GROUND-PENETRATING RADAR STUDY OF ORTSTEIN CONTINUITY IN SOME MICHIGAN HAPLAQUODS

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Abstract

Continuity of ortstein affects many agricultural and urban land uses. This study was conducted to determine the utility of ground-penetrating radar (GPR) in studying ortstein continuity. The GPR data were compared with those collected by conventional field techniques. The ortstein is generally strongly cemented and continuous in an area mapped as Saugatuck soils (sandy, mixed, mesic, ortstein, Aeric Haplaquods), and appeared to occupy 75 to 100% of each pedon. Tongues of E horizons and weakly cemented or noncemented materials in the ortstein horizon were easily identified by GPR. Such breaks in the ortstein are difficult to locate with conventional field techniques. These results demonstrate that GPR is useful in determining ortstein continuity.

ORTSTEIN is defined as a spodic horizon that is at least weakly cemented (Soil Survey Staff, 1975; Canadian Soil Survey Committee, 1978). The ortstein family criterion requires that "all or part of the spodic horizon (be) at least weakly cemented, when moist, into a massive horizon that is present in more than half of each pedon" (Soil Survey Staff, 1975, p. 389). One criterion for Typic Haplorthods is "a continuous horizon at least 2.5 cm thick that is very firm or extremely firm when moist (ortstein)" (Soil Survey Staff, 1975, p. 346). The term *continuous*, however, is not strictly defined. In the Canadian system of soil classification (Canada Soil Survey Committee, 1978), ortstein is defined as a strongly cemented horizon at least 3 cm thick that occurs in more than one-third of the pedon.

Ortstein horizons inhibit root penetration, have high bulk densities, and may have low hydraulic conductivities (Lambert and Hole, 1971; Wang et al., 1978; Ritari and Ojanpera, 1984). Some knowledge of ortstein continuity is important in evaluating sites for agricultural and urban land uses. Historically, research has primarily been directed toward understanding the chemistry and genesis of ortstein. Many of the problems associated with understanding the latter center on pedochemical reactions. Not much work has been done on the morphology of the cemented horizon itself, and little is known about this horizon's continuity. One study (Wang et al., 1978), however, found that ortstein layers were almost continuous in poorly drained soils and intermittent in well drained soils.

Ground-penetrating radar (GPR) is a technique that has been used successfully to study depth to impermeable layers (e.g., bedrock; Doolittle et al., 1988) and spodic horizons (Doolittle, 1982, 1987; Collins and Doolittle, 1987). To our knowledge, an examination of depth to, and continuity of, ortstein has not previously been examined using GPR. Continuous and rapid collection of data by GPR could provide the necessary information to assess ortstein continuity. The objective of this study was to assess the application of GPR to ortstein continuity.

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Methods

The study area was located on a sandy lacustrine plain in Mason County, Michigan, within a delineation of Saugatuck sand (sandy, ortstein, mixed, mesic Aeric Haplaquod), 0 to 3% slopes. Further investigation indicated that this area had inclusions of Pipestone soil (sandy, mixed, mesic Entic Haplaquod). Pipestone soils lack distinct and continuous ortstein layers, but often exhibit small (<10-cm diameter) fragments of cemented materials within the spodic horizon. Because the site was forested, we had to set up the GPR equipment near logging trails. The vehicle powering the equipment was parked on the trail, and the antenna was carried into the forest about 25 m, the length of the power cable.

The GPR system has been described in detail by Shih and Doolittle (1984) and Doolittle (1987). A 500-MHz antenna, producing 0.6-m wavelength emissions, was towed by hand along transects at an average rate of about 3 km h^{-1}. Slower towing speeds (~1 or 0.3 km h^{-1}) were used for more de-

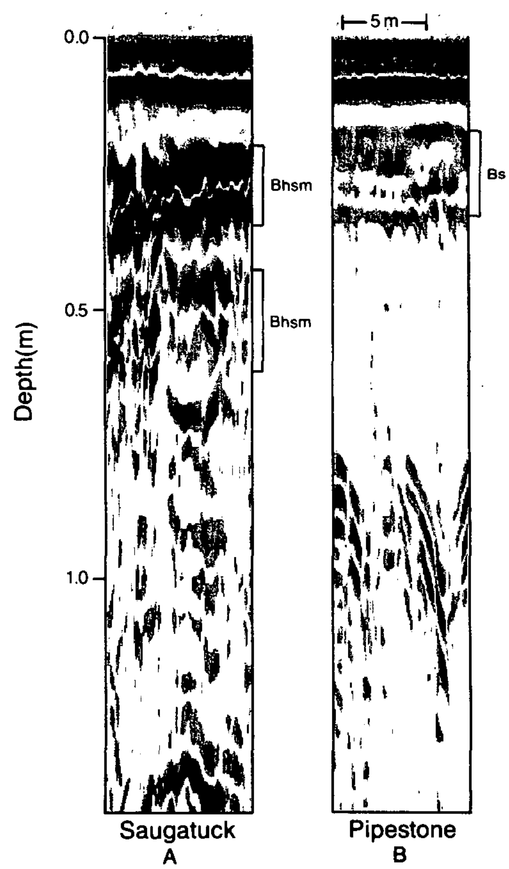

Fig. 1. Ground-penetrating radar profiles showing differing degrees of ortstein expression. The Saugatuck soil (A) has an ortstein horizon (Bhsm), but the Pipestone soil (B) lacks ortstein in the Bs horizon.

tailed investigations of selected short transects. The GPR scanning times were 110 ns, with scanning rates of 25.6 scans s^{-1}. Metallic reflectors, placed at known depths, assisted in depth interpretations of the radar profiles. After a GPR transect had been completed, pits were dug along and beneath that transect in areas of different GPR signals to assist in interpretation of the GPR profiles, and to examine ortstein morphology.

Results and Discussion

The GPR system provided detailed and interpretable profiles of both Saugatuck and Pipestone soils (Fig. 1). The image of the spodic horizon was variable in expression. The Saugatuck spodic horizon (Fig. 1A) contained continuous indurated ortstein, as indicated by the wide, black, uninterrupted bands. Beneath the continuous ortstein was a second horizon of discontinuous, weakly cemented material, as indicated by the small, irregular, coarse-textured pattern between 40 and 70 cm. A Pipestone soil without a cemented spodic horizon (Fig. 1B) exhibited a zone of gray tones with a wide, diffuse white band separating narrow, gray bands.

Changes in bulk density or degree of cementation can be inferred from variations in the gray scale. This variation in consistence was readily verified by observations in pits, and is characteristic of most ortstein (Brandon et al., 1977; Wang et al., 1978; Ritari and Ojanpera, 1984). Increased signal reflections from the spodic horizon produced darker images that were associated with the presence of ortstein. Strongly cemented or indurated ortstein was characterized on the GPR profile by two wide, nearly black bands separated by a narrow, white band (Fig. 1A).

Detailed investigations in Saugatuck soils with the antenna towed at ~1 km h^{-1} showed that the ortstein is generally strongly cemented and continuous across the profile (Fig. 2A). Gray tones on the profile indicate zones of less strongly cemented ortstein. Two ortstein layers were present in these soils. Noticeable breaks in the upper ortstein layer occur as white areas in the layer near observation points 4 and 5, and between observation points 5 and 6, and 8 and 9.

To confirm the presence and nature of the discontinuities in the ortstein horizon, additional transects, at still slower speeds (~0.3 km ha^{-1}), were conducted along two segments of the transect shown in Fig. 2A (between observation points 3 and 4, and 8 and 9).

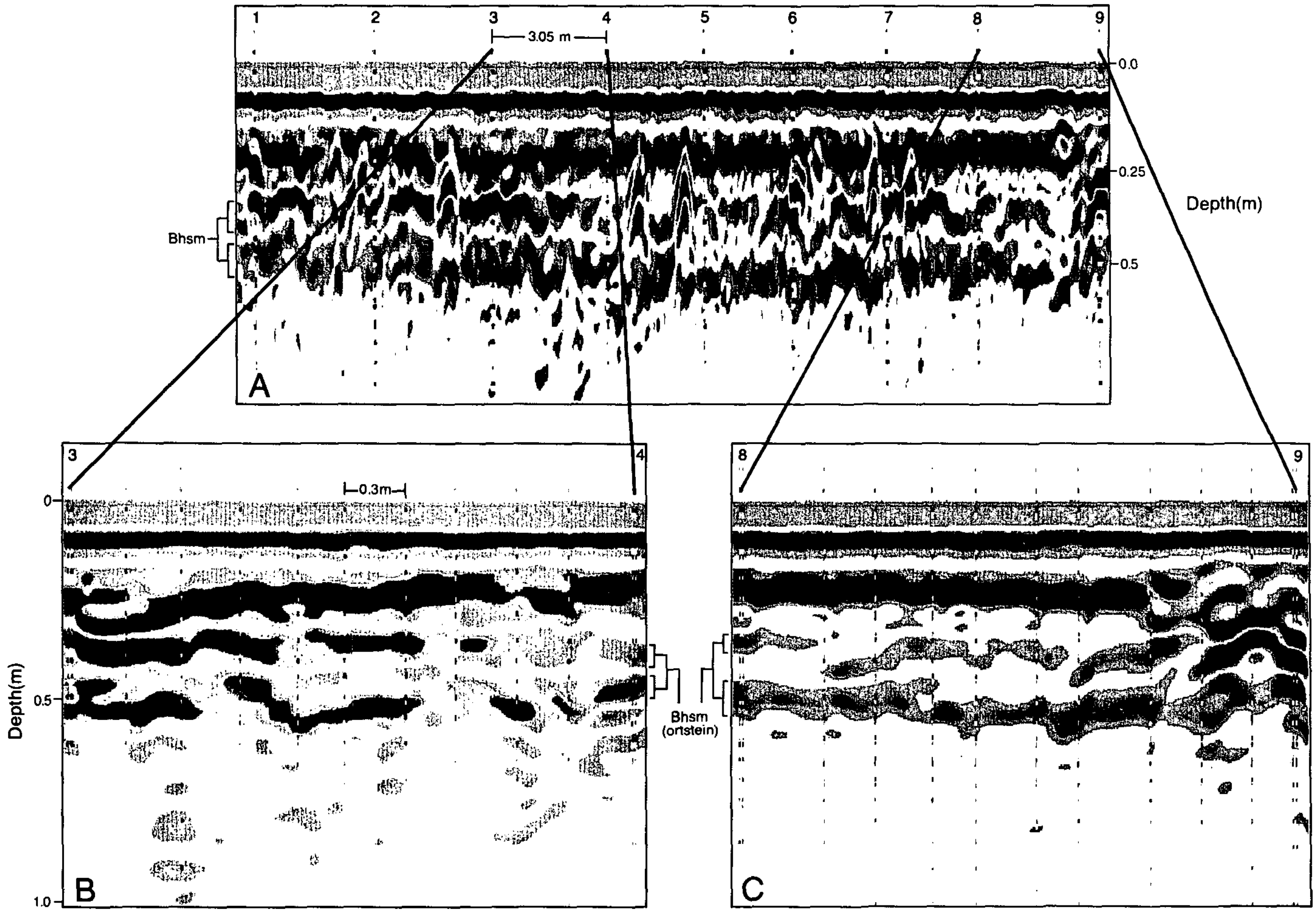

Fig. 2. Ground-penetrating radar (GPR) profile of a Saugatuck soil. (A) nearly continuous ortstein layer; (B) more detailed GPR profile of segment of Transect A between observation points 3 and 4; (C) more detailed GPR profile of segment of Transect A between observation points 8 and 9. Gray tones are related to consistence of the ortstein.

Pits were then excavated to determine the consistence and continuity of the ortstein in these segments. The accuracy of the GPR when towed at slow speeds was excellent. The breaks predicted from Fig. 2 were also observed in the most intensive investigations (Fig. 2B and 2C). These detailed profiles permitted more exact location of the breaks. The breaks in the strongly cemented ortstein were weakly cemented materials or vertical tongues of E horizon material that extended through the ortstein into the spodic horizon. Ortstein appeared to occupy 75 to 100% of each pedon (Fig. 2A), thereby meeting the requirements of the USDA soil taxonomy (Soil Survey Staff, 1975) and the Canadian soil classification system (Canadian Soil Survey Committee, 1978).

This study demonstrates the usefulness of GPR for accessing the continuity of ortstein. Breaks in the ortstein horizon, by tongues of E horizons and weakly or noncemented materials, were easily identified. These breaks would have been difficult to locate with normal auger observations. Locating them would be by pure chance, because they are not related to surface features.

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References

Brandon, C.E., S.W. Buol, E.E. Gamble, and R.A. Pope. 1977. Spodic horizon brittleness in Leon (Aeric Haplaquod) soils. Soil Sci. Soc. Am. J. 41:951–954.

Canadian Soil Survey Committee. 1978. The Canadian system of soil classification. Can. Dep. Agric. Publ. 1646. Supplies and Services Canada, Ottawa.

Collins, M.E., and J.A. Doolittle. 1987. Using ground-penetrating radar to study soil microvariability. Soil Sci. Soc. Am. J. 51:491–493.

Doolittle, J.A. 1982. Characterizing soil map units with the ground-penetrating radar. Soil Surv. Horizons 23(4):3–10.

Doolittle, J.A. 1987. Using ground-penetrating radar to increase quality and efficiency of soil surveys. p. 11–32. *In* W.U. Reybold and G.W. Petersen (ed.) Soil survey techniques. SSSA Spec. Publ. 20. SSSA, Madison, WI.

Doolittle, J.A., R.A. Rebertus, G.B. Jordan, E.I. Swenson, and W.H. Taylor. 1988. Improving soil-landscape models by systematic sampling with ground-penetrating radar. Soil Surv. Horizons 29:46–54.

Lambert, J.L., and F.D. Hole. 1971. Hydraulic properties of an ortstein horizon. Soil Sci. Soc. Am. Proc. 35:785–787.

Ritari, A., and V. Ojanpera. 1984. Properties and formation of cemented ortstein horizons in Rovaniemi, northern Finland. Commun. Inst. For. Fenn. 124:1–32.

Shih, S.F., and J.A. Doolittle. 1984. Using radar to investigate organic soil thickness in the Florida Everglades. Soil Sci. Soc. Am. J. 48:651–656.

Soil Survey Staff. 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Agric. Handb. 436, USDA-SCS. U.S. Gov. Print. Office, Washington, DC.

Wang, C., G.J. Beke, and J.A. McKeague. 1978. Site characteristics, morphology and physical properties of selected ortstein soils from the Maritime provinces. Can. J. Soil Sci. 58:405–420.

COLLECTION OF INTACT CORES FROM A ROCKY DESERT AND A GLACIAL TILL SOIL

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Abstract

A method involving the use of triple-expanding polyurethane foam was developed for the collection of large intact cores from two problem soil types for use in anion/cation transport studies. Intact cores, 36- to 41-cm diameter, were collected from a Jean series (sandy-skeletal, mixed, thermic Typic Torriorthent) and a Colonel series (coarse-loamy, mixed, frigid Aquic Haplorthod). A free-standing pedestal was isolated. The circumference of the core was reduced, to allow encapsulation with a PVC pipe of appropriate inner diameter. The space between the soil and the PVC pipe was filled with polyurethane foam. After the foam cured overnight, the core was severed at the base by driving a steel plate beneath the PVC pipe. Endcaps were fastened to the PVC pipe and the cores were transported to the laboratory.

There is growing evidence that indicates a disparity between solute movement and sorption processes in disturbed vs. undisturbed soils. The extrapolation of laboratory batch adsorption isotherms to field conditions is tenuous (Jardine et al., 1988). In most instances, soils in laboratory batch experiments have been dried, disaggregated, and sieved. This preparation step not only alters the chemical characteristics of the soil (Bartlett and James, 1980), but also eliminates the complex network of micro-, meso-, and macropore structures (White, 1985). In undisturbed, naturally structured soils, especially those with macropores, the infiltrating water causes only partial displacement of resident water and solutes. This phenomenon, often described as channeling, short-circuiting, bypassing, or preferential flow, has been recognized by many researchers (Beven and Germann, 1982; Bouma, 1981; Thomas and Phillips, 1979). Early approaches to collecting intact soil samples involved driving small-diameter metal tubes into the soil (Jamison et al., 1950). When using cores less than three inches in diameter, it is difficult to obtain samples of heavy, compact, or plastic soils without serious compression or disturbance (Jamison et al. 1950). In any event, small-diameter cores are susceptible to boundary flow conditions at or near saturated flow levels. Increasing the core diameter reduces disturbance and flow problems, but makes insertion and withdrawal of the coring device more difficult, often requiring large machinery to recover intact samples (Buchele, 1961; Robertson et al., 1974). Intact cores are especially difficult to obtain in stony soils (Tuttle et al., 1984). Buchter et al. (1984) devised a method for collecting undisturbed cores from stony soils by excavating a free-standing pedestal and encasing it in concrete. The pedestal was then frozen in liquid N,

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