United States Department of Agriculture

Soil Conservation Service

Northeast NTC
160 E. 7th Street
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Subject: SOI - Ground-penetrating Radar (GPR) Field Study, Duchesne and Uintah Counties, Utah; September 21-27, 1986

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To:
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PURPOSE

To explore the potential of using ground-penetrating radar (GPR) to monitor the depth to ground water and to characterize soil features within the Uintah Basin

PARTICIPANTS

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EQUIPMENT

The radar unit is the SIR System-8. Components of the SIR System-8 include the Model 4800 control unit, the ADTEK DT-6000 tape recorder, and the Model 8004H graphic recorder. The ADTEK DT-6000 Tape recorder operated erradicately and was not used. The 80 and 120 MH_z antennas were used interchangeably with the Models 705, 705DA, and 705DA2 transceivers. Neither of the antennas worked well on the selected soils. However, the 120 MH_z antenna with the 705DA tranceiver provided the best balance of probing depth and image resolution.

DISCUSSION

The purpose of this investigation was to evaluate the ability of the GPR to chart and monitor the depth to water table in irrigated soils along the Duchesne River and to characterize soils within the Uintah Basin. Prior to this investigation, the radar's performance had not been evaluated for Aridisols and calcareous soils.

Water tables have been charted with the GPR in many areas of coarse textured soils in eastern United States. Generally, the radar can discern only abrupt changes in electromagnetic properties. In coarse textured soils, pores are relatively large and many are essentially non-capillary. Consequently, the capillary fringe is abrupt, the reflection coefficient pronounced, and the resulting radar image strongly expressed on graphic profiles. As the texture becomes finer, the capillary fringe becomes increasingly more gradual and images of the water table becomes more indistinct on graphic profiles.

Within the study area soils ranged from coarse-loamy to fine. Many soils were stratified with layers ranging from loamy sand to clay.

As the number of subsurface interfaces increase, it becomes increasingly more difficult to trace the image of a water table with a high degree of confidence. Multiple, closely spaced images are often superimposed and some images are cancelled by this overlap. This problem is common in alluvial deposits and was encountered in areas of Jeddito soils.

The maximum probing depth of the GPR is determined by the conductivity of the earthen material. Soils having high electrical conductivities rapidly absorb the radiated energy and severely limit the radar's probing depth. The electrical conductivity of soils increase with moisture, the concentration of dissolved salts in the soil solution, and the amount and type of clays.

Prior to this field study, and with the exception of soils influenced by sea water, the conductivity of soils was believed to be, in most soils, principally determined by clay type and amount, and moisture content. Expanding 2:1 lattice clays, having higher exchange capacities than 1:1 lattice clays, exhibit higher electrical conductivities, and are more restrictive to the radar. Wet soils are more conductive to electromagnetic energy than dry soils.

Electrical conductivity is an electrolytic process. The conductivity of a soil is proportional to the total number of ions in solution. It is known that the conductivity of distilled water can be increased significantly with the addition of only a small amount of salt. Though studies are inconclusive, soils are believed to have a greater buffering capacity than water.

The soils of the Uintah Basin are very conductive to electromagnetic energy. As in many areas of Aridisols, expanding 2:1 lattice clays dominate. Rainfall within the irrigated areas of the Uintah Basin is low and ranges from 6 to 10 inches. Calcium carbonates are enriched in these soils from waters draining from higher elevations or passing through Eocene sedimentary rocks, and from calcareous eolian deposits.

Prior to this field study, the effects of calcium carbonates on the GPR had not been established. Evidently, carbonates have a significant effect on not only the physical and chemical properties of soils, but also the electromagnetic properties.

Within and closely adjacent to the irrigated areas of the Uintah Basin, soils selected for this study were generally calcareous throughout and belonged to the Calciorthids, Camborthids, or Torriorthents great groups. Soils included Bowdish (fine-loamy over sandy or sandy-skeletal, mixed Pachic Haploborolls), Honlu (fine-loamy, mixed, mesic Ustollic Calciorthids), Jeddito (coarse-loamy, mixed (calcareous), mesic Typic Torriorthents), Moenkopie (loamy, mixed (calcareous), mesic Lithic Torriorthents), Nakoy (coarse-loamy, mixed (calcareous), mesic Typic Calciorthids), and Stutzman (fine, montmorillonitic (calcareous), mesic Typic Torriorthents).

RESULTS

Results of this field study were discouraging in terms of an immediate application for the GPR. SCS's state-of-the-arts impulse radar system does not work well and can not be used as a quality control tool in areas of saline or calcareous soils. The high electrical conductivities of calcareous and saline soils severely limits the radar's probing depth and the clarity of the graphic images, and make this geophysical tool unsuitable for soil investigations.

The results of this study are significant and will be remembered because of their implications to the use of GPR technology in the west. Few studies conducted during the last six-years have contributed more to our understanding of the limitations of the GPR system.

In terms of depth of penetration and quality of graphic images, results were poor except at sites located at elevations above 8000 feet with an average precipitation of more than 17 inches. Under these more humid conditions, salts are more effectively leached from the upper part of the soil profile and depths were attained as great as 15 feet in some areas and 4 to 5 feet in most areas depending on the lithology of and depth to bedrock.

At elevations of less than 6700 feet and with average precipitation of less than 14 inches, soils were generally calcareous and probings were restricted to depths of 0 to 2 feet. In areas of saline or calcareous soils, the amount and type of salts rather than clay content was the limiting factors. Coarse or moderately-coarse textured soils (Jeddito) with conductivities of 6.9 mm/cm and 2-percent $CaCO_3$ are as limiting to the radar as fine textured soils (Stutzman) with conductivities of 8 to 49 mm/cm and with 10-percent $CaCO_3$. Depths of 30 to 40 inches were achieved in recently sub-irrigated areas of Jeddito soils having conductivities of less than 0.6 mm/cm and less than 1-percent $CaCO_3$. The radar is very sensitive to slight accumulations of salts and carbonates in soils. The GPR appears to be ineffective in soils having conductivities of more than 1 to 2 mm/cm and with more than 1-percent $CaCO_3$ equivalent. Additional field test will be completed in Wyoming and North Dakota to better qualify these results.

Annotated copies of the graphic profiles have been returned to Joe Downs under a separate cover letter.

I wish to thank you for this opportunity to explore the use of GPR technology in Utah. While disappointing, these results will be vital to the future applications and development of ground-penetrating radar methods within SCS. I wish to extend a special thanks to your staff and especially Joe Downs for his spirited direction of this study, and Garth Leishman for his thorough preparation for this field investigation.

With kind regards.

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