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SUBJECT: SOI – Geophysical Assistance

June 1, 2010

TO: Astor F. Boozer
State Conservationist
NRCS, Syracuse, New York

File Code: 330-7

Purpose:
The use of ground-penetrating radar (GPR) to characterize fragipans has resulted in mixed success. Additional radar studies, conducted on different soils formed in different parent materials, at different times of the years and under different moisture conditions, are needed to improve interpretations and determine the effectiveness of GPR. Increased knowledge of the presence, depth, and expression of fragipans would greatly assist soil surveys and interpretations.

Participants:
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Activities:
Field activities were completed on 17 and 18 May 2010.

Summary:

1. In areas of Empeyville, Westbury and Worth soils, under existing spring moisture conditions, the fragipan was weakly expressed and difficult to trace laterally on radar records with a high degree of confidence. Rock fragments and larger tree roots produced unwanted background noise, which interrupted any continuity in the expression of fragipans and befuddled interpretations.

2. Ground-penetrating radar did identify different near-surface stratigraphic units based on differences in the amounts of coarse fragments.

3. If possible, Jim Doolittle would like to return to the sites profiled in this study for one day in the fall, under presumably drier soil conditions, to further evaluate the suitability of using GPR to image the fragipan in soil formed in till.

/s/ Jonathan W. Hempel

JONATHAN W. HEMPEL
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Technical Report on Ground-Penetrating Radar (GPR) Investigations conducted in Lewis County on 17 and 18 May 2010.

James A. Doolittle

For thirty years, ground-penetrating radar (GPR) has been used in soil survey investigations to chart the variability of soils and soil properties. In many studies, GPR has proven to be a valuable tool for the detection and accurate depth measurement of soil horizons and features. Ground-penetrating radar has been used to chart the depth, lateral extent, and continuity of fragipans (Doolittle et al., 2000; Lyons et al., 1988; Olson and Doolittle, 1985). Results have had varied degrees of success, with the effectiveness of GPR being highly site and parent material specific.

On the Tug Hill Plateau, the presence, spatial continuity and expression of fragipans are difficult to characterize with conventional soil survey tools. Fragipans play an important role in near-surface hydrological processes. Fragipans form a depth restrictive layer to water and tree roots. Temporal differences in the expression of fragipans on radar records are not well documented and no GPR study of fragipans has been conducted in areas of glacial till. The plan of this study is to profile soils with fragipans that have formed in till at different times of the year (under both wet (spring) and Dry (fall) conditions) and evaluate the performance of GPR.

Study Sites:
All study sites (Table 1) are located in Lewis County in forested areas mapped as Empeyville-Westbury complex on 3 to 8 % slopes (3111B), and Worth-Empeyville complex on 3 to 15 % slopes (3115C). These very deep soils formed in loamy till on uplands. Rock fragments, principally gravel, cobblestones and stones, can range from 5 to 35 percent by volume in the soil above the fragipan and from 15 to 60 percent within the fragipan and substratum. Empeyville soils are moderately well drained and have fragipan at depths ranging ranges from 36 to 56 cm (14 to 22 inches). Westbury soils are somewhat poorly drained and have fragipans at depths ranging from 25 to 61 cm (10 to 24 inches). Worth soils are well drained and have fragipans at depths ranging from 46 to 91 cm (18 to 36 inches). Empeyville is a member of the coarse-loamy, isotic, frigid Typic Fragiorthods taxonomic family. Westbury is a member of the coarse-loamy, isotic, frigid Typic Fragiaquods taxonomic family. Worth is a member of the coarse-loamy, isotic, frigid Aquic Fragiorthods taxonomic family. Because of their low clay and cation exchange capacity, these soils are considered to have high potential for deep penetration with GPR.

Table 1. Locations of study sites.

Site	Latitude	Longitude
1	43.5118	75.6010
2	43.4988	75.6053
3	43.4755	75.5987
4.	43.6999	75.6885
5.	43.7000	75.6884

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[1] The SIR-3000

[1] Trade names are used for specific references and do not constitute endorsement.

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 4.1 kg (9 lbs) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. The 200 and 400 MHz antennas were used in this investigation.

The RADAN for Windows (version 6.6) software program; developed by GSSI) was used to process the radar records shown in this report.[1] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, migration, and high-pass filtration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques).

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):

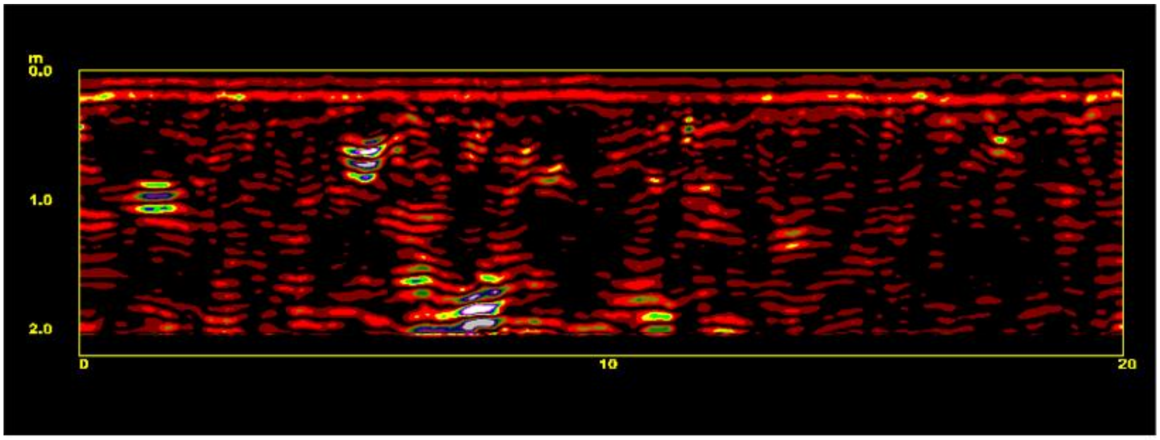
$$E_r = (C/v)^2 \qquad [2]$$

Where C is the velocity of propagation in a vacuum (0.299 m/ns). Typically, 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.

Based on the measured depth and the two-way pulse travel time to a known subsurface reflector (buried metal plate), the velocity of propagation and the relative dielectric permittivity through the upper part of the soil profiles were estimated using equations [1] and [2]. At the time of these studies, soils were moist. The estimated E_r ranged from 4.97 to 7.46. The estimated v ranged from 0.1078 to 0.1341 m/ns.

Results:
At the time of this investigation, soils were moist, but not as wet as desired. It was hoped that, at this time of the year, the fragipans, because of their lower saturated hydraulic conductivity, would cause some perching of the groundwater resulting in a saturated E horizon overlying a relatively dry Bx horizon. This anticipated difference in soil wetness would increase the contrast in dielectric permittivity along this interface, producing a high-amplitude and more easily recognizable radar reflection. While some differences in soil consistency and structure were observed between the E and Bx horizons, differences were not considered great enough to produce a significant GPR reflection. The observed fragipans did contain noticeably more coarse fragments than the overlying (aeolian (?)) materials.

Figure 1 contains two renditions of the same radar record that was collected with a 400 MHz antenna in an area of Empeyville-Westbury complex on 3 to 8 % slopes (Site 1). In the lower plot, the interpreted fragipan has been highlighted with a segmented line. The upper plot lacks this line and should be used for unbiased comparisons. As the fragipan is weakly expressed and segmented, it is difficult to trace laterally with a high degree of confidence. Higher amplitude (colored white, blue, yellow, and green) subsurface reflections are presumably produced by larger rock fragments and some tree roots. In the upper part of the radar record, a discontinuous, low-amplitude (colored in shades of red) reflection indicates a shallow soil horizon, possibly the Bs horizon.



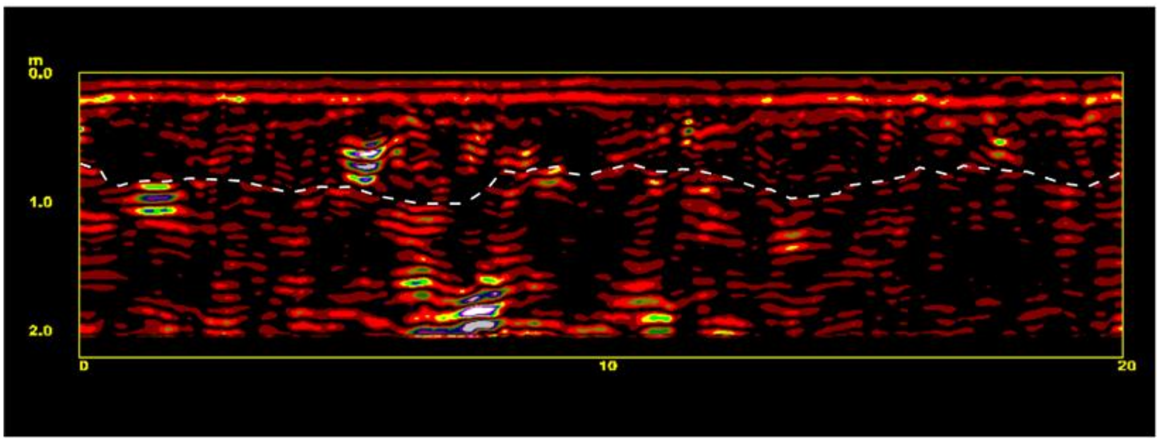


Figure 1. These processed radar images are of the same radar record. The interpreted depths to the fragipan has been highlighted with a white-colored segmented line in the lower image. The radar record was collected at Site 1.

Figure 2 contains a highly processed radar record that was collected with a 400 MHz antenna in an area of Worth-Empeyville complex on 3 to 15 % slopes (Site 5). Migration and range gain adjustments have been applied to this radar record in an attempt to improve interpretations. Though not drawn, an irregular, discontinuous interface can be approximated on this radar record between depths of 50 and 100 cm. This interface separates very fine sandy loam surface materials from underlying cobbly, loamy fine sands. This stratigraphic contact represents a significant *radar facies* and also closely approximates the contact of the E and Bx horizons. A *radar facies* is a mappable three-dimensional unit composed of GPR reflections whose internal reflection patterns and characteristics differ from adjoining units. Based on this image, the fragipan would be described as being spatial variable in expression. The fragipan would best be described as being very weakly expressed in these soils at this time of the year. In this example, I would have greater confidence in making an interpretation on the depths to coarser-textured materials that contain large amounts of coarse fragments than on the depths and expression of a fragipan.

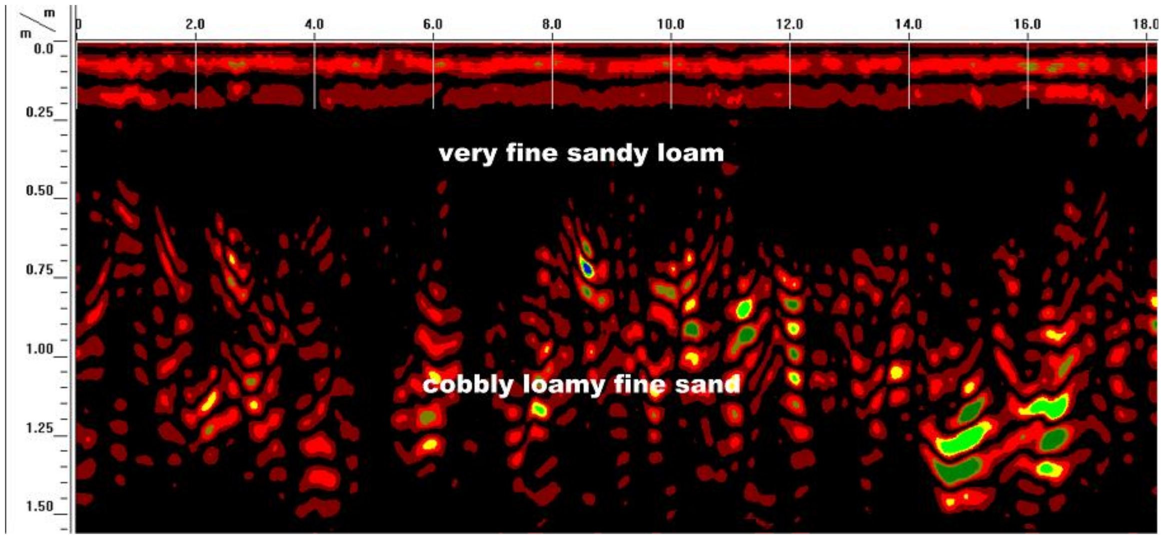


Figure 2. This radar record is from an area of Worth and Empeyville soils. Two radar facies are evident: a shallow facies that contains few subsurface reflections and a deeper facies that contains numerous reflections, which presumably represent larger rock fragments.

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