, the depth to this interface varies from 21 to 334 cm and averages 124 cm. At one half of the observation points along this traverse line, the depth to this interface is between 43 and 182 cm. In many portions of this radar record, additional, lower-lying, planar interfaces (B and C) can be identified below the reflections from the base of the eolian mantle. While the identifications of these interfaces are presently unknown, they are suspected to represent structural features within the underlying basalt bedrock.

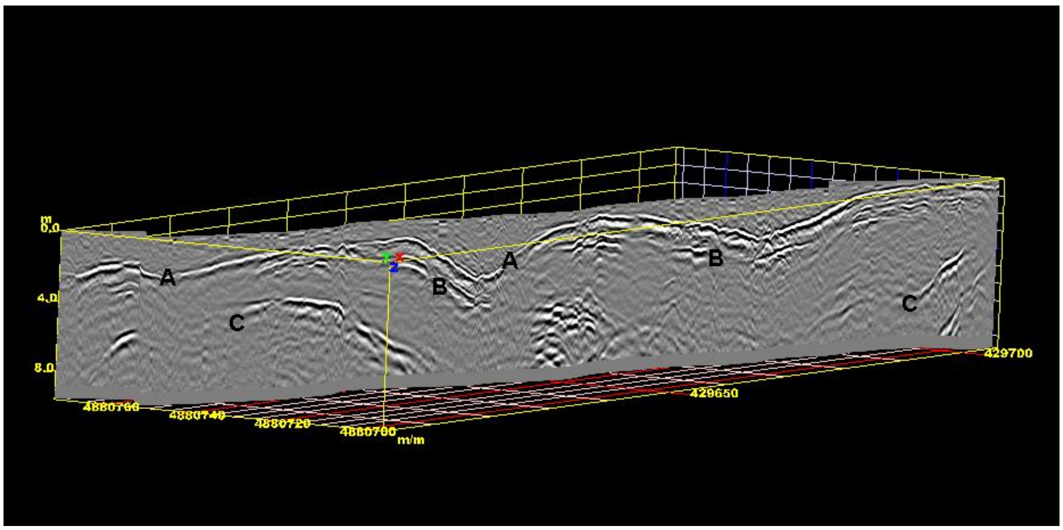

Figure 5. This radar record is from an area of Juniperbute Rock outcrop complex, 1 to 30 % slopes in Fremont County.

Table 4. The number and the frequency distribution of soil/bedrock observations made in a delineation of Juniperbute Rock outcrop complex, 1 to 30 % slopes

Depth Class	Observations	Frequency
shallow	2109	0.34
moderately deep	1178	0.19
deep	1507	0.24
very deep	1481	0.24

References:

Daniels, D. J. 2004. Ground Penetrating Radar; 2nd Edition. The Institute of Electrical Engineers, London, United Kingdom.