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

Subject: Eng – Ground-Penetrating Radar (GPR) Field Assistance **Date:** 1February 2000

To: Patricia S. Leavenworth
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Purpose:
A ground-penetrating radar survey was conduct on slopes adjacent to Jersey Valley Lake on the West Fork of the Kickapoo River to help determine the condition of the underlying sandstone bedrock. It was hoped that the GPR survey would provide additional information on the amount of rock material to be removed by "common excavation" and/or "ripping" methods.

Participants:
Dan Chroninger, Technician, Vernon County LCD, Viroqua, WI
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Barbara Lensch, Geologist, USDA-NRCS, Madison, WI
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Activities:
All activities were completed on 25 January 2000.

Background:
Joints and fracture patterns in solid rock may not be readily detectable by conventional drilling or geologic mapping techniques. Ground-penetrating radar has been used to map bedrock depths (Collins et al., 1989), faults (Wyatt and Temple, 1996), and fractures in bedrock (Imse and Levine, 1985;Toshioka et al., 1995; Ulriksen, 1982). In rock, GPR has been found to be sensitive to changes in rock types, and water filled or dry fractures (Davis and Annan, 1989).

Equipment:
The radar unit is the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc.[1] Morey (1974), Doolittle (1987), and Daniels (1996) have discussed the use and operation of GPR. The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. A 12-volt battery powered the system. This unit is backpack portable and requires two people to operate. A 120 mHz and a 200 mHz antenna were used in this study. For this survey, the scanning time was 150 nanoseconds (ns); the scanning rate was 32 scan/second. Hard copies of the radar data were printed in the field on a model T-104 printer.

Study Site:
The study area was located along the eastern side of Jersey Valley Lake in an area of Stony rock land, steep (Slota, 1969). This miscellaneous map unit consists of materials derived from sandstone. Depth to bedrock is generally less than 24 inches but ranges to depths of 42 inches.

Field Procedures:
Nine short traverse lines were established along a west-facing slope that borders the lake. Three stakes were inserted in the ground along each traverse lines and served as reference points. The radar survey was completed by pulling the 200 mHz antenna along these traverse lines. The survey was carried out under challenging field conditions. The slopes were very steep, snow covered, and slippery. Maintaining uniform antenna speeds of advance along the traverse lines was extremely difficult. As the antenna passed

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

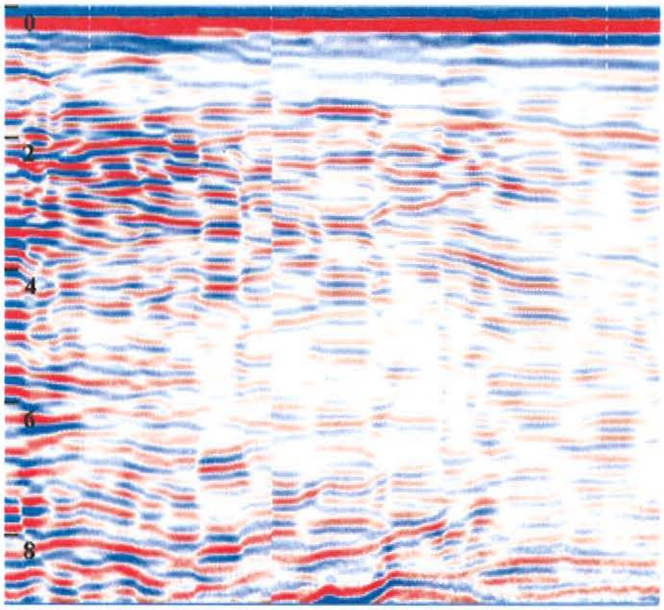

Figure 1A. GPR Profile #11. Depth Scale is in m.

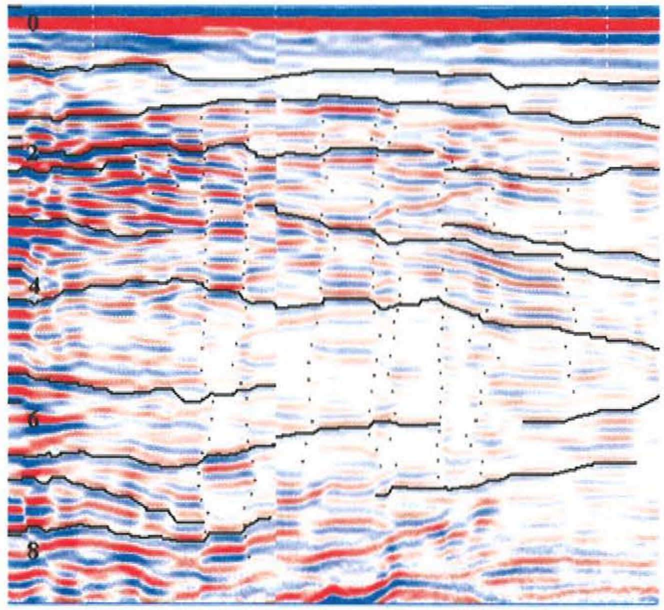

Figure 1B. GPR Profile #11. Lines show location of some of the sheet joints; dots show location of some of the vertical joints. Depth scale is in m.

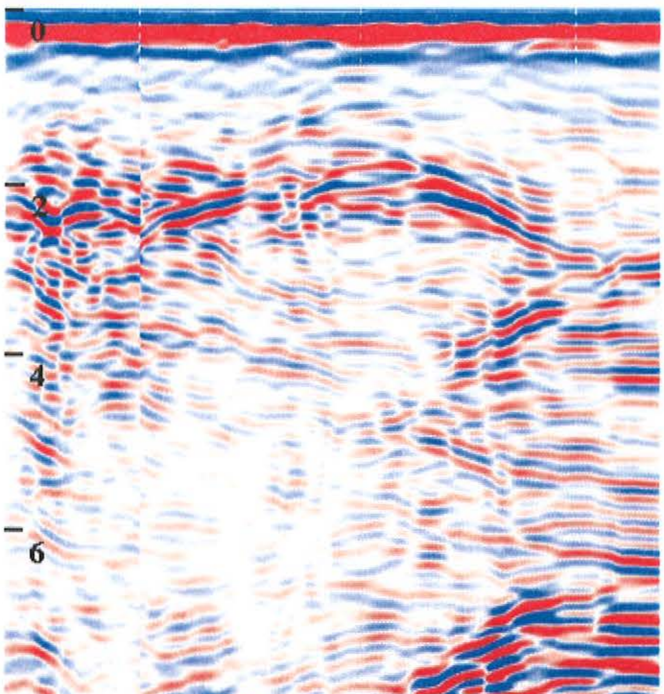

Figure 21A. GPR Profile #7. Depth Scale is in m.

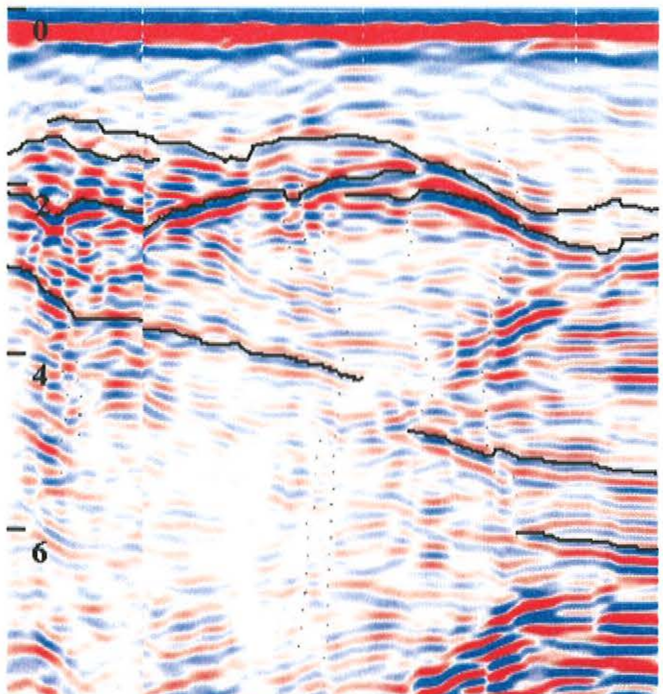

Figure 2B. GPR Profile #7. Lines show location of some of the sheet joints; dots show location of some of the vertical joints. Depth scale is in m.

each reference stake, a vertical dash line was impress on the radar profile by the operator. These segmented vertical lines identified relative locations along each traverse line

Calibration of GPR:
Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from the antenna to an interface (e.g., fracture, stratigraphic layer, bedrock surface) 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 (Morey, 1974):

$$v = 2d/t \qquad [1]$$

The velocity of propagation is principally affected by the dielectric permittivity (e) of the profiled material(s) according to the equation:

$$e = (c/v)^2 \qquad [2]$$

Where c is the velocity of propagation in a vacuum (0.3 m/nanosecond). Velocity is expressed in meters per nanosecond (ns). A nanosecond is one billionth of a second. The amount and physical state of water (temperature dependent) have the greatest effect on the dielectric constant of a material.

As the ground was frozen at the time of this investigation, no ground-truth auger observations were made to identify subsurface reflectors and to determine their depths. A tabled value of 6 was used to approximate the dielectric permittivity of sandstone (Ulriksen, 1982). Based on this value and equation [2], the velocity of propagation was estimated to be about 0.1225 m/ns. A scanning time of 150 ns was used in this investigation. Using equation [1], a scanning time of 150 ns, and a propagation velocity of 0.1225 m/ns, the depth of observation was estimated to be about 9.2 m.

Results:
With a scanning time of 150 ns, high-resolution profiles were obtained with the 200 mHz antenna along each transect to a depth of about 9.2 meters. Figures 1 and 2 are representative radar profiles from the site. These radar profiles have not been terrain corrected. In both profiles, regardless of slope, the surface appears horizontal. Numerous planar reflectors are apparent in these and all radar profiles from the site. In Figures 1and 2, several of the more prominent planar reflectors have been highlighted with a dark line. These reflectors represent stratification and/or sheet joints developed in the sandstone bedrock. Reflectors that are presumed to represent stratification or sheet joints are continuous, often roughly parallel or slightly inclined with the surface, and variable in amplitude. These patterns are repetitive on radar profiles. Sheet joints, if present, represent fracturing due to the relief of pressure caused by the removal of overlying rock materials by erosion. It is most probable that not all sheet joints or stratification were detected with GPR. Toshioka and others (1995) observed that closed or dry fractures are not detected with GPR. However, larger joints or facture zones filled with dissimilar soil materials and having higher water contents than the host rock, may be detected.

Vertical joints are generally vertical or traverse to the beds or sheet joints. In Figures 1and 2, several conspicuous vertical features suggest the possible presence of vertical joints. These vertical features are narrow, linear, and have low or no signal amplitude. These features suggest fracturing of the bedrock. In each figure, several of the more prominent and continuous "vertical joints" have been highlighted with segmented lines. Bedding planes on either side of these joints lack signs of appreciable movement. Wyatt and Temple (1996) noted the difficulty of detecting joints and fractures in unconsolidated sediments with GPR. The size, pattern, and orientation of these features determined the ease of detection with GPR. These authors noted that narrow vertical joints were often not detected unless filled with dissimilar materials. In addition, Wyatt and Temple (1996) used vertical and non-vertical patterns of no signal or chaotic signal returns to indicate jointing. However, Lieblich and others (1992) reported that images of a fracture should appear as a "sublinear coherent event to a diffraction hyperbola with a ringy appearance." These authors also noted that other in-homogeneities in the host rock would also produce these patterns.

Vertical features of no signal or chaotic signal returns occur throughout the radar profiles and at all depths. Within the upper 5 meters of the profile and between the three referenced locations along each traverse line, the number of vertical features detected on the unprocessed radar profiles printed in the field averaged 9.3 and ranged from 3 to 18. If these features represent vertical joints in the bedrock, the number detected undoubted represent only the larger and not necessarily all of these features.

In the lower right-hand corner of Figure 2, at an estimated depth of 7 to 9 m, high amplitude reflections signify contrasting materials within the bedrock.

Conclusions:

The radar profiles provided no evidence suggesting a change in the structure, composition, or competent of the host rock to a depth of about 7 meters. Bedrock conditions that are evident at the surface are believed to extend to a depth of about 7 m. Similar spatial patterns are evident on all radar profiles. Conspicuous breaks in the continuity of linear features (presumed to represent stratification and/or sheet joints) were apparent on all radar profiles. These breaks are believed to represent vertical joints. The frequency of these vertical linear features suggests that the sandstone bedrock is highly fractured and jointed.

It was my pleasure to work once again in Wisconsin and with members of your fine staff.

With kind regards,

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References:

Collins, M. E., J. A. Doolittle, R. V. Rourke. 1989. Mapping depth to bedrock on a glaciated landscape with ground-penetrating radar. Soil Sci. Soc. Am. J. 53(3): 1806-1812.

Daniels, D. J. 1996. Surface-Penetrating Radar. The Institute of Electrical Engineers, London, United Kingdom. 300 p.

Davis J. L., and A. P. Annan. 1989. Ground-penetrating radar for high resolution mapping of soil and rock stratigraphy. Geophysical Prospecting 37:531-551.

Doolittle, J. A. 1987. Using ground-penetrating radar to increase the quality and efficiency of soil surveys. 11-32 pp. In: Reybold, W. U. and G. W. Peterson (eds.) Soil Survey Techniques, Soil Science Society of America. Special Publication No. 20. 98 p.

Imse, J. P. and E. N. Levine. 1985. Conventional and state-of-the-art geophysical techniques for fracture detection. IN: Proceedings of the Second Annual Eastern Regional Ground Water Conference. July 16-18, 1985. Portland, ME. National Ground Water Association, Dublin, OH. 261-276 p.

Lieblich, D. A., F. P. Haeni, and J. W. Lane. 1992. Integrated use of surface-geophysical methods to indicate subsurface fractures at Milford, New Hampshire. U.S. Geological Survey, Water-Resources Investigation Report 92-4056. Hartford, Connecticut. 38 p.

Morey, R. M. 1974. Continuous subsurface profiling by impulse radar. p. 212-232. *IN:* Proceedings, ASCE Engineering Foundation Conference on Subsurface Exploration for Underground Excavations and Heavy Construction, held at Henniker, New Hampshire. Aug. 11-16, 1974.

Slota, R. W. 1969. Soil Survey of Vernon County, Wisconsin. USDA-Soil Conservation Service. U. S. Government Printing Office, Washington, D.C. p 82.

Toshioka, T., T. Tsuchida, and K. Sasahara. 1995. Application of GPR to detecting and mapping cracks in rock slopes. Journal of Applied Geophysics 33: 119-124.

Ulriksen, C. P. F. 1982. Application of impulse radar to civil engineering. Doctoral Thesis. Department of Engineering Geology, Lund University of Technology, Lund, Sweden. p. 179

Wyatt, D. E., and T. J. Temples. 1996. Ground-penetrating radar detection of small-scale channels, joints and faults in unconsolidated sediments of the Atlantic Coastal Plain. Environmental Geology 27: 219-225.