United States Department of Agriculture
Soil Conservation Service
Northeast NTC
160 East 7th Street
Chester, PA 19013

Subject: SOI- Investigations - Ground-penetrating Radar Ortstein Study, Mason County, Michigan, August 29 to September 3, 1988

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To: Homer R. Hilner
State Conservationist
SCS, East Lansing, MI

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Purpose:
To use ground-penetrating radar to study ortstein and the composition of several soil map units in Mason County.

Principal Participants:
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Activities:
Nine sites were examined with the ground-penetrating radar (GPR). Sites had been selected beforehand and considerable ground truth data was obtained by means of soil auger borings. At each site, several GPR transects were conducted. Some were for calibration of the GPR, some were for analysis and interpretation of the soil map units. A final step was the prediction of the occurrence of soil features, in particular, the presence and induration of the ortstein layer, followed in some cases by confirmation by auger borings or small observation pits.

GPR Equipment:

The GPR unit is the SIR System-8 manufactured by Geophysical Survey Systems, Inc. The unit consists of a power distribution unit, the model 4800 control unit, the ADTEK model DT-6000 graphic recorder, and the ADTEK model SR 8004H tape recorder. The system was powered by a 12 volt vehicular battery.

The 120 and 500 MHz antennas were both used in this study. Antenna frequency affects the resolution and the profiling depth of the GPR. The profiling depth is controlled, in part, by the pulse width. A general rule is that as the antenna frequency is decreased, the minimum and maximum profiling depths increase. The lower frequency, 120 MHz antenna with a pulse width of 5 nanoseconds (ns) was unable to resolve the shallow (20 to 35 cm) ortstein layers. The long pulse width of the

120 MHz antenna made attempts to resolve features within the upper 60 cm of the soil profile impracticable. The 500 MHz antenna, with a pulse width of 2 ns, provided adequate profiling depths (8 cm to 4 m) and superior depth and lateral resolution of the ortstein layers. However, images of the water table in Saugatuck and Pipestone soils and clay layers in the Wallace soil were more clearly expressed with the 120 MHz antenna.

Discussion:

1.ORTSTEIN STUDY

Why an Ortstein Study?

Ortstein is derived from the German words "ort" for place and "stein" for stone, and means "stone formed in place."1. The Soil Survey Manual defines ortstein simply as a "horizon cemented with iron and organic matter."2.

The significance of ortstein was sumarized by Wang et al. (1978). These authors noted that :

> "The significance of ortstein to use interpretations of soils is not completely known partly because until recently, ortstein was defined loosely and included a wide range of characteristics. However, in general, the presence of ortstein indicates a poor soil for forestry and agriculture. Fertility is low; wetness may be excessive in the spring and yet plants may suffer droughtiness later in the growing season due to shallow rooting zone. The ortstein hampers cultivation; blocks of ortstein are commonly brought to the surface by cultivation and may persist for years. The presence of ortstein also increases the excavation cost and downgrades the potential of the soil as a source of sand and gravel."

The definition of ortstein given in Soil Taxonomy appears concise and straightforward. When used as a family differentia, ortstein is defined as a cemented, massive, spodic horizon that is present in more than half of each pedon. Ortstein is cemented throughout, however, the degree of cementation is allowed to vary from weak to indurated. As a minimum requirement, when moist, all or part of this horizon must be at least weakly cemented (Soil Survey Staff, 1987). This requirement eliminates horizons composed of cemented concretions and fragments. However, noncemented horizons with "ortstein fragments" have been recognized as a developmental phase of ortstein (Karavayeva, 1968) and are accessory characteristics which have aided field identification of spodic horizons (Nettleton et al, 1986).

The present definition of ortstein has created soil mapping problems. Ortstein is variable in expression over short distances. Ortstein can

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1. G. Plaisance and A. Cailleux. 1981. Dictionary of soils. Amerind Publishing Co. Pvt. Ltd., New Delhi. p. 694.

2.United States Department of Agriculture. 1951. Soil survey manual. U.S. Dep. Agric. Handb. 18, p. 241.

be weakly cemented, strongly cemented, or indurated. "Cemented" soil materials have a brittle consistence. Presently, the most common method for determining the brittleness of a soil layer (and defining whether or not it is ortstein) is resistance to soil augering. Measurements of soil brittleness obtained by this method are subject to personal biases and temporal variations. Classes or measures of brittleness are not defined in the Soil Survey Manual (1951). This has necessitated the use of local definitions which are often arbitrary and inconsistent among survey areas, states, and regions. As an example, the Leon (sandy, siliceous, thermic Aeric Haplaquods) soils described with brittle spodic horizons by Brandon et al. (1977) in North Carolina would probably have been classified as a sandy, siliceous, hyperthermic, ortstein Aeric Haplaquods (Lawnwood) in Florida. Florida is the only state in the south that has established soil series which recognize ortstein families. Have present definitions and interpretations fostered among soil scientists a gray scale of predispositions to recognize ortstein in mapping?

Additional confusion is added to the definition of ortstein by the word "continuous" in the statement that "no single family should include soils that have a continuous, shallow, cemented horizon and soils that do not."3. The word "continuous" also appears in one of the additional requirement for the spodic horizon:

> "1. have a subhorizon >2.5 cm thick that is continuously cemented by some combination of organic matter with iron or aluminium, or both;" 4.

What is meant by "continuous"? Continuous denotes an "uninterrupted extension in space" or "joined without intervening space." Ortstein layers are fractured by processes of pedoturbation. If ortstein needs to be present in only half of each pedon, and the minimum size of a pedon is 1 meter, does a minimum lateral dimension of 50 cm constitute continuous? Probably not. McKeague et al. (1983) noted that ortstein is "cemented either continuously, or discontinuously in nodules from a few cubic meters to a cubic meters in volume." 5. Others, such as Wang et al. (1978), observed that the varying degrees of expression and the intermittent nature of ortstein created soil mapping problems. These authors noted that areas of continuous ortstein rarely exceeded 40 ha in the Maritime Provinces. Undoubtedly, there are problems dividing the ortstein continuum in our hierarchical classification scheme. Confusion appears to exist over its expression and minimum lateral extent required for recognition.

The GPR provides a continuous profile of subsurface soil features and conditions. For the first time, with the GPR, it is possible to document the presence, and measure the depth to and the lateral extent

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3. Soil Survey Staff. 1987. Keys to soil taxonomy. SMSS Tech. Mono.#6. Cornell University, Ithaca, NY. p.51.

4. Ibid, p. 18.

5. J. A. McKeague, F. DeConinck, and D. P, Franzmeier. 1983. Spodosols. p.217-252. In L. P. Wilding, N. E. Smeck, and G. F. Hall (ed.) Pedogenesis and Soil Taxonomy, II. The Soil Order. Elsevier, Amsterdam. p. 245.

or continuity of ortstein layers across the landscape. This study will also explore the possibilities of using the GPR data to make qualitative statements concerning variations in the degrees of cementation.

Principals of Operation

The GPR is an impulse radar system that has been designed to penetrate earthen materials. Short pulses of electromagnetic energy are radiated into the ground from a transmitting antenna. Each pulse consists of a spectrum of frequencies that is distributed about the center frequency of an antenna. As electromagnetic energy travel through the soil, it interacts with and is partially absorbed, scattered, reflected, and transmitted through the medium. A portion of the radiated energy is reflected back to the receiving antenna whenever a pulse contacts an interface separating layers of differing electromagnetic properties. The receiving unit amplifies and samples the reflected energy and converts it into a similarly shaped waveform in the audio-frequency range. The processed, reflected waveforms are displayed on the graphic recorder or taped for future playback or processing.

The amount of energy reflected back to the receiving antenna by an interface is a function of the difference in dielectric properties of the two layers. The reflection coefficient, R, is a measure of this difference and is expressed as :

$$R = \frac{\sqrt{E1 - E2}}{\sqrt{E1 + E2}}$$

where E1 is the apparent dielectric constant of the overlying material; E2 is the apparent dielectric constant of the underlying material (Sellman et al., 1983). According to this equation, the greater the dissimilarity in dielectric properties of the two layers, the stronger will be the reflected signal.

The principal factors influencing dielectric constants are moisture content, porosity, and the scanning frequency of the antenna (Jesch, 1978; and Morey, 1974). Next to soil moisture, porosity is one of the most significant parameters affecting the dielectric permittivity of earthen materials (Olhoeft, 1985). The dielectric constant of a soil layer is inversely related to porosity and directly related to moisture content (Okrasinki et al., 1978).

The graphic recorder is a gray scale recorder; it displays signal amplitudes in sequences of gray tones ranging from black to gray. The stronger the reflected signal, the greater the amplitude and the darker the images on graphic profiles. Strong reflections are recorded as black images and intermediate reflections are recorded in tones of gray.

Ortstein is distinquished from adjacent noncemented soil layers by its hardness, higher bulk density, and lower hydraulic conductivity (Ritari and Ojanpera, 1984). The upper boundary of Ortstein is abrupt and strongly contrasts with the overlying material. Ortstein provides a highly contrasting and abrupt interface which is readily discerned by the GPR.

Field Methods

Three study areas were selected in areas of Saugatuck (sandy, mixed, mesic, ortstein Aeric Haplaquods) and Pipestone (sandy, mixed, mesic Entic Haplaquods) soils northwest of Scottville, Mason County, Michigan. Each site was known to have areas of well expressed ortstein. One transect was conducted in each study area.

Transects were 577 m (1B), 319 m (2), and 289 m (3) in length with observation flags placed at 15.2 meter intervals. The 500 MHz antenna was towed behind a 4WD vehicle at speeds of 1-3 km/h. Several soil borings were made at each site to scale the radar imagery and to confirm interpretations.

A more intensive investigation of ortstein was conducted in an area near observation points one and two of transect 1B. In this investigation 6 transects lines were established with observations at 3.05 meter intervals. The 500 Mhz antenna was hand-towed along each of these transect lines at speeds of less than 1 km/h.

Interpretation of GPR Imagery

A. Areas of Saugatuck and Pipestone soils

The GPR provided detail profiles of subsurface conditions in areas of Saugatuck and Pipestone soils. Figure 1 is a radar profile from a representative area of Saugatuck and Pipestone soils along transect 2. The image of the spodic horizon, though variable in expression, can be traced across the upper part of this profile. In Figure 1, the upper boundary of this horizon has been highlighted with a dark line. The depth to the spodic horizon ranges from about 20 to 35 cm.

Changes not only in depth to the spodic horizon, but in soil strength, bulk density, and/or degrees of cementation can be inferred from variations in the gray scale and the graphic signatures. Increased signal reflections and amplitudes across the spodic horizon produce darker images and are associated with the more electromagnetically contrasting ortstein. The signature of strongly cemented or indurated ortstein is characterized by two wide, black bands separated by a narrow, white band. Bevans and Kenyon (1975) noted that as the amplitude of a reflected signal increases, the width of the white band decreases. In the upper left-hand portion of Figure 1, a zone of "continuous", indurated ortstein (A) is inferred from the wide, extremely black, uninterrupted bands. Generally, this layer is indurated, has a relatively high organic carbon content, and colors of 5 or 7.5YR 1-3/2-4.

In Figure 1, beneath the "continuous", indurated ortstein (A), is a zone of discontinuous, weakly cemented to indurated ortstein layers. The characteristics of this zone is inferred from the small size, irregular shape, coarse texture, and association of the images between depths of 40 to 70 cm.

An area of noncemented to weakly cemented spodic horizon is inferred about "C" (Figure 1). The image from this area (Pipestone soils) has an intermediate gray scale tone with a wide, diffuse white band separating narrow, relatively indistinct gray to black bands. Here the spodic horizon lacks ortstein and, because of its high color value and chroma (7.5 YR 4/6), is presumed to have a lower organic carbon content.

In Figure 1, areas of "ortstein fragments" or discontinuous ortstein layers appear at "B" and "D". The images at "B" are associated with an ortstein layer having numerous, narrow, closely-spaced fractures. The image at "D" reflects a spodic horizon having widely spaced ortstein fragments which are separated by weakly cemented or noncemented areas.

The radar profiles from each transect were analyzed to determine the proportion of Saugatuck and Pipestone soils and the continuity of the ortstein. For each profile, the horizontal distance (15.2 m) separating the flagged observation points was divided into ten equally spaced intervals. At each interval, the presence or absence of ortstein was inferred from the imagery and the series recorded. Tables 1, 2, and 3 list the number of observations of Saugatuck and Pipestone soils within each 15.2 meter unit. The averaged and total number of observations of Saugatuck and Pipestone soils along each transect line are summarized in Table 4.

The areas transected with the GPR appears to be a complex with an average composition of 65.2 % Saugatuck soil and 34.8 % Pipestone soil. The median proportion of Saugatuck soil is 70 %. The lower quartile is 40 % and the upper quartile is 90 %. The interquartile range is 40 to 90 %. Therefore, it may be said that one-half of the sample units have between 40 and 90 % Saugatuck soils.

The frequency and extent of sampling units, grouped by occurrence of ortstein, are summarized in Table 5. Sampling units with continuous ortstein (100%) occupy about 19 % of the transected sites. Areas of continuous ortstein tend to be clustered in the landscape and have an average linear extent of about 25 m. If the definition of "continuous" ortstein includes sites with greater than or equal to 90 % ortstein, these areas occupy about 35 % of the transected sites and have an averaged linear extent of about 29 m. If the percent ortstein within each sample unit is equivalent to the percent of each pedon having ortstein, then: 35 % of the sampling meets the requirement for "continuous" ortstein; 76 % of the sampling units appear to satisfy the United State requirement for the ortstein family; and 86 % of the sampling units may meet the Canadian requirements for ortstein.

The frequency of ortstein within the 78, 15.2 m sampling units is graphically summarized in Figures 2 and 3. Both graphs depicit a division in the data: (i) areas having 0 to 59 % ortstein and (ii) areas having >60 % ortstein.

Six detailed GPR surveys were conducted in an area having a known high proportion of Saugatuck soil. Observation flags were placed at 3.05 m intervals along each transect line. Figure 4 is a representative profile from transect 1N. Again, the upper boundary of the ortstein layer has been highlighted with a dark line. The ortstein layer is well expressed and fairly continuous across this profile. However several breaks in this layer can be observed near observation flags 4, 6, 8, 9, and 10. The interruptions between observation flags 9 and 10, and at 10 are the result of wheel-ruts in a trail. The ruts extend below the upper boundary of the ortstein. The other breaks in the ortstein appear to have been caused by pedoturbation, in particular floral pedoturbation. Several hyperbolic images (inverted ice-cream cones) between observation flags 1 and 8 were associated with tree roots.

To confirm the presence and nature of the breaks evident in Figure 4, several additional and more detailed transects were conducted along this transect. Three sections (observation points 3 to 4, 5 to 6, and 8 to 9) of transect 1N were re-flagged at 30 cm interval and re-surveyed with the 500 MHz. The 500 MHz antenna was hand-towed along each line at a very slow rate of advance.

Figure 5 is the radar profile from section 5 to 6; Figure 6 is the radar profile from section 8 to 9. The accuracy of the GPR is impressive. All breaks in the image of the ortstein layer recorded in Figure 4 were reproduced in Figures 5 and 6. With the narrower interval (30 cm) between flags, the location of these breaks were pin-pointed. Pits were excavated along each section to verify the presence of these breaks, and to confirm the presence, depth to, and degree of cementation of the ortstein. All recorded interruptions (A) in the ortstein layer were confirmed. The breaks in the ortstein layer are extremely narrow and tortuous, and appear to be the result of floral pedoturbation. The breaks included areas of noncemented and weakly cemented materials.

B. Area of Wallace and Epworth Soils

Not all areas of ortstein are continuous. Two transects were conducted across a dune in an area of Wallace (sandy, mixed, frigid, ortstein Typic Haplorthods) and Epworth (sandy, mixed, mesic, Entic Haplorthods) soils. The Wallace soil is a mesic taxadjunct; Epworth is a proposed series. As evident in Figure 7, the ortstein is not continuous but consists of pellet-like masses (A). The pellets or ortstein fragments are weakly cemented to strongly cemented. These fragments occur in a noncemented, weakly developed spodic horizon. The ortstein fragments occur at depths ranging from 20 to 50 cm. The proportion of soils having ortstein fragments appeared to be higher on concave sideslopes of dunes.

Within the transected areas, a binomial distribution was assumed as there were only two possible outcomes: Wallace (ortstein present) or Epworth (ortstein absence) soils. Ortstein fragments occur at 66 of the 136 observation marks. Therefore, the area could be characterized as consisting of 52 % Epworth and 48 % Wallace soils. However, the ortstein is not continuous and is often only weakly cemented. Should the ortstein fragments in Figure 7 be recognized at the same level as the ortstein layer in Figures 4, 5, and 6?

Recommendations

This study has demonstrated the effectiveness of GPR techniques for determining the presence and induration of the ortstein layers. The planned acquisition of the RADAN software package will enable the gray scale images of the ortstein layer to be quantitatively analyzed, related to field and laboratory measurements, and interpreted across landscapes. As recommended by Gamble and Turner (1988), "the study of ortstein horizons [should] be continued and expanded to other areas of the country." These studies should be supported by field and laboratory measurements.

The principal participants recommended continuing this study in Michigan and Florida. Florida was suggested because it had known, sizeable acreage of ortstein. The continued and expanded study would determine the presence of ortstein in each state and compare the continuity and characteristics of this horizon.

Distribution of Ortstein within the United States

As a preliminary for future studies, a scan was conducted of soils belonging to ortstein families. Data on soil name, component acreage, and survey area were obtained from National Soil Survey Area Database, MUUF, Iowa State Computer Center, Ames, Iowa. This data reflects information entered into the MUUF file as of 27 September 1988.

The results of this data search are summarized in Figures 8 and 9, and in Tables 6, 7, 8, 9, 10, and 11. Most suprising, the greatest extent of soils with ortstein layers are in the west region (76.5 % of reported acreage) and in the state of Washington (73 % of reported acreage). The states of Washington, Florida, Oregon, and Michigan account for about 97 % of the reported acreage of ortstein (Figure 9). Florida is the only state in the south region reporting or recognizing soils with ortstein. Soils having ortstein are most commonly mapped as consociations.

2. TOPOGRAPHIC RELATIONSHIP OF GROUND SURFACE WITH UNDERLYING LACUSTRINE CLAY SUBSTRATUM ON A DUNE.

While surveying an area of Wallace soils, the radar signal was severely attenuated by a subsurface interface. The interface was interpreted as a layer of finer textured materials. However, detailed auger borings conducted before the GPR survey revealed lacustrine clays at only one observation point along the transect line. Soil auger probes were again conducted at several observation points. Results confirmed the presence of a clay layer.

A cross section of the transect line was constructed using data obtained with the GPR and an engineering level (Figure 10). The engineering level was used to determine relative ground elevations; the GPR was used to determine the depth to lacustrine clays. As a limiting layer, knowledge of the depth to and the topography of this layer can help to improve site assessments, soil interpretations, and soil-landscape models, to summarize map unit composition, and to predict the flow of ground water and contaminants. Based on GPR data, the distribution of the depths to clay are: 42 %, 0 to 2 feet; 28 %, 2 to 4 feet; 24 %, 4 to 6 feet; 6 % > 6 feet.

3. COMPOSITION OF MAP UNITS INVOLVING SPINKS AND COLOMA SOILS.

Since the late 1970s the USDA - Soil Conservation Service has been exploring the potential of using ground-penetrating radar technology to assist and to improve soil survey operations (Johnson et al., 1979). The principal use of the GPR in soil investigations has been to determine the composition of soil map units (Asmussen et al., 1986; Doolittle, 1982, 1983, 1987; Collins et al., 1986; and Schellentrager et al., 1988), improve soil-landscape models (Collins and Doolittle, 1987; Doolittle and Collins, 1987; Doolittle et al., 1988; Olson and Doolittle, 1985; Puckett et al., 1987, and Rebertus et al., 1987), and characterize soil features (Lyons et al., 1988; Shih et al., 1985a, 1985b, and 1986, Truman et al., 1988). These uses of the GPR require the recognition of diagnostic soil horizons and features.

Figure 11 is an arrangement of representative graphic profile of Perrinton (fine, mixed, mesic Glossic Hapludalfs), Tustin (clayey, mixed, mesic Arenic Hapludalfs), Spinks (sandy, mixed, mesic Psammentic Hapludalfs), Coloma (mixed, mesic Alfic Udipsamments) and Grattan (sandy, mixed, mesic Entic Haplorthods). Unique expressions of profile characteristics enable each soils to be identified on the basis of their graphic signatures.

The profiles in this interpretation key have been arranged from left to right in order of increasing depths of radar penetration. It is evident that the GPR does not perform equally well in these soils. The maximum probing depth of the GPR is, to a large degree, determined by the conductivity of the soil. Soils having high conductivities rapidly dissipate the radar's energy and restrict its probing depth. The principal factors influencing the conductivities of soils to electromagnetic radiation and the probing depth of the GPR are (i) degree of water saturation, (ii) amount and type of salts in solution, and (iii) the amount and type of clays.

These soils vary in the amount and distribution of sands, loams, and clays within their profiles. Depth of radar penetration is inversely related to clay content. While moisture content and the amount of salts in solution may vary in each of the profiles (Figure 11), changes in the distribution, arrangement, and content of sands, loams, and clays have been used to identify the soils.

The Hapludalfs (Perrinton, Tustin, and Spinks) have higher clay contents throughout their profiles. In these soils, the probing depth of the GPR is restricted to depth of less than 2 meters. Hapludalfs are recognized by the occurrence of "white-out" zones in the lower part of their profiles. These areas of no signal return are caused by either the absence of contrasting reflectors or by the dissipation of radiated energy. It was assumed that the high clay contents of the Hapludalfs produced a rapid dissipation of the radar's energy in the upper part of the soil profile and caused the white out zones.

Each Hapludalfs has a recognizable signature. Images of Perrinton soils can be distinguished from Tustin soil on the basis of the depth to the argillic horizon. Argillic horizons are recognized by either a smooth, continous interface (see Perrinton profile) or a narrow (< 0.5 m) transition zone consisting multiple, small, irregularly shaped images (see Tustin profile). The coarse texture of this transition zone reflects the presence of clay lamellea, balls or lenses and sand (E/BT and BT/E horizons). Spinks soil has a relatively wide transition zone

(1.0 - 2.5 meters) of lamellea which begins within the upper 40 - 100 cm of the soil profile.

Depth of radar penetration is greater in Udipsamments and Haplorthods. The predominantly sandy Coloma and Grattan soils have lower clay contents and less rapid rates of signal attenuation. These soils have images to depths of 4 to 6 meters and lack white out zones within the upper 3 meters of their profiles. The presence of a spodic horizon distinguishes Grattan from Coloma soils.

Figure 12 is a representative profile from an area of the Coloma-Spink complex. Areas of Spinks, Grattan, Perrinton, and Tustin soils have been identified on the basis of their graphic signatures. The spodic horizon (A) of Grattan soil and the argillic horizon (B) of Perrinton and Tustin soils has been labelled. Furthermore, the argillic horizon has been highlighted by a dark line.

Eleven transects were conducted with the 120 MHz antenna in areas of the Coloma-Spink complex. An interpretation key similar to Figure 11 was used to identify the soils at each equally space observation point along the transect lines. Tables 12 and 13 summarizes the transect data. Transects 1 to 4 were conducted on the Dittmer' farm; 5 to 8 were conducted on the Epenback's farm; and 9 to 11 at the site of the newspaper interview.

Collectively, the areas transected with the GPR are: 38 % Coloma, 37 % Spinks, 11 % Tustin, 9 % Perrinton, 4 % Grattan, and 1 % Plainfield soils. The composition of soils along these transect lines supports a Coloma-Spinks complex. However, transects 4 to 7 have a large proportion of Hapludalfs and a separate Spinks-Tustin complex map unit may be considered in these areas.

Recommendations:

A brief paper should be written discussing the results of this investigation in Michigan.

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References:

Asmussen, L. E., H. E. Perkins, and H. D. Allison. 1986. Subsurface descriptions by ground-penetrating radar for watershed delineation. Georgia Ag. Exp. Stat. Res. Bull. 340. pp 15.

Bevans, B. and J. Kenyon. 1975. Ground-penetrating radar for historical archaeology. MASCA Newsletter 11(2): 1-7.

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.

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

Collins, M. E., G. W. Schellentrager, J. A. Doolittle, and S. F. Shih. 1986. Using ground-penetrating radar to study changes in soil map unit composition in selected Histosols. Soil Sci. Soc. Am. J. 50(2):408-412.

Doolittle, J. A. 1982. Characterizing soil map units with the ground penetrating radar. Soil Survey Horizons 22(4):3-10.

Doolittle, J. A. 1983. Investigating Histosols with ground penetrating radar. Soil Survey Horizons 23(3):23-28.

Doolittle, J. A. 1987. Using ground-penetrating radar to increase the quality and efficiency of soil surveys. IN Soil Survey Techniques, Soil Sci. Soc. Am. Special Publ. No. 20. pp 11-32.

Doolittle, J. A. and M. E. Collins. 1987. Mapping the depth to bedrock with ground-penetrating radar. p 223. IN Agronomy abstract, ASA, Madison WI.

Gamble, E. E., and R. I. Turner. 1988. SOI-Investigations-Report-Trip Report, Mason County, Michigan, Ground Penetrating Radar Study, August 29 to September 2, 1988. USDA, Soil Conservation Service, NSSC, MNTC, Lincoln, NE

Jesch, R. L. 1978. Dielectric measurements of five different soil textural types as a function of frequency and moisture content. National Bureau of Standards, Report No. 87-896. pp. 21.

Johnson, R. W., R. Glaccum, and R. Wojtasinski. 1979. Application of ground-penetrating radar to soil survey. Proc. Soil Crop Soc. Fla. 39:68-72.

Karavayeva, N. A. 1968. Formation and evolution of cemented ortstein horizons in the Taiga zone. 9th International Congress of Soil Science. IV: 451-458.

Lyon, J. G., C. A. Mitchell and T. E. Zobeck. 1988. Impulse radar for identification of features in soil. J. Aerosp. Eng. 1(1):18-27.

McKeague, J. A., F. DeConinck, and D. P, Franzmeier. 1983. Spodosols. p.217-252. In L. P. Wilding, N. E. Smeck, and G. F. Hall (ed.) Pedogenesis and Soil Taxonomy, II. The Soil Order. Elsevier, Amsterdam.

Morey, R. M., 1974. Continuous subsurface profiling by impulse radar. Proceedings ASCE Engineering Foundation Conference on Subsurface Exploration for Underground Excavations and Heavy Construction. Henniker, NH. August 11-16. p. 212-232.

Nettleton, W. D., R. B. Parsons, A. O. Ness, and F. W. Gelderman. 1982. Spodosols along the southwest Oregon coast. Soil Sci. Soc. Am. J. 46:593-598.

Okransinski, T. A., R. M. Koerner, and A. E. Lord, Jr. 1978. Dielectric constant determination of soil at L band microwave frequencies. Geotech. Testing J. 1(3):134-140.

Olhoeft, G. R. 1985. Electrical properties of rocks and minerals: short course notes. November 19-21, Golden, CO. 400pp.

Olson, C. G. and J. A. Doolittle. 1985. Geophysical techniques for reconnaissance investigations of soil and surficial deposits in mountainous terrain. Soil Sci. Soc. Am. J. 49:1490-1498.

Plaisance, G. and A. Cailleux. 1981. Dictionary of soils. Amerind Publishing Co. Pvt. Ltd., New Delhi.

Puckett, W. E., M. E. Collins, and G. W. Schellentrager. 1987. Radar signatures of subsurface features on karst in west-central Florida. p. 230. IN Agronomy abstract, ASA, Madison WI.

Rebertus, R. A. J. A. Doolittle, and R. L. Hall. 1987. Landform and stratigraphic influences on loess thickness in northern Delaware. p. 230. IN Agronomy abstract, ASA, Madison WI.

Ritari, A. and V. Ojanpera. 1984. Properties and formation of cemented ortstein horizons in Rovaniemi, northern Finland. Finnish Forest Research Institute Report No. 124. Helsinki. 32 pp.

Schellentrager, G. W., J. A. Doolittle, T. E. Calhoun, and C. A. Wettstein. 1988. Using ground-penetrating radar to update soil survey information. Soil Sci. Soc. Am. J. 52(3)746-752.

Shih, S. F., J. A. Doolittle, D. L. Myhre, and G. W. Schellentrager. 1986. Using radar for groundwater investigation. J. Irrigation and Drainage Eng. 112(2):110-118.

Shih, S. F., D. L. Myhre, G. W. Schellentrager, V. W. Carlisle, and J. A. Doolittle. 1985a. Using radar to assess the soil characteristics related to citrus stress. Soil and Crop Sci. Soc. Fla. Proc. 45:54-59.

Shih, S. F., D. L. Myhre, G. W. Schellentrager, and J. A. Doolittle. 1985b. Using radar to improve soil salinity management. Am. Soc. Agric. Engn. Winter Meeting. Paper No. 85-2611.

Sellmann, P. V., S. A. Arcone and A. J. Delaney. 1983. Radar profiling of buried reflectors and the groundwater table. US Army Cold Regions

Research and Engineering Laboratory, Hanover, NH. CRREL Rep. 83-11. 10 pp.

Soil Survey Staff. 1987. Keys to soil taxonomy. SMSS Tech. Mono. 6. Cornell University, Ithaca, NY. 208 pp.

Truman, C. C., H. F. Perkins, L. E. Asmussen, and H. D. Allison. 1988. Using ground-penetrating radar to investigate variability in selected soil properties. Journal of Soil and Water Cons. July-August 1988. p. 341-345.

United States Department of Agriculture. 1951. Soil survey manual. U.S. Dep. Agric. Handb. 18, 503 pp.

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

TABLE 1

PROPORTION OF SAUGATUCK AND PIPESTONE SOILS WITHIN 15.2 METER UNITS ALONG TRANSECT 1B

UNIT	1	2	3	4	5	6	7	8	9	10	11	12
SAUGATUCK	6	9	6	6	8	3	6	4	8	10	6	10
PIPESTONE	4	1	4	4	2	7	4	6	2	0	4	0

UNIT	13	14	15	16	17	18	19	20	21	22	23	24
SAUGATUCK	10	8	7	9	9	5	1	0	4	10	4	8
PIPESTONE	0	2	3	1	1	5	9	10	6	0	6	2

UNIT	25	26	27	28	29	30	31	32	33	34	35	36
SAUGATUCK	8	10	5	7	10	10	10	5	10	10	9	7
PIPESTONE	2	0	5	3	0	0	0	5	0	0	1	3

UNIT	37	38
SAUGATUCK	2	0
PIPESTONE	8	10

TABLE 2

PROPORTION OF SAUGATUCK AND PIPESTONE SOILS WITHIN 15.2 METER UNITS ALONG TRANSECT 2

UNIT	1	2	3	4	5	6	7	8	9	10	11	12
SAUGATUCK	10	10	9	10	9	1	6	5	6	2	2	6
PIPESTONE	0	0	1	0	1	9	4	5	4	8	8	4

UNIT	13	14	15	16	17	18	19	20	21
SAUGATUCK	7	3	0	6	8	9	4	9	9
PIPESTONE	3	7	10	4	2	1	6	1	1

TABLE 3

PROPORTION OF SAUGATUCK AND PIPESTONE SOILS WITHIN 15.2 METER UNITS ALONG TRANSECT 3

UNIT	1	2	3	4	5	6	7	8	9	10	11	12
SAUGATUCK	10	10	7	8	9	9	8	7	7	9	8	6
PIPESTONE	0	0	3	2	1	1	2	3	3	1	2	4

UNIT	13	14	15	16	17	18	19
SAUGATUCK	8	2	3	2	1	3	6
PIPESTONE	2	8	7	8	9	7	4

TABLE 4

PROPORTIONS OF SAUGATUCK AND PIPESTONE SOILS

SOIL	OBSERVATIONS			MEAN			STANDARD DEVIATION		
	Transects			Transects			Transects		
	1	2	3	1	2	3	1	2	3
SAUGATUCK	260	131	123	68.4	62.4	64.7	29.4	31.1	28.0
PIPESTONE	120	79	67	31.6	37.6	35.3	29.4	31.1	28.0

TABLE 5

ESTIMATED EXTENT OF UNITS HAVING
DIFFERING PROPORTIONS OF SOILS WITH ORTSTEIN LAYERS

PERCENT ORTSTEIN	PROPORTION OF SAMPLING AREA	AVERAGE LENGTH (m)
0	3.9%	396
10	3.9%	203
20	6.4%	158
30	5.1%	130
40	5.1%	122
50	5.1%	83
60	14.1%	64
70	9.0%	52
80	12.8%	38
90	15.4%	29
100	19.2%	25

TABLE 6

EXTENT AND DISTRIBUTION OF ORTSTEIN WITHIN THE UNITED STATES*

STATE	ACREAGE	PERCENTAGE
INDIANA	607	0.00
MASSACHUSETTS	637	0.00
MAINE	2845	0.00
VERMONT	2906	0.00
ALASKA	7925	0.00
NEW YORK	16732	0.01
NEW HAMPSHIRE	25002	0.02
MICHIGAN	39348	0.03
OREGON	39491	0.03
FLORIDA	260981	0.18
WASHINGTON	1090277	0.73
	1486751	1.00

TABLE 7

MAP UNITS HAVING ORTSTEIN SOILS AS NAMED COMPONENTS
BY NTC REGIONS

	NORTHEAST		SOUTH	
	MAP UNITS	FREQ	MAP UNITS	FREQ
CONSOCIATIONS	25	63%	25	83%
COMPLEXES	1	3%	5	17%
ASSOCIATIONS	6	15%	0	0%
UNDIFFERENTIATED	8	20%	0	0%

	MIDWEST		WEST	
	MAP UNITS	FREQ	MAP UNITS	FREQ
CONSOCIATIONS	16	52%	100	78%
COMPLEXES	12	39%	28	21%
ASSOCIATIONS	0	0%	0	0%
UNDIFFERENTIATED	3	10%	1	1%

* Data obtained from National Soil Survey Area Database, MUUF, Iowa State Computer Center, Ames, Iowa; reflects data entered into the MUUF file as of 27 September 1988.

TABLE 8

EXTENT OF SOILS WITH ORTSTEIN IN THE NORTHEAST

COMPONENT NAME	COMP ACRES	SURVEY AREA NAME	YR	MU KIND
SAUGATUCK	2845	CUMBERLAND COUNTY, ME	69	C
DUANE	0	WASHINGTON COUNTY AREA, ME		C
SAUGATUCK	637	FRANKLIN COUNTY, MA	64	C
BERRYLAND VARIA	920	NANTUCKET COUNTY, MA	77	C
DUANE	2100	CARROLL COUNTY, NH	73	C
DUANE	1200			C
DUANE	857	MERRIMACK COUNTY, NH	63	C
SUCCESS	300	COOS COUNTY AREA, NH		C
SUCCESS	200			C
SUCCESS	200			C
SUCCESS	800			C
SUCCESS	400			C
SUCCESS	200			C
SUCCESS	400			C
SUCCESS	200			C
SAUGATUCK	5411	STRAFFORD COUNTY, NH	67	C
SAUGATUCK	400	HILLSBOROUGH COUNTY E. NH	80	C
DUANE	670	OSWEGO COUNTY, NY	73	X
CONSTABLE	750	FRANKLIN COUNTY, NY	55	U
CONSTABLE	3500			U
CONSTABLE	500			U
CONSTABLE	1000			U
CONSTABLE	429			U
DUANE	800			C
DUANE	800			C
DUANE	300			C
DUANE	300			C
DUANE	3081	LEWIS COUNTY, NY	56	C
SAUGATUCK	4602			C
DUANE	246	ADDISON COUNTY, VT	67	C
DUANE	715			C
DUANE	110	CHITTENDEN COUNTY, VT	69	U
DUANE	570			U
DUANE	1165			U
DUANE	2300	COOS COUNTY AREA, NH		C
DUANE	3900			C
SUCCESS	200			A
SUCCESS	467			A
SUCCESS	800			A
SUCCESS	467			A
SUCCESS	1067			A
SUCCESS	3133			A

TABLE 9

EXTENT OF SOILS WITH ORTSTEIN IN THE SOUTH

COMPONENT NAME	COMP ACRES	SURVEY AREA NAME	YR	MU KIND
JONATHAN	2134	HARDEE COUNTY, FL	81	C
WAVELAND	54500	MANATEE COUNTY, FL	81	C
SALERNO	6937	MARTIN COUNTY AREA, FL	79	C
JONATHAN	4173			C
NETTLES	382			C
NETTLES	17218			C
JONATHAN	170	ST. JOHNS COUNTY, FL	81	C
DELKS	5650	OCALA NATIONAL FOREST AREA, FLORIDA	68	C
ANKONA	1122	OSCEOLA COUNTY AREA, FL	76	C
ANKONA	566	ST. LUCIE COUNTY AREA, FL	77	X
ANKONA	14198			C
JONATHAN	322			C
LAWNWOOD	19293			C
LAWNWOOD	505			X
NETTLES	29798			C
PENDARVIS	1805			C
PENDARVIS	193			X
PEPPER	9349			C
SALERNO	2592			C
SUSANNA	1486			C
TANTILE	4017			C
WAVELAND	23714			C
WAVELAND	3040			X
LAWNWOOD	3040			
WAVELAND	724			X
PEPPER	1004	INDIAN RIVER COUNTY, FL	84	C
JONATHAN	206			C
WAVELAND	3918	MARTIN COUNTY AREA, FL	79	C
WAVELAND	34581			C
LAWNWOOD	2089			C
LAWNWOOD	15295			C

TABLE 10

EXTENT OF SOILS WITH ORTSTEIN IN THE MIDWEST

COMPONENT NAME	COMP ACRES	SURVEY AREA NAME	YR	MU KIND
SAUGATUCK	607	LAPORTE COUNTY, IN	79	X
FINCH	1193	ANTRIM COUNTY, MI	76	X
SAUGATUCK	237	ARENAC COUNTY, MI	64	C
SAUGATUCK	152			C
WALLACE	835	CHARLEVOIX COUNTY, MI	70	C
SAUGATUCK	718			C
WALLACE	293	EMMET COUNTY, MI	68	C
SAUGATUCK	356			C
SAUGATUCK	564	GLADWIN COUNTY, MI	66	C
OGEMAW	128			C
SAUGATUCK	264	GRAND TRAVERSE COUNTY, MI	63	X
SAUGATUCK	31			X
OGEMAW	40			X
OGEMAW	503			X
OGEMAW	162			X
WALLACE	597	LEELANAU COUNTY, MI	67	X
SAUGATUCK	510	MONTCALM COUNTY, MI	56	U
SAUGATUCK	11370	MUSKEGON COUNTY, MI	66	X
WALLACE	216	OSCEOLA COUNTY, MI	66	C
WALLACE	337			C
SAUGATUCK	389			C
OGEMAW	106			C
SAUGATUCK	6758	OTTAWA COUNTY, MI	67	X
SAUGATUCK	58	SANILAC COUNTY, MI	55	U
SAUGATUCK	405			U
WALLACE	1590	DELTA CO AND HIAWATHA NATIONAL FOREST OF ALGER AND SCHOOLCRAFT COS., MI	69	C
WALLACE	707			C
SAUGATUCK	799			C
FINCH	4660	LAKE AND WEXFORD COS, MI	83	X
FINCH	4765	KALKASKA COUNTY, MI		X
SAUGATUCK	600	NEWAYGO COUNTY, MI		C

TABLE 11

EXTENT OF SOILS WITH ORTSTEIN IN THE WEST

COMPONENT NAME	COMP ACRES	SURVEY AREA NAME	YR	MU KIND
TOKLAT	2080	TOTCHAKET AREA, AK	78	X
TOKLAT	2200			C
BANDON	4588	COOS COUNTY, OR	83	C
BANDON	3320			C
BANDON	520			C
BANDON	1357			X
BLACKLOCK	452			
BLACKLOCK	2110			C
BLACKLOCK	5020			C
JOENEY	1690			C
JOENEY	615			X
BANDON	240	LANE COUNTY AREA, OR	81	C
BANDON	220			C
BANDON	270			C
WHETSTONE	2610	MARION COUNTY AREA, OR	66	C
WHETSTONE	7720			C
WHETSTONE	9030			C
KAPOWSIN	1630	THURSTON COUNTY, WA	83	C
KAPOWSIN	640			C
KAPOWSIN	1030			C
KAPOWSIN	1160			C
KAPOWSIN	9610			C
KAPOWSIN	8475			C
ALDERWOOD	410			C
ALDERWOOD	7180			C
ALDERWOOD	26440			C
ALDERWOOD	5230			C
ALDERWOOD	408	JEFFERSON COUNTY AREA, WA	68	X
ALDERWOOD	167			X
ALDERWOOD	712			X
ALDERWOOD	160			X
ALDERWOOD	680			X
ALDERWOOD	360			X
ALDERWOOD	3800			C
ALDERWOOD	5800			C
ALDERWOOD	260			C
ALDERWOOD	6980			C
ALDERWOOD	16110			C
KLAUS	420	KING COUNTY AREA, WA	69	C
ALDERWOOD	4202			X
ALDERWOOD	26000			U
ALDERWOOD	14280			C
ALDERWOOD	165170			C
ALDERWOOD	22000			C
ALDERWOOD	296	KITSAP COUNTY AREA, WA	77	X
KAPOWSIN	5700			C
KAPOWSIN	11030			C
ALDERWOOD	8080			C
ALDERWOOD	17600			C
ALDERWOOD	18040			C

EXTENT OF SOILS WITH ORTSTEIN IN THE WEST

EDMONDS	96	MASON COUNTY, WA	53	C
EDMONDS	110			C
ALDERWOOD	4571			C
ALDERWOOD	8669			C
ALDERWOOD	80510			C
ALDERWOOD	221			C
KAPOWSIN	2261	PIERCE COUNTY AREA, WA	74	C
KAPOWSIN	1722			C
KAPOWSIN	3421			C
KAPOWSIN	19141			C
KAPOWSIN	54372			C
ALDERWOOD	6977			C
ALDERWOOD	22709			C
ALDERWOOD	16635			C
TOKUL	7895	SNOHOMISH COUNTY AREA, WA	79	X
TOKUL	11134			X
TOKUL	6081			X
TOKUL	10533			C
TOKUL	34751			C
TOKUL	22552			C
TOKUL	553			C
TOKUL	6779			C
GETCHELL	1972			X
ELWELL	1367			X
TOKUL	247			X
GETCHELL	7558			X
GETCHELL	3005			X
GETCHELL	3576			C
ELWELL	19271			X
ELWELL	7652			X
ELWELL	10743			C
CUSTER	4521			C
ALDERWOOD	7060			X
ALDERWOOD	36301			X
ALDERWOOD	6572			X
ALDERWOOD	19229			C
ALDERWOOD	26420			C
ALDERWOOD	49020			C
EDMONDS	7412	WHATCOM COUNTY AREA, WA	87	X
WOODLYN	3088			
GETCHELL	5000			C
GETCHELL	1890			C
KINDY	1970			C
KINDY	3125			C
KINDY	2044			X
SEGIDAL	922	KLICKITAT COUNTY AREA, WA		C
SEGIDAL	2980			C

EXTENT OF SOILS WITH ORTSTEIN IN THE WEST

TOKUL	208	SNOQUALMIE PASS AREA, PARTS OF KING AND PIERCE COUNTIES, WA	86	X
TOKUL	4115			X
TOKUL	6051			C
TOKUL	15144			C
TOKUL	33941			C
TOKUL	9137			C
PHILIPPA	3445			C
PHILIPPA	6950			C
KLAUS	360			C
KLAUS	716			C
KLAUS	1465			C
KLAUS	464			C
KLAUS	11527			C
KINDY	1453			C
KINDY	3695			C
KINDY	984			C
KAPOWSIN	601			C
KAPOWSIN	1202			C
KAPOWSIN	480			C
GETCHELL	543			C
GETCHELL	1715			C
GETCHELL	1268			C
ELWELL	3980			C
ELWELL	14694			C
CHINKMIN	646			C
CHINKMIN	782			C
CHINKMIN	4919			C
CHINKMIN	10846			C
CHINKMIN	2540			C
ALDERWOOD	948			C
ALDERWOOD	2567			C
DINGLISHNA	1965	SUSITNA VALLEY AREA, AK	68	X
DINGLISHNA	1680			C
DEPOE	181	ALSEA AREA, OR, LINCOLN, BENTON AND LANE COUNTIES	68	C
NELSCOTT	0	LINCOLN COUNTY AREA, OR		C
NELSCOTT	0			C
BANDON	0			C
BANDON	0			C
DEPOE	0			C

TABLE 12

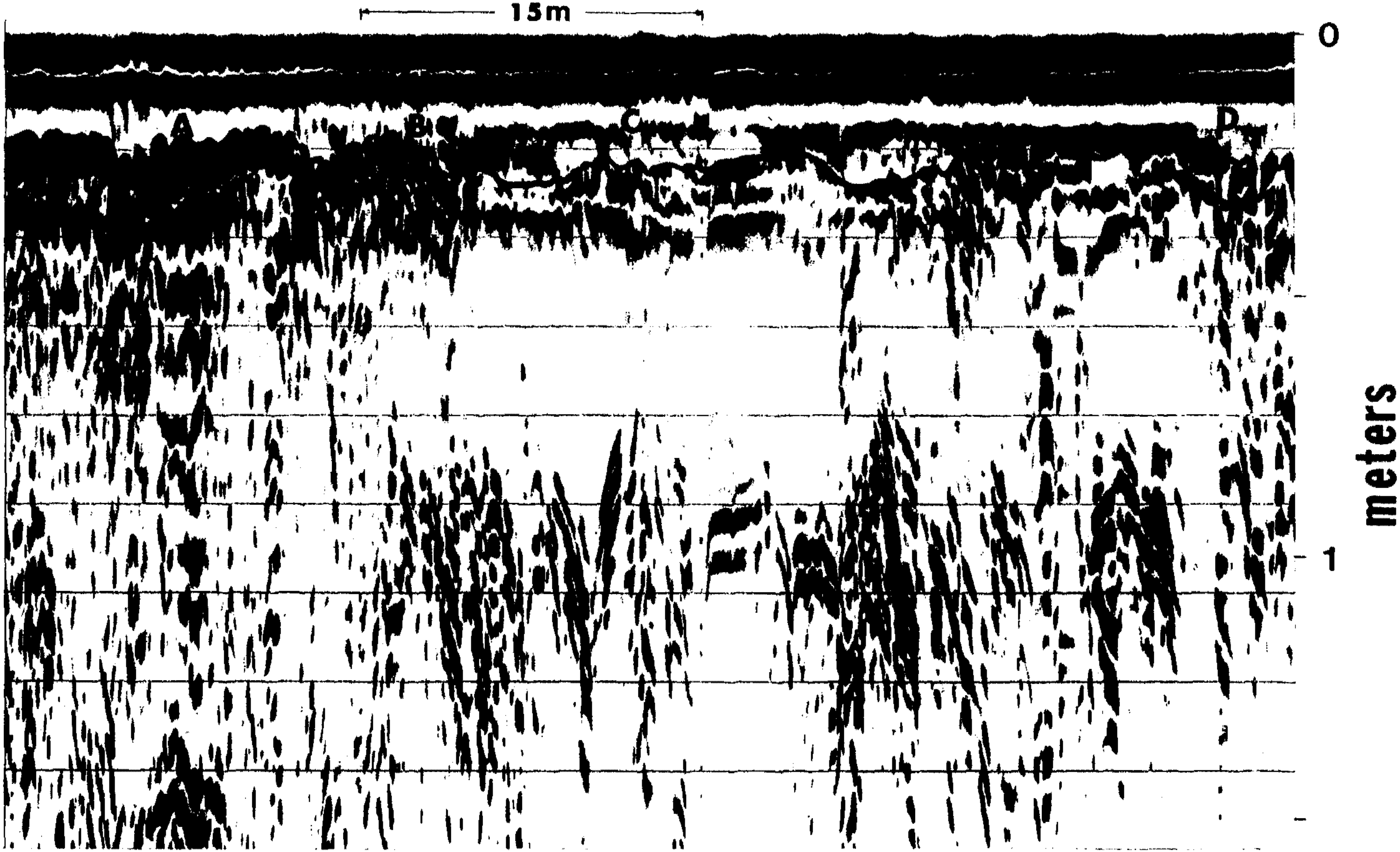
FREQUENCY OF SOILS IN AREAS OF COLOMA-SPINKS COMPLEX
MASON COUNTY, MICHIGAN

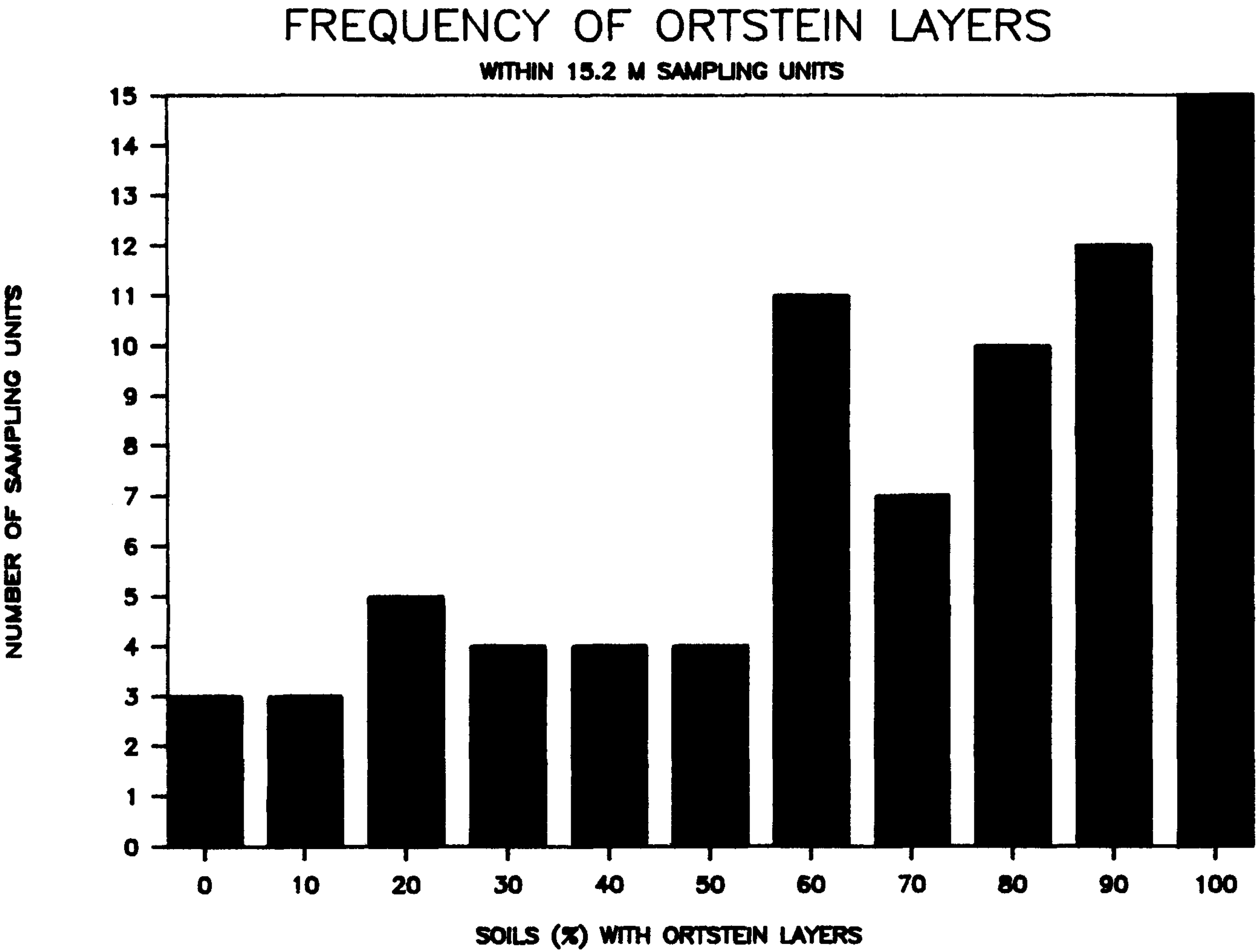
	TRANSECTS										
SOILS	1	2	3	4	5	6	7	8	9	10	11
Perrinton	0	2	3	15	0	0	4	6	0	10	10
Tustin	1	2	2	16	2	2	6	8	5	9	4
Spinks	4	5	2	21	21	14	20	14	28	29	9
Coloma	27	20	21	0	1	5	8	10	32	24	33
Plainfield	1	2	1	0	0	0	0	0	0	1	0
Grattan	0	0	0	0	0	0	1	0	12	5	16

TABLE 13

COMPOSITION OF TRANSECTS CONDUCTED IN AREAS OF COLOMA-SPINKS COMPLEX
MASON COUNTY, MICHIGAN

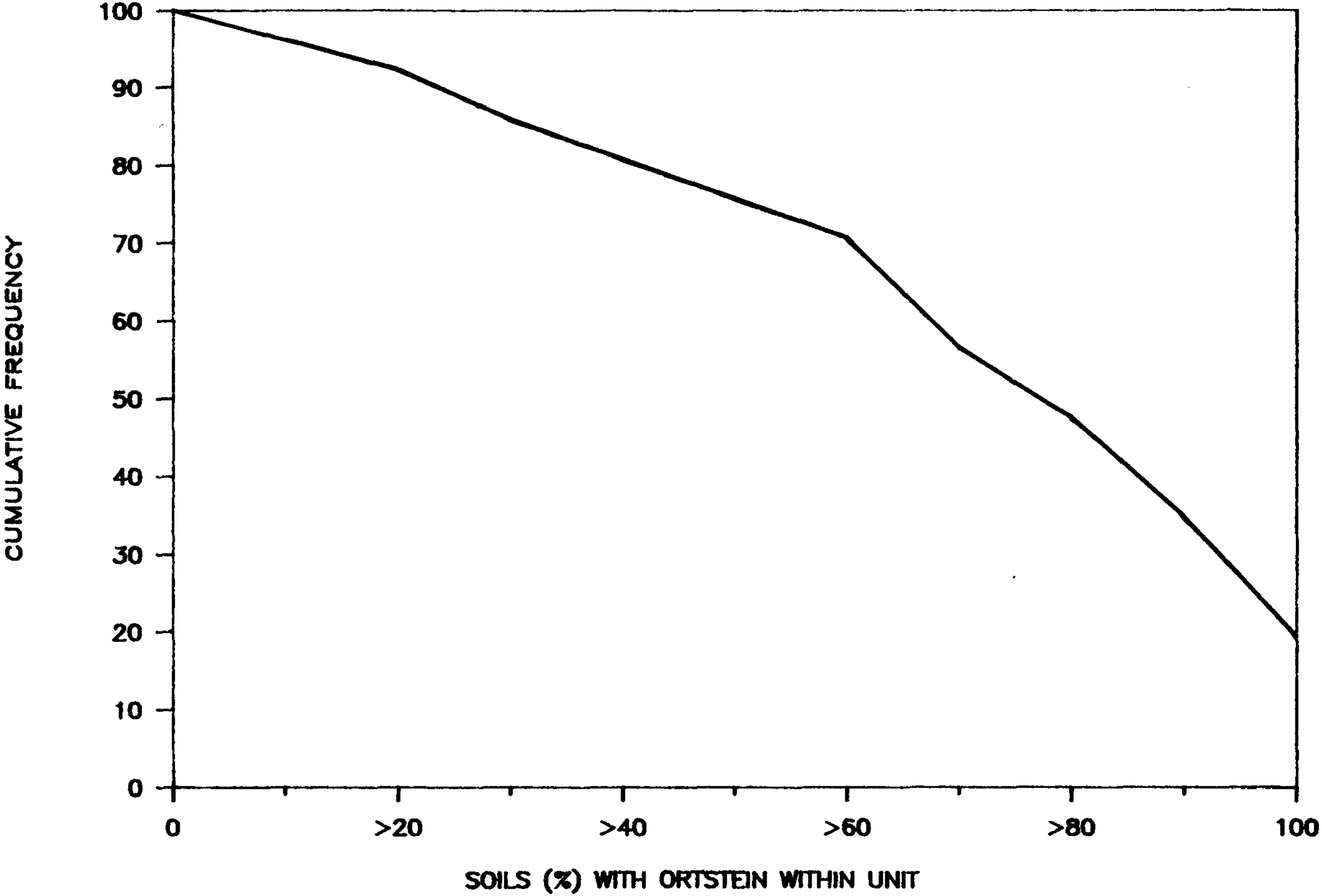
	PERCENT COMPOSITION TRANSECTS										
SOILS	1	2	3	4	5	6	7	8	9	10	11
Perrinton	0	6	10	29	0	0	10	16	0	13	14
Tustin	3	6	7	31	8	10	15	21	6	12	6
Spinks	12	16	7	40	88	66	51	37	36	37	12
Coloma	82	66	72	0	4	24	21	26	42	31	46
Plainfield	3	6	4	0	0	0	0	0	0	1	0
Grattan	0	0	0	0	0	0	3	0	16	6	22

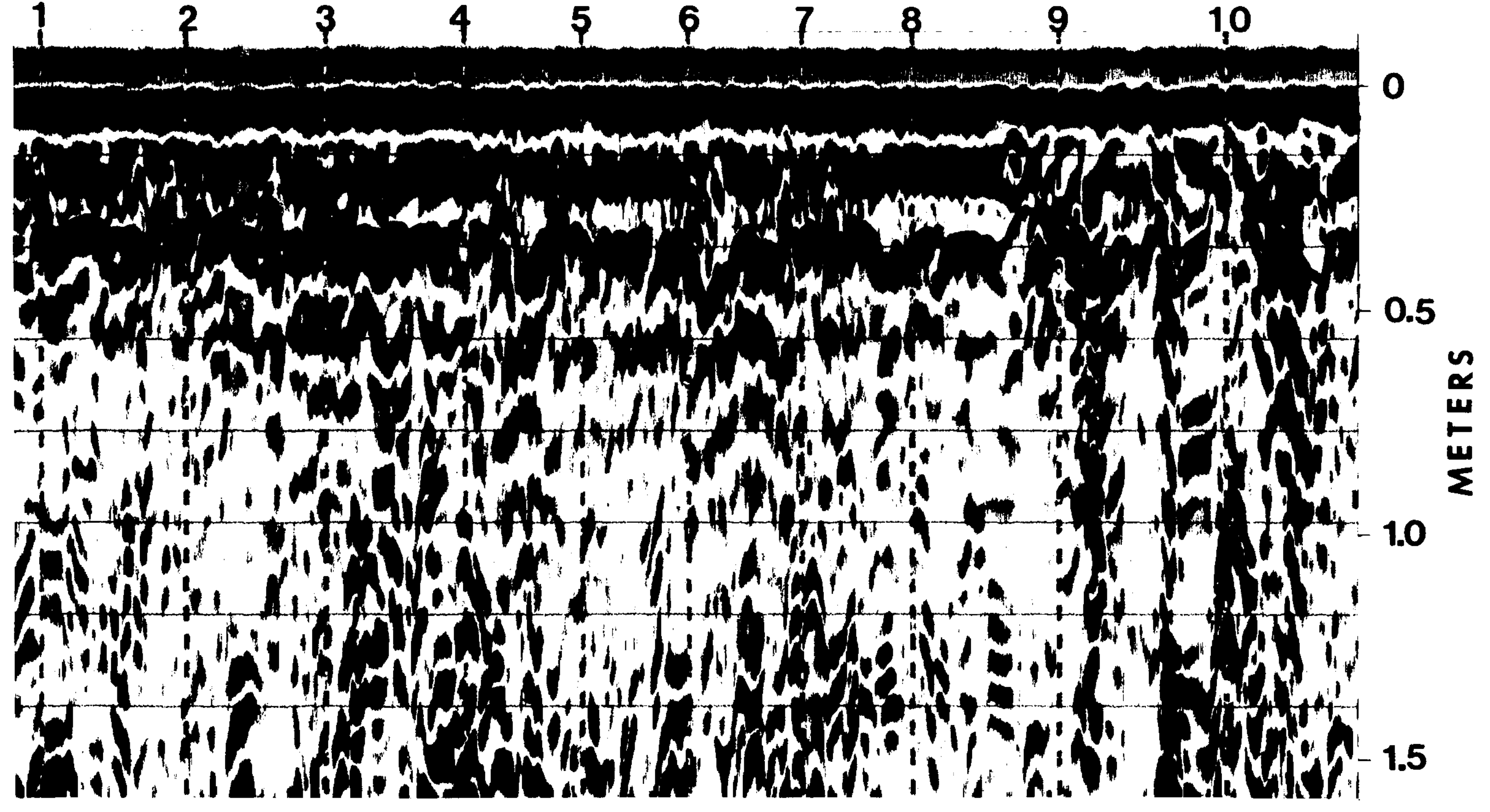

15m
0
1
meters
A
B
C
D

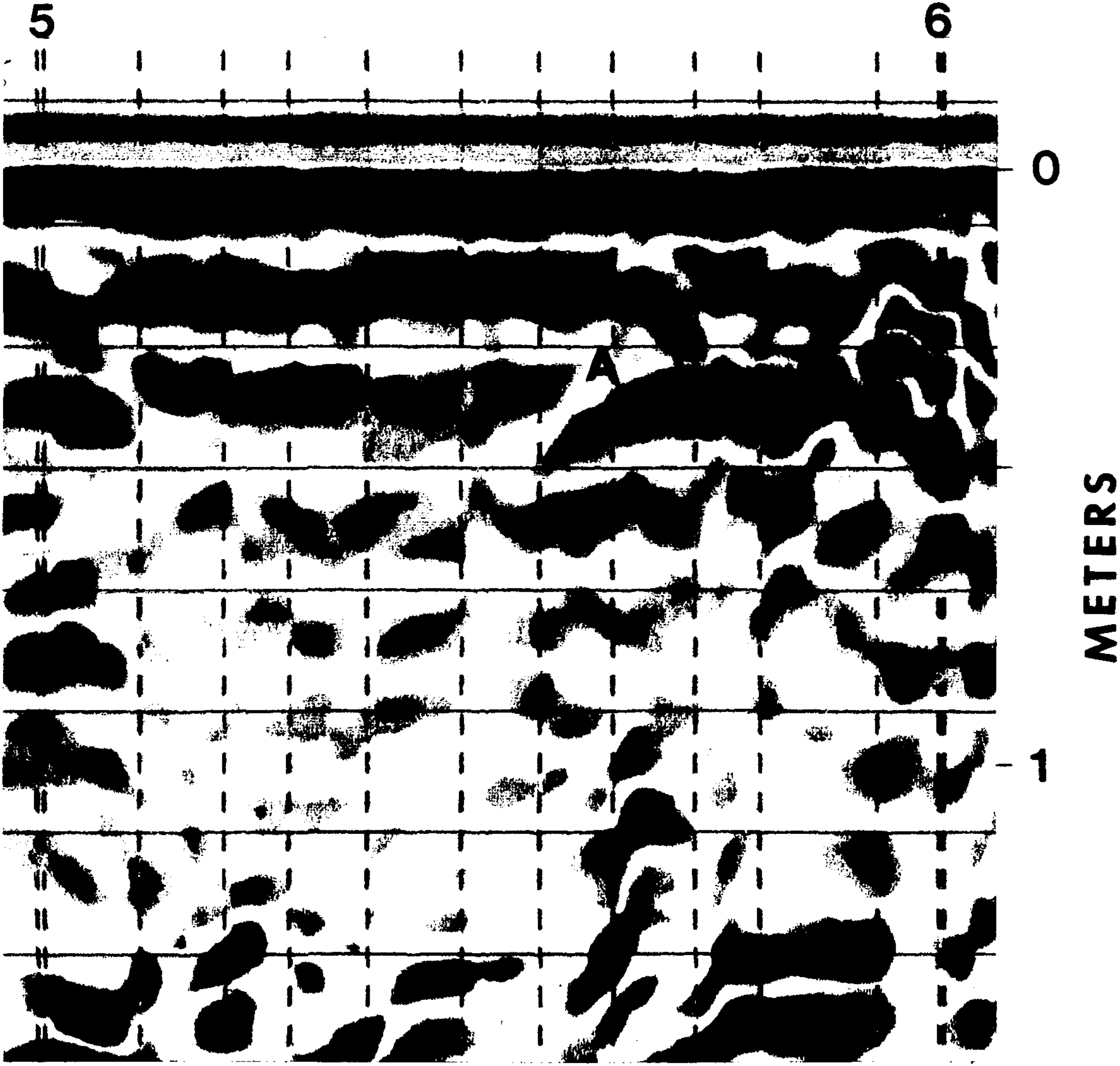

FREQUENCY OF ORTSTEIN LAYERS
WITHIN 15.2 M SAMPLING UNITS
NUMBER OF SAMPLING UNITS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0
10
20
30
40
50
60
70
80
90
100
SOILS (%) WITH ORTSTEIN LAYERS

FREQUENCY OF ORTSTEIN LAYERS

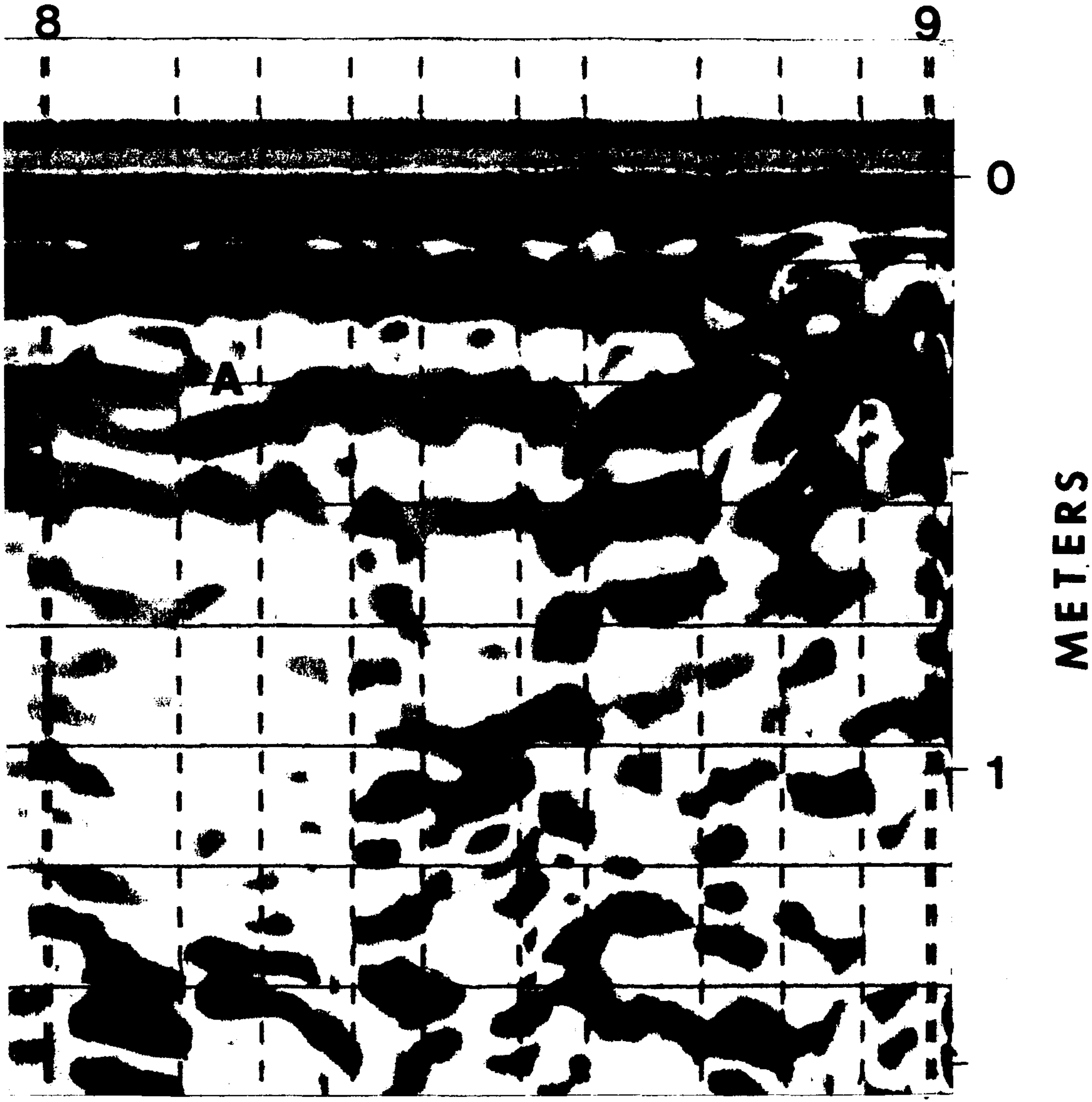
WITHIN 15.2 M SAMPLING UNITS

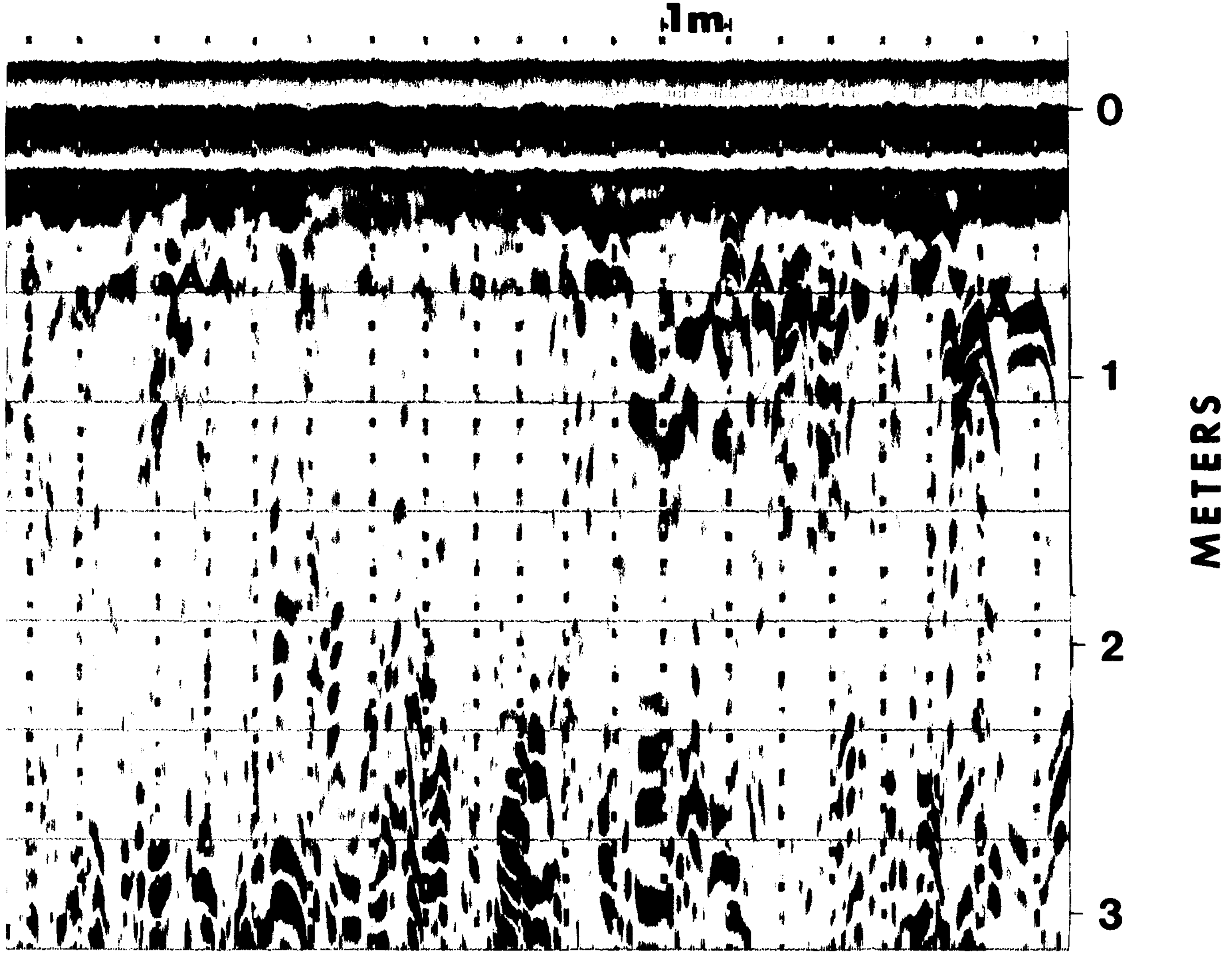



1
2
3
4
5
6
7
8
9
10
0
0.5
1.0
1.5
METERS



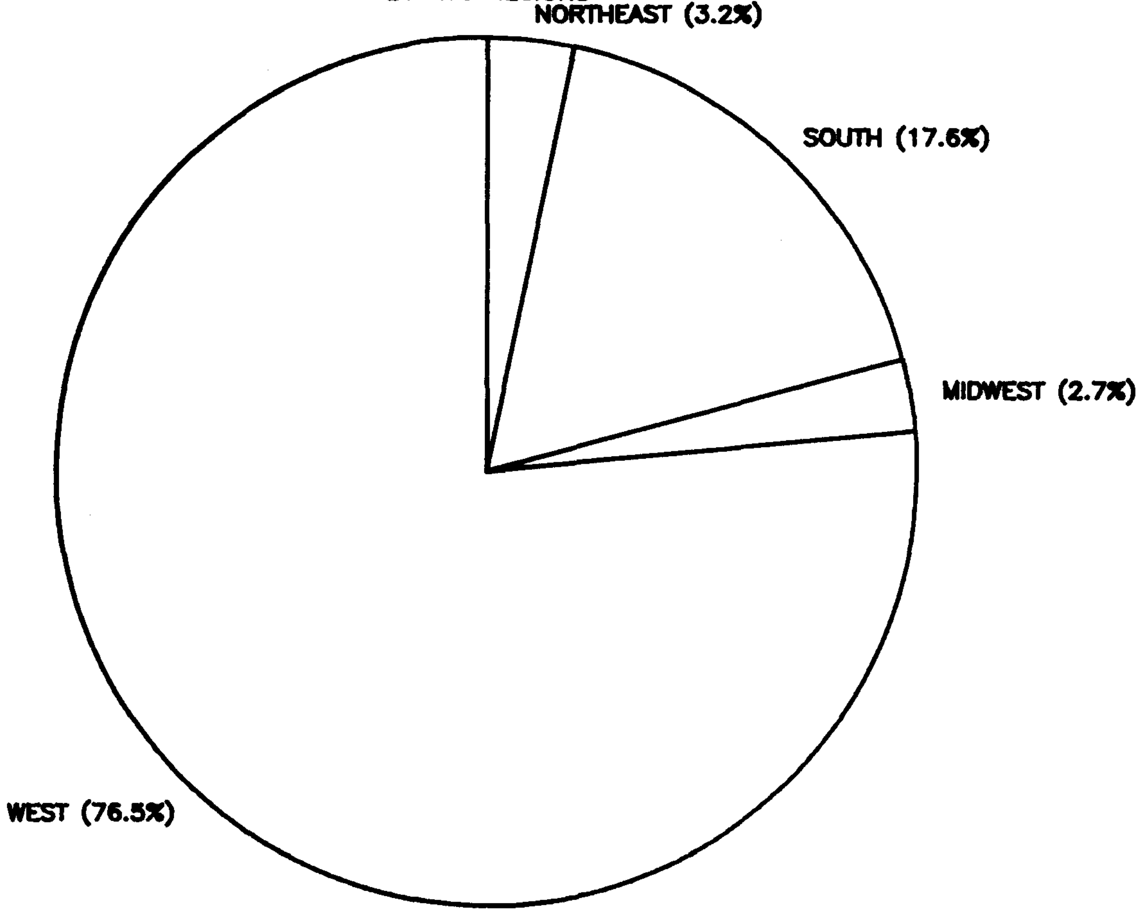
5
6
0
A
METERS
1

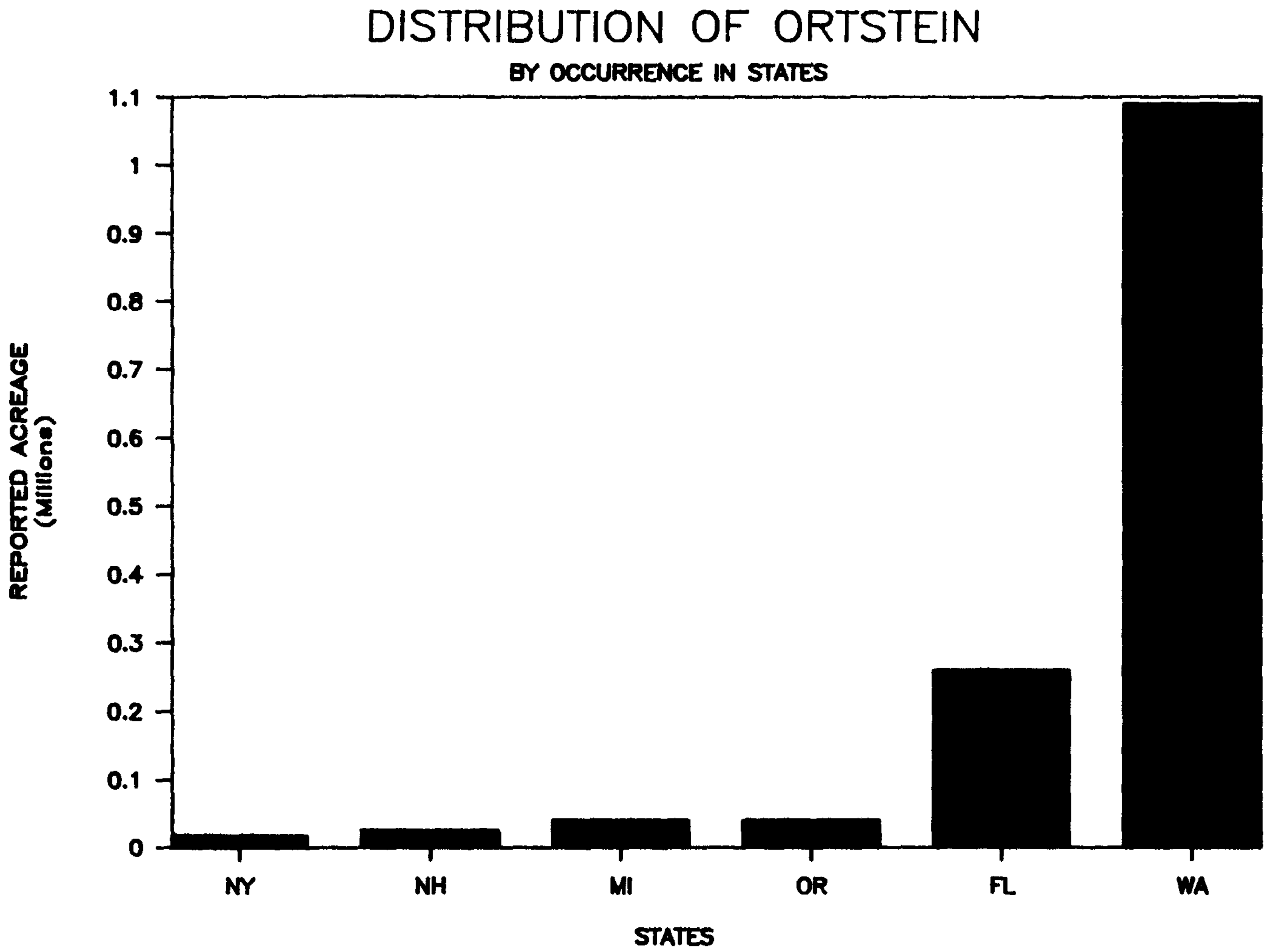

8
9
0
1
A
METERS


1m
0
1
2
3
METERS

ACREAGE OF ORTSTEIN

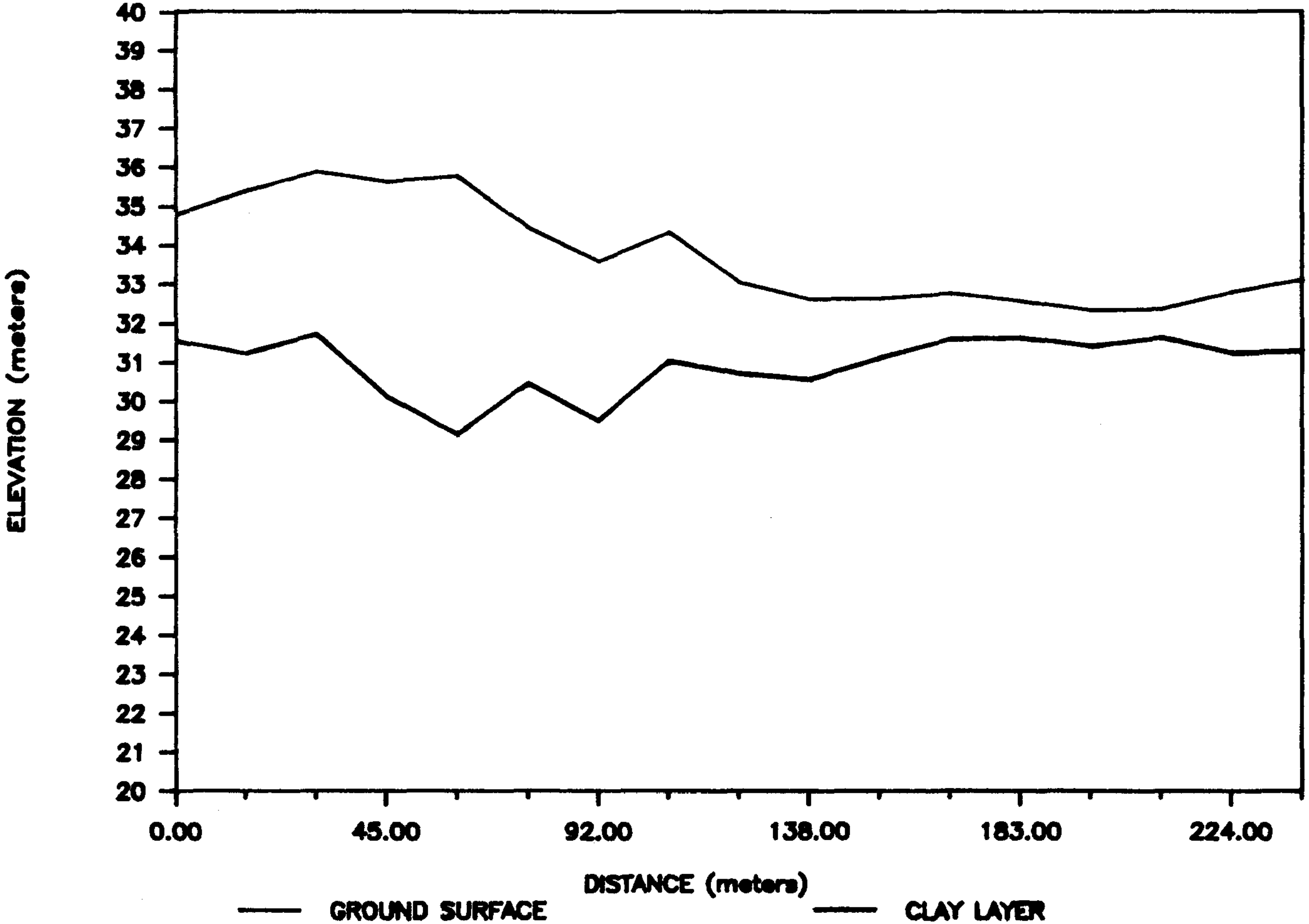
BY NTC REGIONS

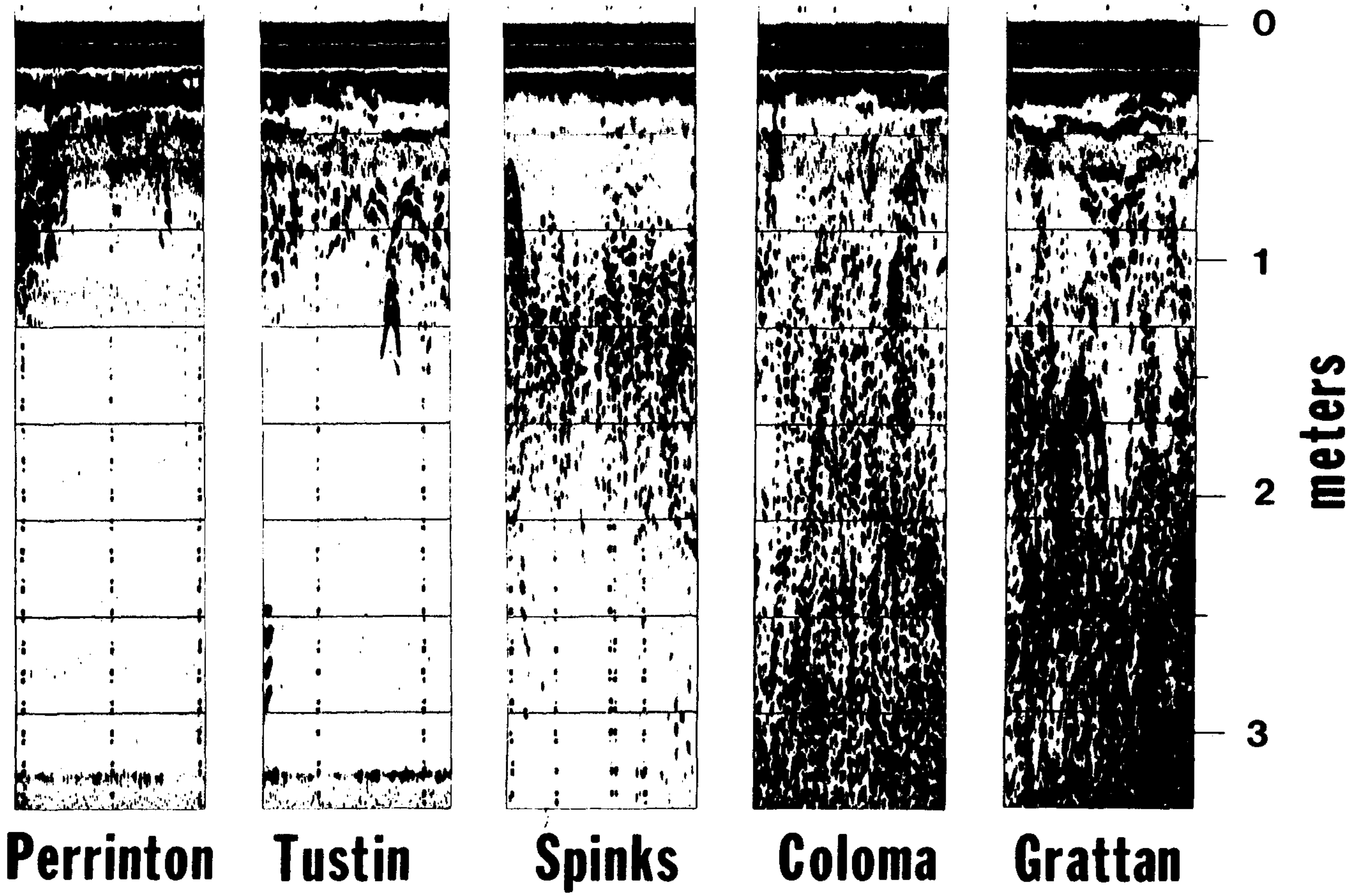


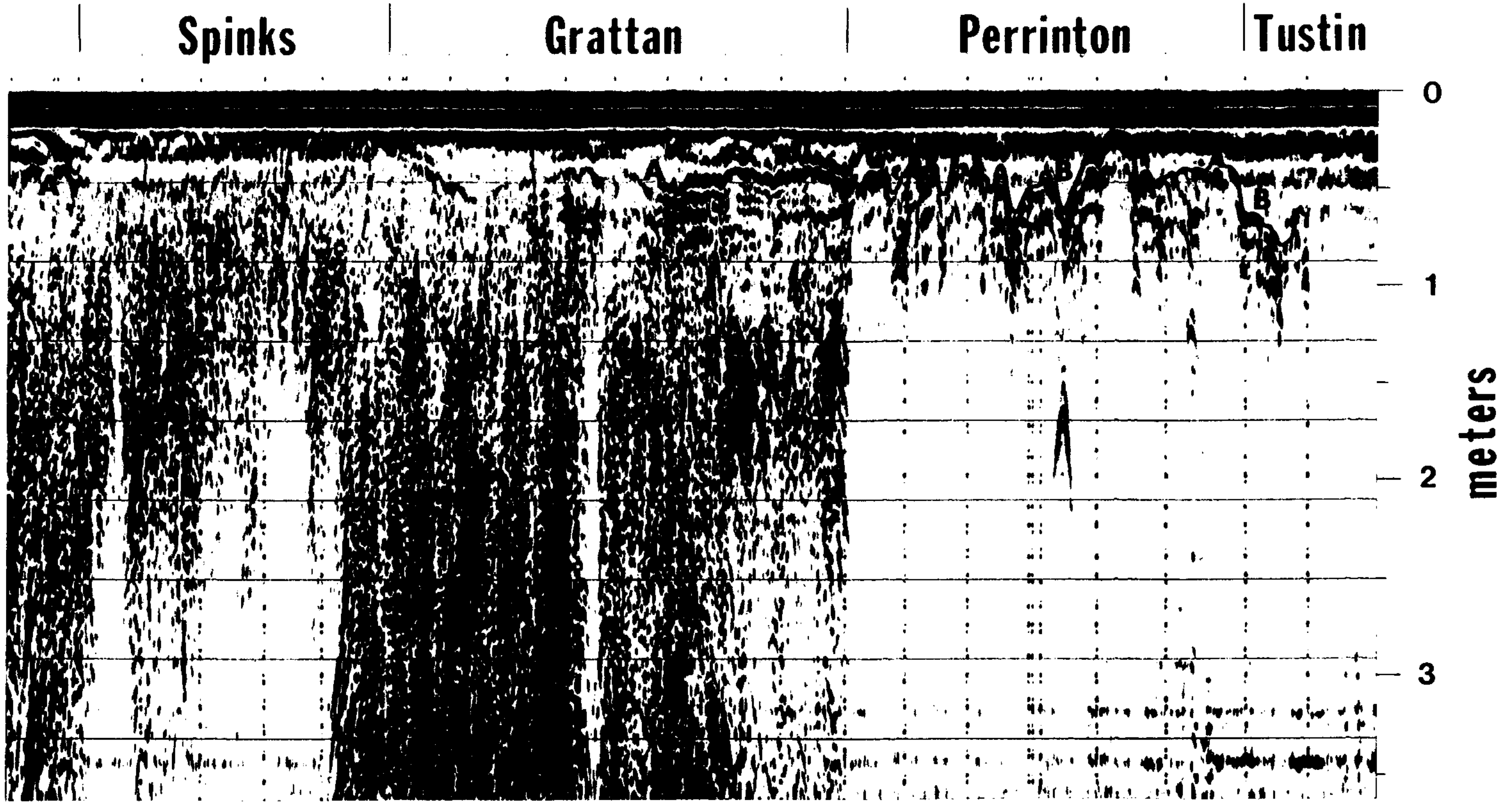

DISTRIBUTION OF ORTSTEIN
BY OCCURRENCE IN STATES
REPORTED ACREAGE (Millions)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
NY
NH
MI
OR
FL
WA
STATES

SOIL–LANDSCAPE RELATIONSHIPS IN AN AREA

OF WALLACE SOILS




0
1
2
3
meters
Perrinton
Tustin
Spinks
Coloma
Grattan



Spinks
Grattan
Perrinton
Tustin
0
1
2
3
meters