United States Department of Agriculture

Soil Conservation Service

401 S.E. First Avenue, Room 248
Gainesville, Florida
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Subject: SOILS - Ground-Penetrating Radar (GPR) - Trip Report - New Jersey

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To: Joseph C. Branco, State Conservationist
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A field study was made to familiarize personnel with ground-penetrating radar (GPR) technology and to assess the system's potential in New Jersey. During the period of May 27, 1984 through June 8, 1984, the GPR was applied to a variety of soil and site conditions in several diverse physiographic areas of New Jersey.

Participants included:

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The equipment utilized during this field trip was the SIR System-8 with microprocessor, the ADTEK SR-8004H graphic recorder, and the ADTEK DT-6000 tape recorder. The 80, 120, 300, and 500 MHz antennas were utilized. All equipment operated well with no noted malfunctions.

The GPR worked exceptionally well in New Jersey. Excluding areas underlain by shale bedrock and residium, good to excellent results were achieved at all sites. Generally about 60 percent of the graphic profiles were clear and easy to interpret; for the remaining 40 percent, either the equipment was operated in unfavorable ground conditions or was temporarily out of optimum adjustment, or greater experience was required of the operator for proper interpretations.

On the basis of limited field work, the GPR appears to be a very useful tool for differentiating bedrock from rock fragments in the Appalachian Highlands. In some areas, depths as great as 4 to 6 meters were achieved. But in areas underlain by shale or shaly residium, depth of penetration was restricted to less than 2 meters and profiles were often poorly resolved.

The potential of the present GPR system to define the occurrence, depth, extent, and expression of argillic horizons and lithologic discontinuities is high. Effective depths of penetration in most fine and moderately fine textured soils of the Coastal Plain is 1 to 2 meters.

The potential application of the GPR will depend on its need, use, and development. The enclosed report summarizes the major factors affecting the GPR's operation and interpretations in New Jersey. All pertinent graphic profiles have been returned to Wendell Kirkham, State Soil Scientist.

I wish to pass along my personal thanks for the cooperation and enthusiasm that all members of your staff extended to me.

Thomas [signature] for

James A. Doolittle
Soil Specialist (GPR)

Enclosure

cc: w/enclosure
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PRINCIPLES OF OPERATION

The GPR is a broad bandwidth, pulse modulated radar system that has been specifically designed to penetrate earthen materials. Relatively high frequency, short duration pulses of energy are transmitted into the ground from a coupled antenna. When a pulse strikes an interface (boundary) separating layers of differing electromagnetic properties, a portion of the pulse's energy is reflected back to the receiving antenna. The reflected pulse is received, amplified, sampled, and converted into a similarly shaped waveform in the audio frequency range. The processed reflected signal is displayed on the graphic recorder or is recorded and stored on magnetic tape.

The graphic recorder uses a variable gray scale to display the data. It produces images by recording strong signals as black, intermediate signals in shades of gray, and weak signals as white. As a general rule, the more abrupt the interface and the greater the difference in electromagnetic properties across the interface, the stronger the reflected signal and the darker the generated image.

The graphic profile is developed as electrosensitive paper moves under the revolving styli of the graphic recorder. Reflections above a preset threshold level are "burned" onto the electrosensitive paper. Each scan of a stylus draws a line across the paper in the direction of increasing signal travel time (depth). The intensity of the images printed along each line is dependent upon the amplitude of the processed signals. A continuous profile of subsurface conditions is "burned" onto the paper by the graphic recorder by towing the antenna along the ground surface.

Figure 1 is an example of a graphic profile. The horizontal scale represents unit of distance traveled along the transect line. This scale is dependent upon the speed of antenna advance along the transect line, the rate of the paper advance through the graphic recorder, and the playback speed of data recorded on magnetic tape. The vertical scale is a time or depth scale which is based upon the velocity of signal propagation. The dashed vertical lines are event markers inserted on the graphic profile by the field operator to indicate known antenna positions or reference points along the transect line. The evenly spaced horizontal lines are scale lines. Scale lines provide reference planes for relative depth assessments.

Most graphic profiles consist of four basic components: the start of scan image (A), inherent system images (B), surface images (C), and subsurface interface images (D). All of these components, with the exception of the start of scan image, are generally displayed in groups of three dark bands unless limited by high rates of signal attenuation or the proximity of two or more closely spaced interface signals. These bands, which are produced by oscillations in the reflected pulses, limit the ability of the GPR to discriminate shallow or closely spaced interfaces. The dark bands occur at both positive and negative signal amplitudes. The narrow white line(s) separating the bands represent the neutral or zero crossing between the polar amplitudes.

The start of scan image (A) is a result of the direct coupling of the transmit and receive antennas. Though a source of unwanted clutter, the start of scan image is often used as a time reference line.

Reflections inherent in and unique to each of the system's antennas are the first series of multiple bands on graphic profiles. Generally the number and width of these bands increase with decreasing antenna center carrier frequency. These reflections (B) are a source of unwanted "noise" in graphic profiles.

The surface images (C) represent the first major interface signal. The first zero crossing of the surface images is normally selected as a matter of its convenience and repeatability as the soil surface for depth calibrations and measurements.

Below the images of the surface reflection are the images from subsurface interfaces (D). Interfaces can be categorized as being either plane reflectors or point objects. Most soil horizons and geologic layers will appear as continuous, parallel, multiple bands similar to those appearing in the left-hand portion of Figure 1. Small objects, such as rocks or buried pipes, will appear as point objects and will produce hyperbolic patterns similar to those appearing in the right-hand portion of this figure. Hyperbolic patterns are a function of the radar's conical area of radiation which enables the antenna to receive echoes even though it is not directly over the object.

APPALACHIAN HIGHLANDS AND PIEDMONT

Several areas within New Jersey's Appalachian Highlands and Piedmont physiographic provinces were selected to evaluate the potential of the ground-penetrating radar (GPR) to determine the occurrence, depth, and lateral extent of bedrock. In these provinces the depth to bedrock is a major concern of management. Typically, the soils of these provinces are underlain by bedrock at variable depths. These soils also contain a large number of coarse fragments of varying sizes. It is exceedingly difficult to auger through these soils. When augering is halted by a rock surface it is often impossible to adequately confirm whether a bedrock surface or a detached coarse fragment has been encountered.

The quantity and quality of soil data can be improved in many areas of the Appalachian Highlands and Piedmont provinces, if a faster, more comprehensive, and less labor intense method were available. The ground-penetrating radar, a new technological tool, has been specifically designed for shallow subsurface site investigations.

On the basis of limited field work in New Jersey, the GPR appears to be suitable for differentiating bedrock from other earthen materials. With the GPR, the depth to bedrock can be determined and its lateral extent defined by correlating a limited number of soil borings with the graphic profile or by using tabled values for the assumed rates of signal propagation through the medium.

In all GPR field investigations, the first step is antenna selection. Four antennas (80, 120, 300, and 500 MHz) were available for this study. Generally the most suitable antenna is the one having the highest possible frequency which will penetrate to the desired depth. In any soil, the higher the frequency of the antenna, the better the resolution of subsurface features, provided sufficient energy is available to penetrate to the desired depth. Lower frequency antennas can penetrate the soil more deeply as a result of their greater average and peak powers of radiation. Unfortunately, images produced with the lower frequency antennas are more poorly resolved than are comparable images produced with high frequency antennas. The poor resolution of the lower frequency antennas is a result of their larger radiated band widths.

In areas of coarse and moderately coarse textured tills, and on crystalline bedrock, the 300 MHz antenna provides excellent resolution and ample depth of penetration (see Figure 2). The 500 MHz antenna is suitable for detailed investigations of shallow features in coarse and moderately coarse textured tills and on crystalline bedrock. In soils which more rapidly attenuate the radar's energy, the 120 MHz antenna appears to provide the best balance of resolution and depth of penetration (see Figures 4 and 5). Generally the 120 MHz antenna is more suitable for work in moderately fine textured soils and/or wetter soil conditions. The 120 MHz antenna provided the best results in areas underlain by sedimentary rocks.

The depth scale on all graphic profiles is initially a time scale. The time scale can be converted into a depth scale once the average rate of signal propagation through the soil has been determined or ground-truth field observations are used to confirm the depths to interfaces.

During the early part of this investigation, prolonged periods of high intensity rains and generally inclement weather restricted the number of completeness of ground-truth observations made. Consequently, depth scales were based on "tabled values" for the rate of signal propagation through wet, loamy soils. These values assume uniform soil conditions; an impractical assumption considering the the ansiotrophic nature of soils. Though close approximations, these depth scales should not be used for detailed or highly precise depth measurements.

The second step in all field operations is the calibration of the control and recording units to achieve optimal signal returns. This procedure is relatively simple in areas of similar soils and uniform soil conditions. In areas of similar soils, once the optimal settings have been achieved, readjustments are generally unnecessary. As the complexity of soils and soilscapes increase, readjustments are required to maintain the most optimal settings.

The control and recording units are adjusted to achieve the most optimal setting at the beginning of each transect. No single combination of range gain or filtration settings is suitable for diverse soil conditions encountered along transects conducted across complex soilscapes. Along several transects, the lack of subsurface interfaces can be attributed to wetter soil conditions and the radar being temporarily out of optimal adjustment.

The SIR-4800 control unit was designed to satisfy the needs for variable range gain and filtration settings in areas having dissimilar soils or soil conditions. Transects recorded on magnetic tapes can be played back with the range gain and/or filtration settings being continuously adjusted to handle variations in site conditions. Though time-consuming, this procedure enhances the imagery on most graphic profiles.

An area of the Appalachian Highlands in Morris County was selected as the first site for the GPR field study. Here the soils have formed in moderately coarse till. Precambrian gneissic bedrock outcrops in many areas or underlies the till at shallow to very deep depths. The study site consisted of Rockaway (coarse-loamy, mixed, mesic Typic Fragiudults) and Hibernia (coarse-loamy, mixed, mesic Aquic Fragiudults) soils and areas of rock outcrops. Slopes ranged from 3 to 15 percent.

In Figure 2, the multiple, dark, continuous bands representing bedrock interface (A) are evident between depths of 1 to 2 meters. Below this boundary, images from the gneiss bedrock are generally absent or are subparallel (D). Exceptions can be found along highly inclined fracture planes. In areas having highly weathered bedrock surfaces or large concentrations of cobbles and boulders immediately above the bedrock surface, identification of the till/bedrock interface is more problematic.

The till is composed of numerous rock fragments of all grain sizes. These rocks represent point reflectors and produce a unique appearance on graphic profiles (C). The nonsorted, nonstratified nature of till produces numerous randomly spaced, short, segmented images on graphic profiles. In some areas, such as the upper right-hand portion of Figure 2, the images of the rocks appear to be orientated into linear thrust planes.

Soil horizon parallel the surface at shallow depths. In the upper left-hand portion of Figure 2, the image from a well expressed argillic horizon (B) is apparent.

Not all rocks are equally transparent to the radar. Figure 3 is a portion of the graphic profile from a transect conducted with the 120 MHz antenna in an area of shaly residium in the Musconetcong Valley of Warren County. The study area consisted of Berks (loamy-skeletal, mixed, mesic Typic Dystochrepts), Nassau (loamy-skeletal, mixed, mesic Lithic Dystochrepts), and Washington (fine-loamy, mixed, mesic Ultic Hapludalfs) soils. Depths to the thinly bedded, highly fractured and folded shale bedrock ranged from shallow to deep.

In Figure 3, interpretations are very limited and at best, speculative. Signal processing did not significantly enhance the radar imagery. The effective depth of penetration was less than 1.5 meters.

The poor performance of the GPR can be attributed to the high shale content and saturated conditions of the soils. Shales and clays represent high loss materials which rapidly attenuate and restrict the effective probing depth of the radar signals. Returning to this site during a drier period would probably increase the depth of penetration and the resolution of subsurface features.

The soil/shale bedrock interface was ill-defined and transitional in the study area. The shale content gradually increased with increasing depth. Viewed in a pit exposure, the upper boundary of the shale was highly weathered, indistinct, and often consisted of an admixture of shale and loamy sediments.

The GPR will seldom discern gradual or weakly expressed boundaries. As a general rule, the more abrupt the boundary and the greater the electromagnetic gradient across the boundary, the stronger the reflected signal. Also, saturation dilutes the contrast of electromagnetic properties across interfaces and weakens the intensity of the reflected signal.

Excluding areas of shale bedrock, the 120 MHz antenna provided the best balance of depth of penetration and resolution of subsurface features in the moderately fine textured soils of the Appalachian Highlands and Piedmont provinces. It is seriously doubted that the present GPR system, regardless of soil or site conditions, will be able, in areas of shale residium, to penetrate to a depth significantly greater than 3 meters.

Several transects were conducted in an area of Edneyville (fine-loamy, mixed, mesic Typic Hapludults) and Califon (fine-loamy, mixed, mesic Aquic Fragiudults) soils near Montana, New Jersey. The 120 MHz antenna provided consistent and detailed profiles of subsurface features to depths of 4 meters in the well drained areas of Edneyville soils (Figures 4 and 5) and 2 meters in the somewhat poorly drained areas of Califon soils. The effective depth of penetration was less in Califon as a result of wetter soil conditions. In areas of Califon soil, the effective depth of penetration could have been slightly improved by readjusting the controls which were calibrated on the drier soil conditions of Edneyville. Though inconsistently achieved, depths as great as 6 meters were obtained in many areas of Edneyville soil.

The argillic horizon (A) is weakly evident in the upper part of Figure 4. In places, the image of the argillic horizon appears diffuse and segmented. In those areas, it is inferred that the textural change in less abrupted, weakened by the occurrence of cobbles, or nonexistent. Nonsorted accumulations of rocks and lenses of coarser textured drift can be inferred from the mottled appearance of the graphic profile (B). With increasing depth, the radar will only discern increasing larger reflectors. The apparent absence of cobbles and boulders in the lower part of the till is a result of these fragments passing below a critical size to depth ratio. With increasing depth, the radar can discern only the larger reflectors. A bedrock interface is evident at "C."

In Figure 5, the scanning time was reduced along the Edneyville transect line. As a procedure, reducing the scanning time will lessen the depth scanned and increase the available printing space on the graphic profile per unit depth scanned. This enlargement procedure increases the detail and accuracy of most shallow depth measurements.

The argillic horizon (A) is more evident in Figure 5 and several properties can be inferred from its graphic expression. Lateral changes in the electromagnetic properties along the argillic horizon can be inferred from changes in the widths of the light and dark bands. As a general rule: the more abrupt or contrasting an interface, the stronger the amplitude of the reflected signal, the blacker and wider the dark bands and the narrower the widths of the white bands. An abrupt change in texture from the surface layer to the subsoil should produce images having wide dark bands and narrow white bands. In Figure 5, the intensity of the image of the argillic horizon changes from near white to black.

At "B," a "white-out" area is observed. White-out areas are zones of no signal return. They result from the rapid and complete dissipation of the radar signal, the absence of subsurface interfaces, or both. At "C," the weaker subsurface interface is present, though less apparent.

Figure 6 is a portion of a graphic profile from an area of Duffield (fine-loamy, mixed, mesic Ultic Hapludalfs) soils. Typically the depth to limestone ranges from 4 to 7 feet, but in the areas examined, the depth to limestone was shallower. The contact with the limestone bedrock is at "B." The limestone is generally free of interface signals except for possible bedding or fracture planes (A), solution pipes (below B), and solution cavities (C).

The GPR was exceedingly depth restricted and required signal processing to enhance the imagery in areas of residium weathered from Triassic shales and siltstone on the Piedmont Plateau. Depths were restricted to less than 2 meters in areas of Penn (fine-loamy, mixed, mesic Ultic Hapludalfs) soils. Though most near surface imagery was removed during processing, rock fragments are visible at "A." The Model 30 microprocessor has seven programs designed to enhance radar imagery. Each program has a unique filtration bypass. Though each program is unique, all are designed to either remove background noise, stack weaker subsurface signals, or both. In figure 7, a background removal and signal stacking program was used to bring out the imagery.

ATLANTIC COASTAL PLAIN

Several soils of the Atlantic Coastal Plain were profiled with the GPR in Monmouth and Salem Counties. Soils profiled included Atsion (sandy, siliceous, mesic Aeric Haplaquods), Aura (fine-loamy, mixed, mesic Typic Hapludults), Chillum (fine-silty, mixed, mesic Typic Hapludults), Downer (coarse-loamy, siliceous, mesic Typic Hapludults), Freehold (fine-loamy, mixed, mesic Typic Hapludults), Fort Mott (loamy, siliceous, mesic Arenic Hapludults), Galestown (sandy, siliceous, mesic Psammentic Hapludults), Holmdel (fine-loamy, mixed, mesic Aquic Hapludults), Keyport (clayey, mixed, mesic Aquic Hapludults), Matapeake (fine-silty, mixed, mesic Typic Hapludults), Sassafras (fine-loamy, siliceous, mesic Typic Hapludults), and Woodstown (fine-loamy, siliceous, mesic Aquic Hapludults). Though texturally diverse, many of these soils are similar and all but one are Ultisols. Most of these soils have argillic horizons within depths of 50 cm. One, Fort Mott, has a sandy epipedon greater than 50 cm thick; one, Galestown, has a loamy sand argillic horizon. The remaining soils share similar characteristics.

Generally the investigated soils were fairly uniform in expression. The GPR detected three major features in these soils: argillic horizons, lithologic discontinuities, and stratified substratum layers. Argillic horizons were easily identified and traced laterally, except in areas where they closely approached or parallelled the soil surface, or were masked by bands of induced resonances. In areas where the argillic horizon approached to within a one-half wavelength distance of the soil surface, its image was masked by the broad bands of the surface pulse. The argillic horizon was difficult to identify and trace laterally with a high level of confidence in soils where it closely parallelled the ground surface or was partially masked by induced resonances.

On graphic profiles, resonances appear as multiple bands which maintain constant depths. The higher gain settings, required to amplify weaker subsurface signals in most Coastal Plain soils, increase the level of unwanted resonances appearing on graphic profiles.

Most lithologic discontinuities profiled with the GPR were contrasting; either in terms of their texture or density. Abrupt or strongly contrasting boundaries produce distinct dark images on graphic profiles. Gradual or less contrasting boundaries produce weak, faint to indistinct images on graphic profiles.

On most graphic profiles, stratified layers are evident in the substratum. Collectively, stratified layers are identifiable by their unique pattern on graphic profiles. But on the basis of limited ground-truth observations, individual layers are exceedingly difficult to correlate.

Coastal Plain soils having moderately fine or finer textured solums rapidly attenuate the radar signal. As a result of the higher rates of signal absorption and scattering, the 80 and 120 MHz antennas were selected for use in this portion of the field investigation. These antennas provided adequate resolution of subsurface features and sufficient probing depths in most soils profiled. In the loess capped soils of Salem County, the 80 MHz antenna provided adequate resolution of subsurface features to depths of 1 to 2 meters. Deeper depths of penetration were achieved with the 80 MHz antenna in areas of coarse and moderately coarse textured soils. Occasionally depths as great as 4 meters were achieved with the 80 MHz antenna. The 120 MHz antenna was more depth restricted. In Salem County, graphic profiles produced with the 120 MHz antenna were plagued with multiple bands of induced resonances. Later it was noticed that two metallic flags had slipped between the bottom of the antenna and the sled. It is believed that these flags had produced the resonances observed on the graphic profiles.

Figure 8 is from an area of Freehold fine sandy loam in Monmouth County. Detailed subsurface information was attained with the 120 MHz antenna to a depth of 1 meter. The Freehold soil appears uniform in expression except for the weakening of the argillic horizon near "A." At "A" the soil is eroded. The argillic horizon is closer to the soil surface and has been mixed with the plow layer. The argillic horizon closely parallels the soil surface at a depth of 30 to 46 cm. Two subsurface strata (B and C) are evident. The upper most subsurface layer (B) decreases in expression and becomes discontinuous near the right-hand border of this figure. Segmentation and interfingering of layers within the substratum are common in the soils of the Atlantic Coastal Plain.

In many areas of the Atlantic Coastal Plain, interpretations are complicated by the large number of short interfingering strata in the substratum. If a large number of ground-truth observations are required to correctly identify each subsurface layer, the cost effectiveness of the GPR may be reduced.

In Figure 9, an intermittent and weakly expressed traffic pan is seen at "A." A thin sandy loam layer (B) appears in the upper portion of this profile. This layer maintains a fairly uniform depth of about 40 cm in the central portion of the profile, but plunges to a depth of approximately 90 cm along the right-hand margin. A spodic horizon parallels the soil surface at "C." Though not readily apparent in this reproduced copy, the image of the spodic horizon has a unique, intermediate gray expression.

Numerous segmented and interfingering subsurface layers (D) can be seen in the lower part of Figure 9. Signal interference and superpositioning are inferred from the abrupt termination of several merging bands, and the occurrence of white-out areas. These white-out areas represent areas in which signals have cancelled each other out.

Deep penetration and detailed subsurface information results from favorable electromagnetic properties of soils. These results are often more attainable in coarse and moderately coarse textured soils. Taken in an area of Downer and Sassafras soils, Figure 10 demonstrates the potential for deep and detailed penetration in generally coarser textured sediments.

Regardless of slope, the soil surface on all graphic profiles is horizontal. But slope effects the apparent inclination of subsurface layers on all graphic profiles. Many of the layers seen in Figure 10 are the inverse of the topographic expression of the landform. Only layers "A" and "B" parallel the soil surface and should be considered pedogenetic in origin. Lower lying layers (C and D) mirror the inverse of the topography and are considered geologic in origin. Though appearing to be steeply inclined these layers are essentially horizontal and intersect the surface on the lower lying portions of the concave sideslopes.

A thin continuous stone line (A), a product of an earlier erosional cycle, parallels the soil surface. It varies in depth from 38 to 66 cm. A zone of clay balls and/or lenses in a coarse textured matrix, produces the mottled pattern about "B." The clay balls are variable in size and orientation.

A second transect was conducted in the area of Downer and Sassafras soils with a reduced scanning time. This procedure produced the enlarged and more detailed profile of near surface features seen in Figure 11. The clay balls and lenses are more apparent. The superpositioning of images from numerous, closely spaced rock fragments produces the planar interface (A) in the upper part of this profile.

The vertical scale in Figure 11 has been greatly exaggerated. Decreasing the scanning time (or depth scanned) while maintaining a uniform speed of antenna advance, increases the vertical exaggeration. Because of this exaggerated scale, the subsurface strata (C) appears to be more steeply inclined than it actually is.

Several areas of Chillum soils were studied with the GPR. At the Rutgers University's Bridgeton Experiment Station, the interface separating the thin loess cap from the substratum was diffuse and weakly expressed. The gradational nature of this interface diluted the electromagnetic gradient and weakened the reflected signal below a critical level of graphic visibility.

In other areas the contact between the loess and the gravelly substratum was more abrupt and appears as a distinct image (A) on the graphic profile (Figure 12). Cross bedding within the underlying sands and gravels can be inferred in many areas from the crossing bands (B).

Radar pulses consist of a positive and negative signal component. In Figure 13 and as done in the other figures, positive and negative signal components are indicated by black and hatchured bands, respectively. When the transmitted electromagnetic energy encounters an interface separating two dissimilar materials a phase reversal occurs. The presence of several closely spaced negative signal components near "A" and the absence of positive signal components suggest the occurrence of multiple, closely spaced interfaces. Viewed in a roadcut, this area of Keyport soil was composed of several thin layers of clay separated by thicker layers of gravelly sandy clay loam or gravelly sandy loam. It was difficult to determine in the exposure which layer represented the major interface (B). This interface appears to correspond to the thickest clay bed.

The GPR was later used as a reconnaissance tool to pinpoint the precise locations of buried house foundations at old Fort Mott. A grid system of flags was laid out over a suspected site. The grid system facilitated locating subsurface features in relationship to fixed reference points on the surface. The grid system consisted of a series of equidistant parallel lines which were laid out in generally a north-south and an east-west direction.

Figure 14 is representative of the transects that were taken at Fort Mott. Images from a foundation wall are apparent in the right-hand portion of this figure. The ground-penetrating radar appears to have the potential to rapidly locate focal points for archaeological excavations in Coastal Plain soils of New Jersey.

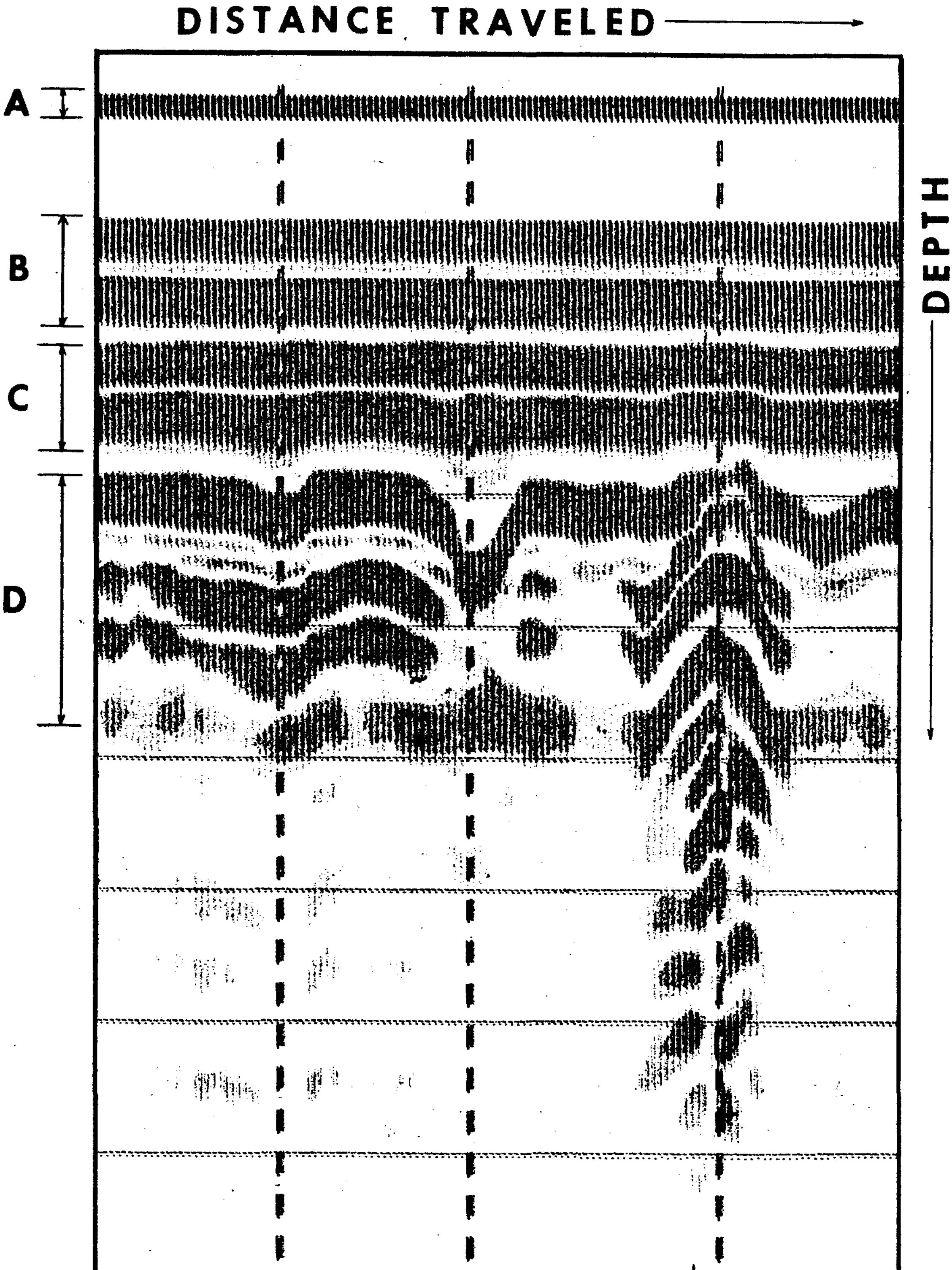


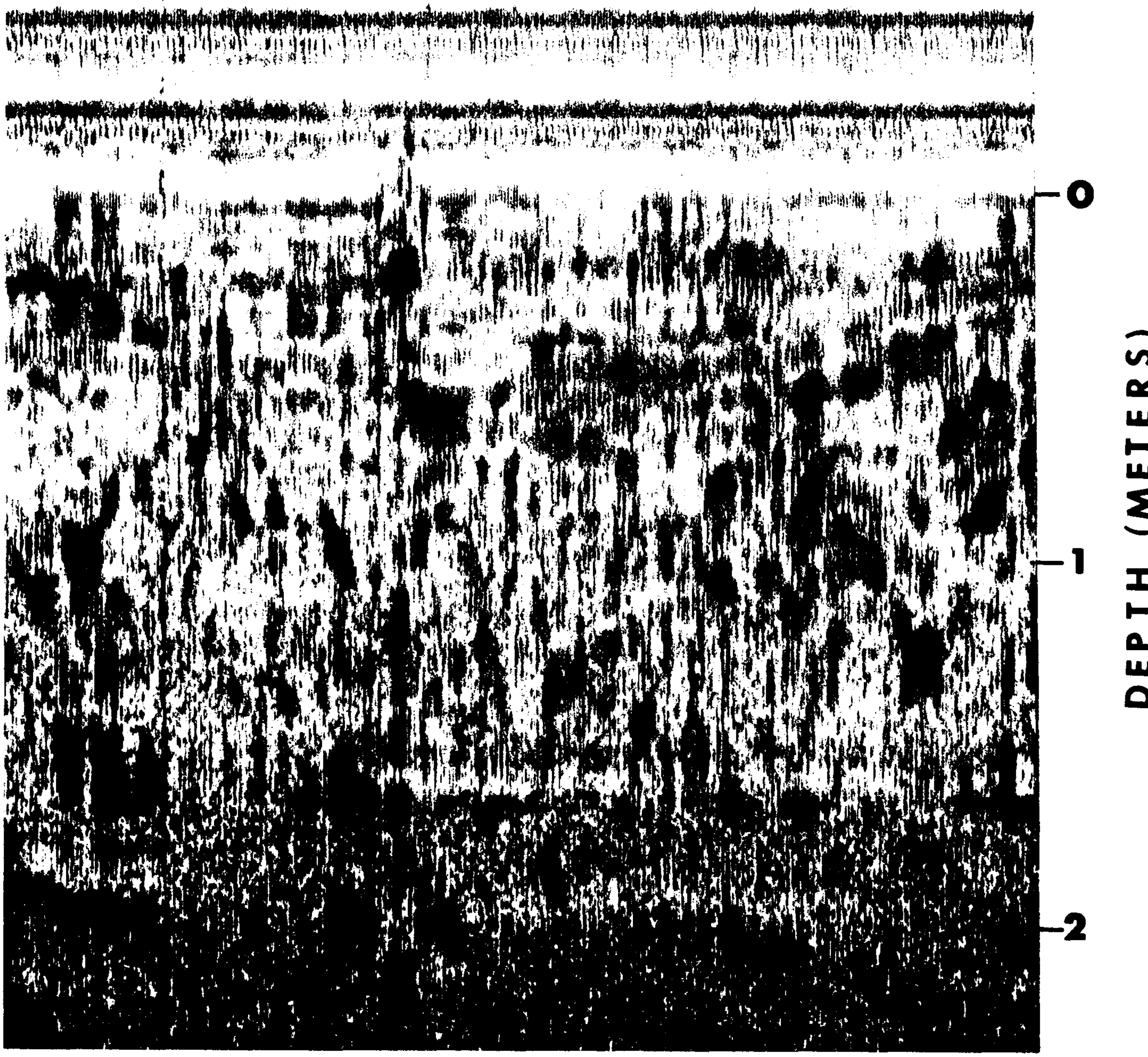
FIG. 1

A GRAPHIC PROFILE

FIG 2

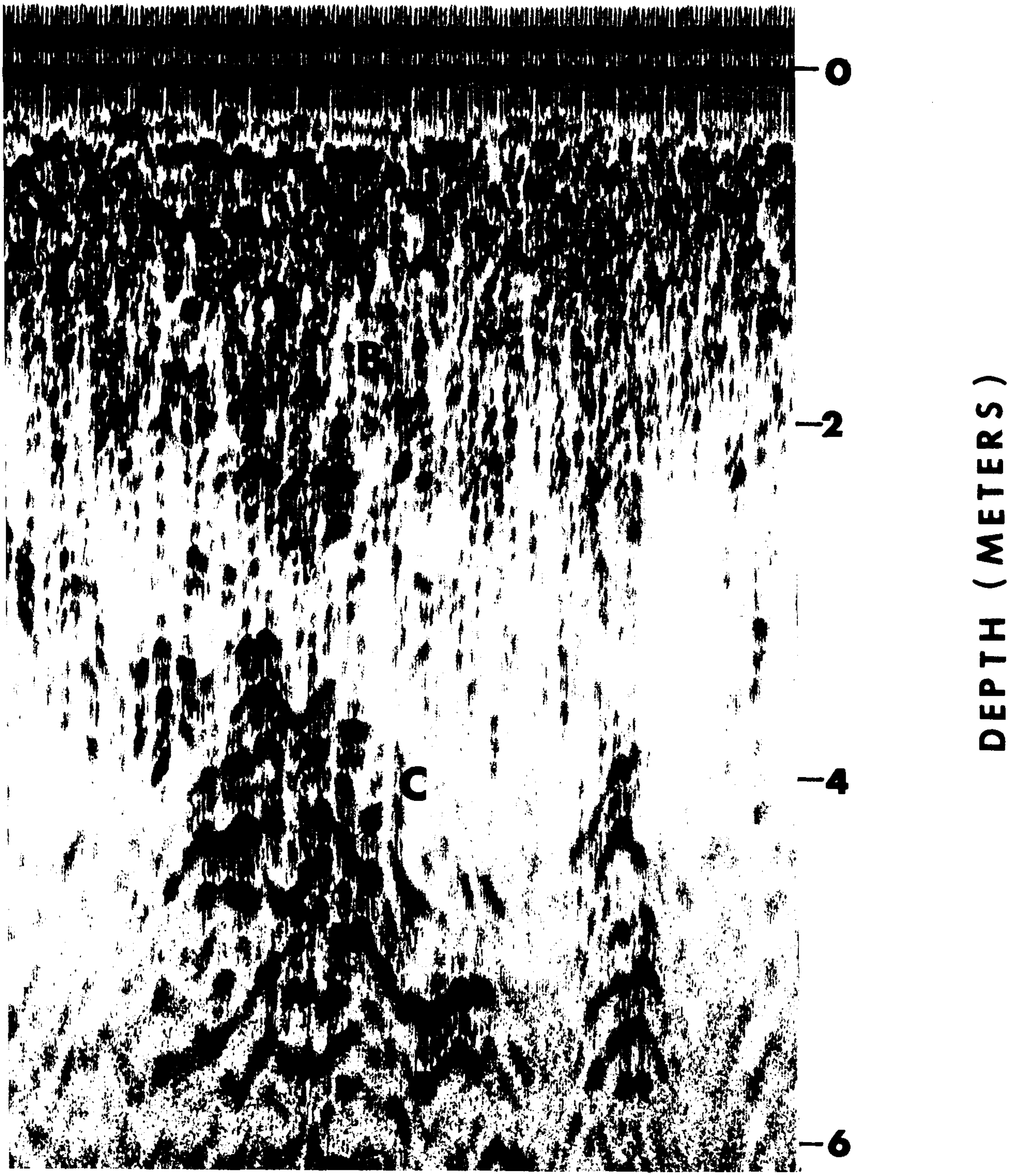
GPR PROFILE FROM AN AREA OF
ROCKAWAY ROCK OUTCROP

FIG. 3



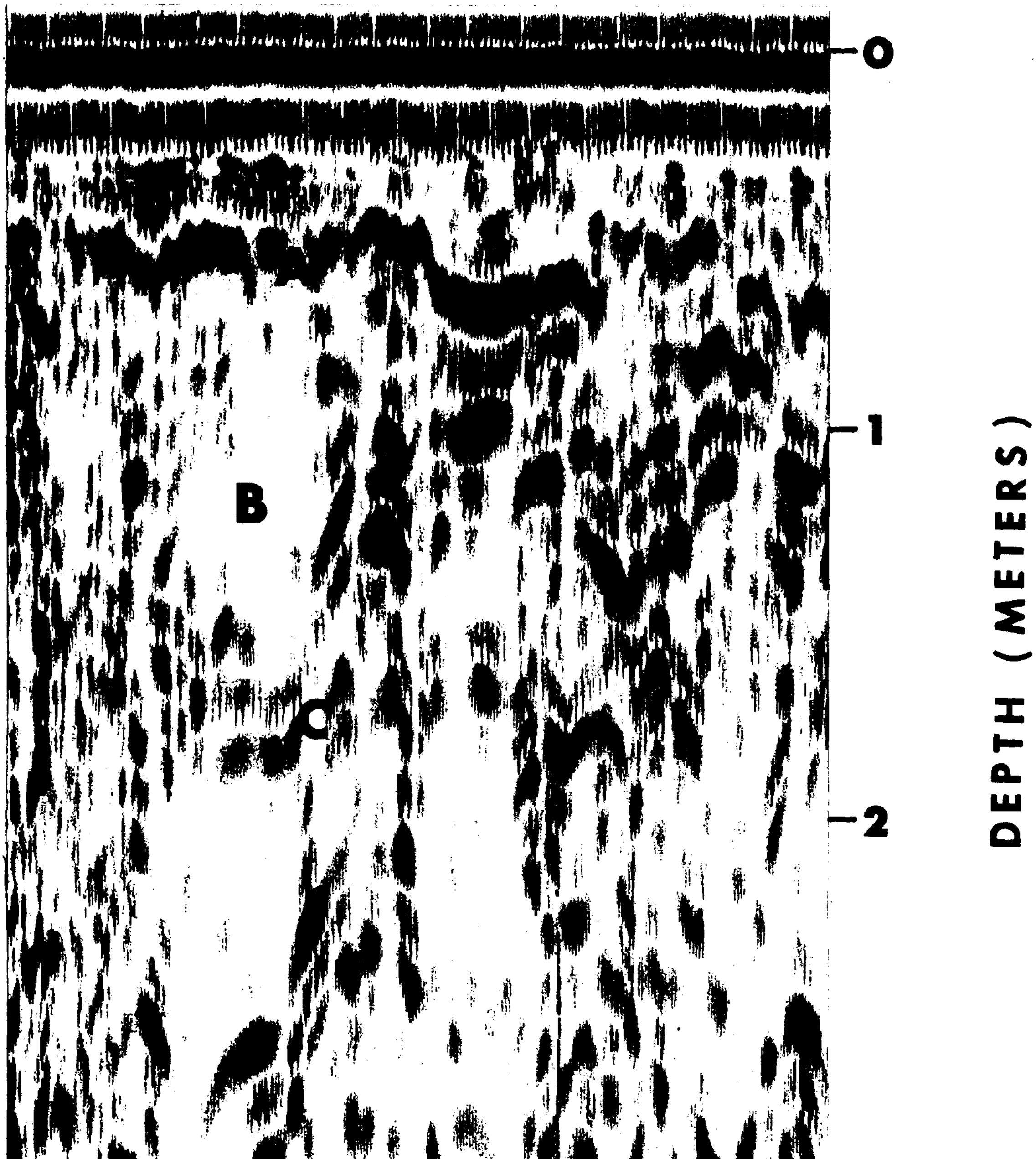
PROCESSED PROFILE FROM AN AREA OF NASSAU AND BERKS SOILS

FIG. 4



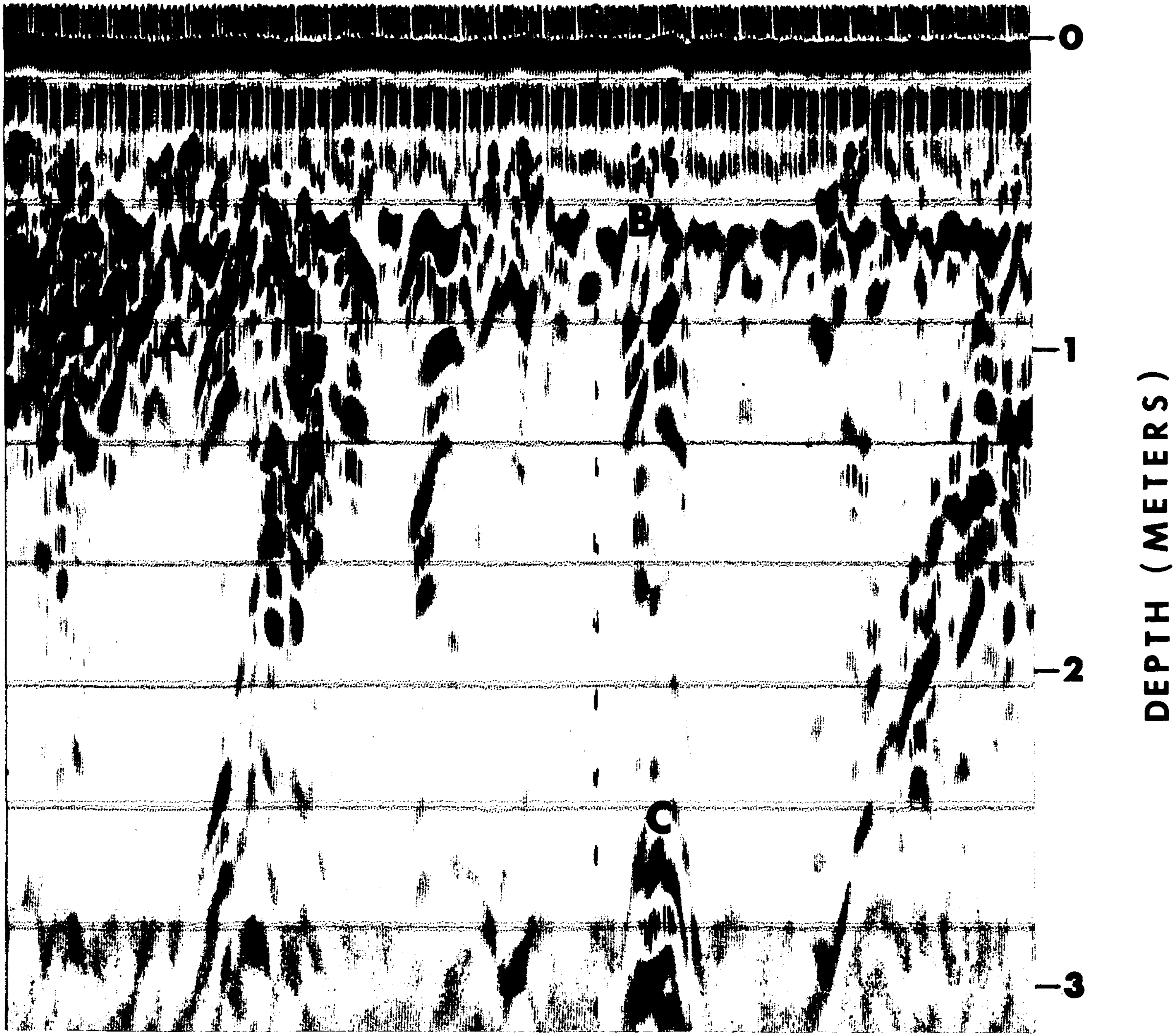
AN AREA OF EDNEYVILLE SOIL

FIG. 5



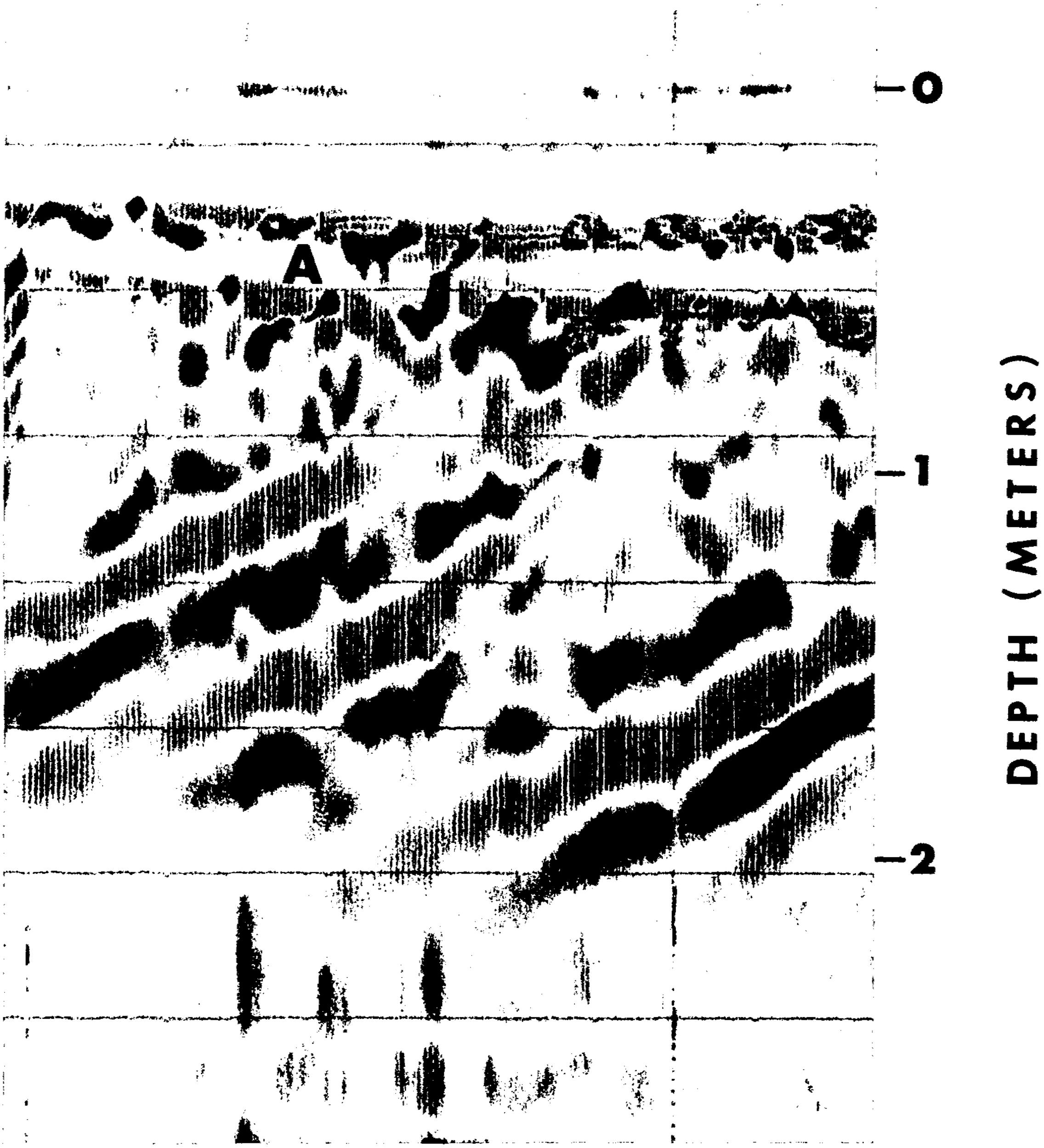
EDNEYVILLE SOILS

FIG. 6



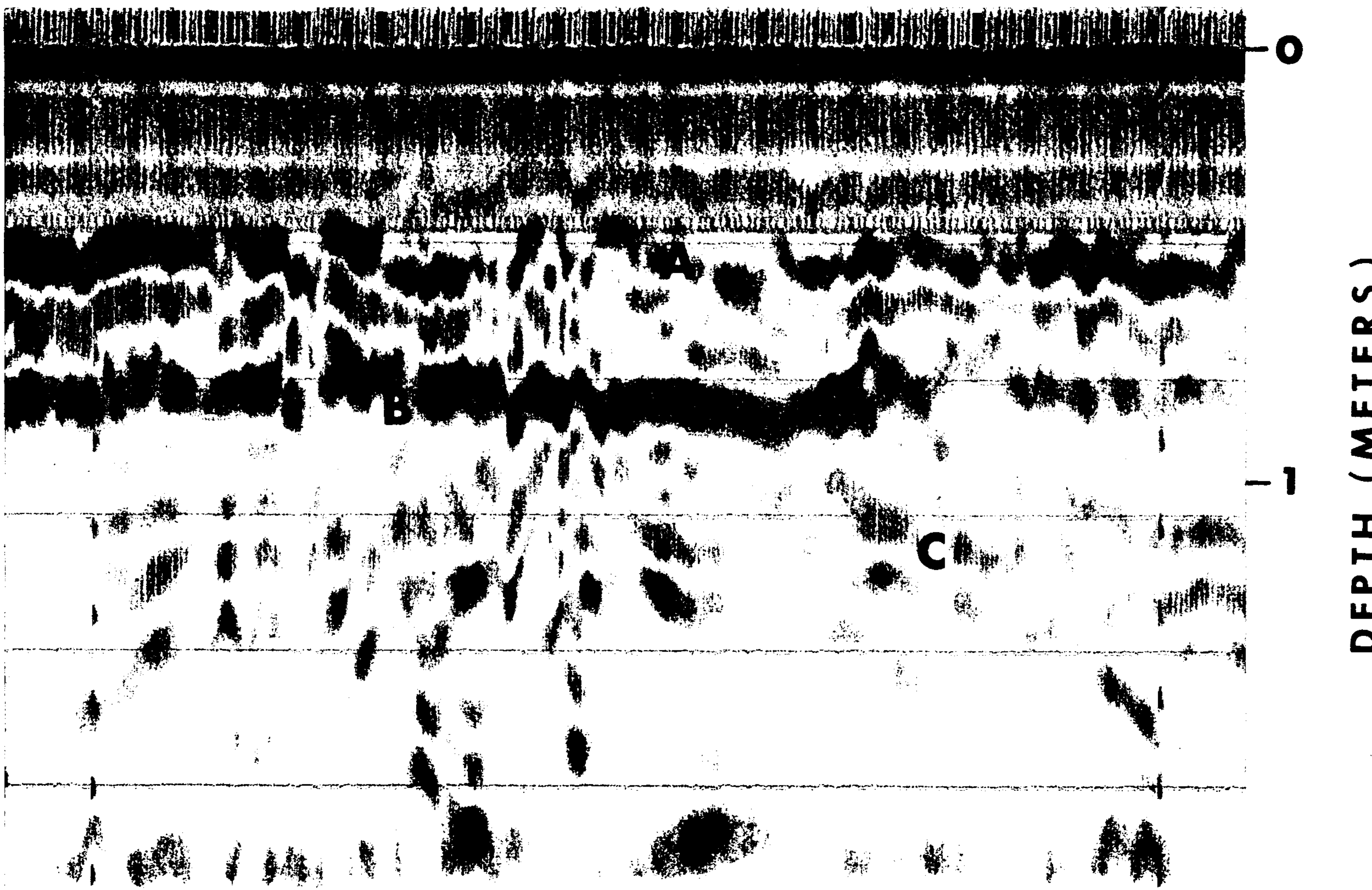
DUFFIELD SILT LOAM

FIG. 7



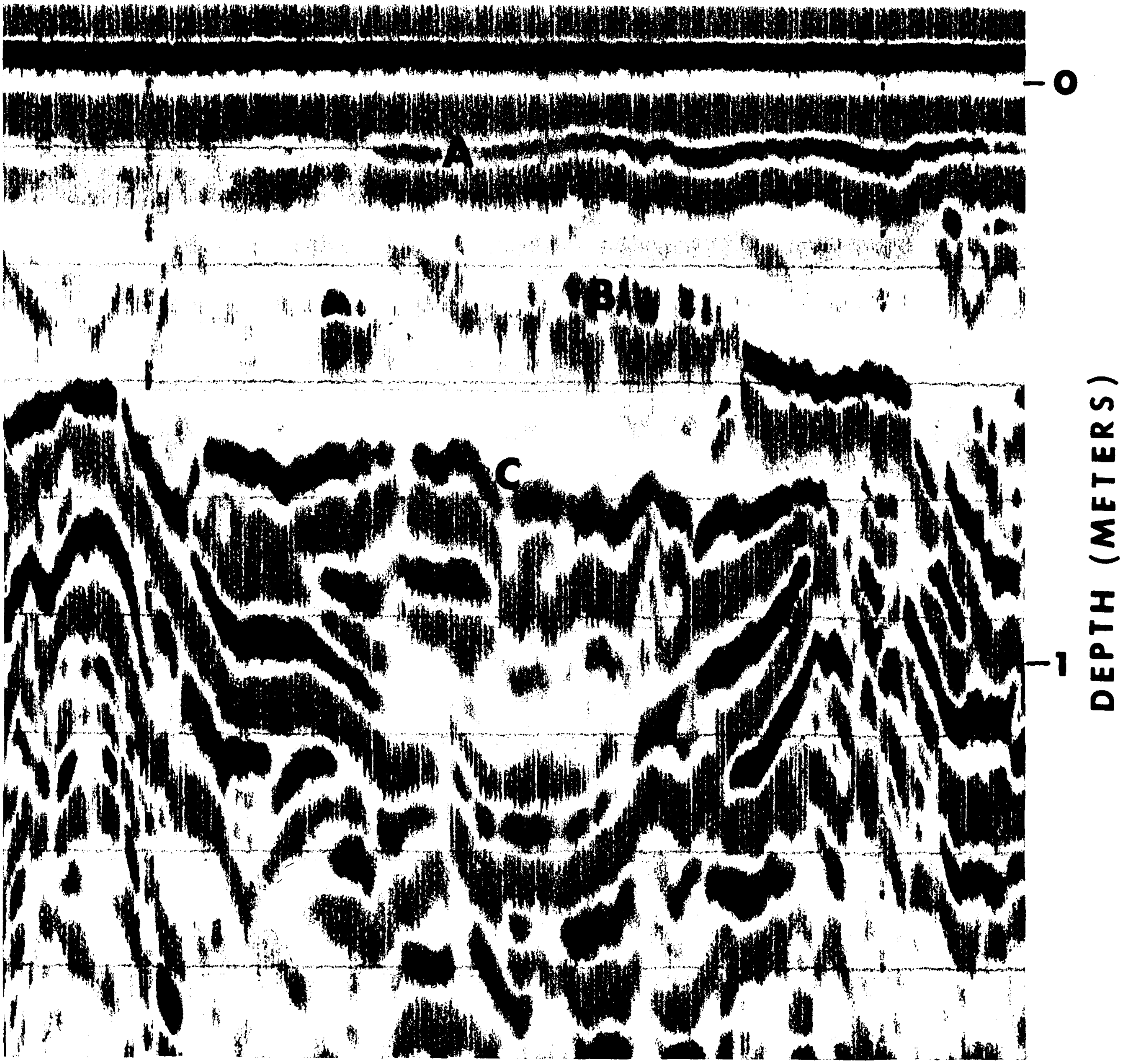
PENN SHALY SILT LOAM

FIG. 8



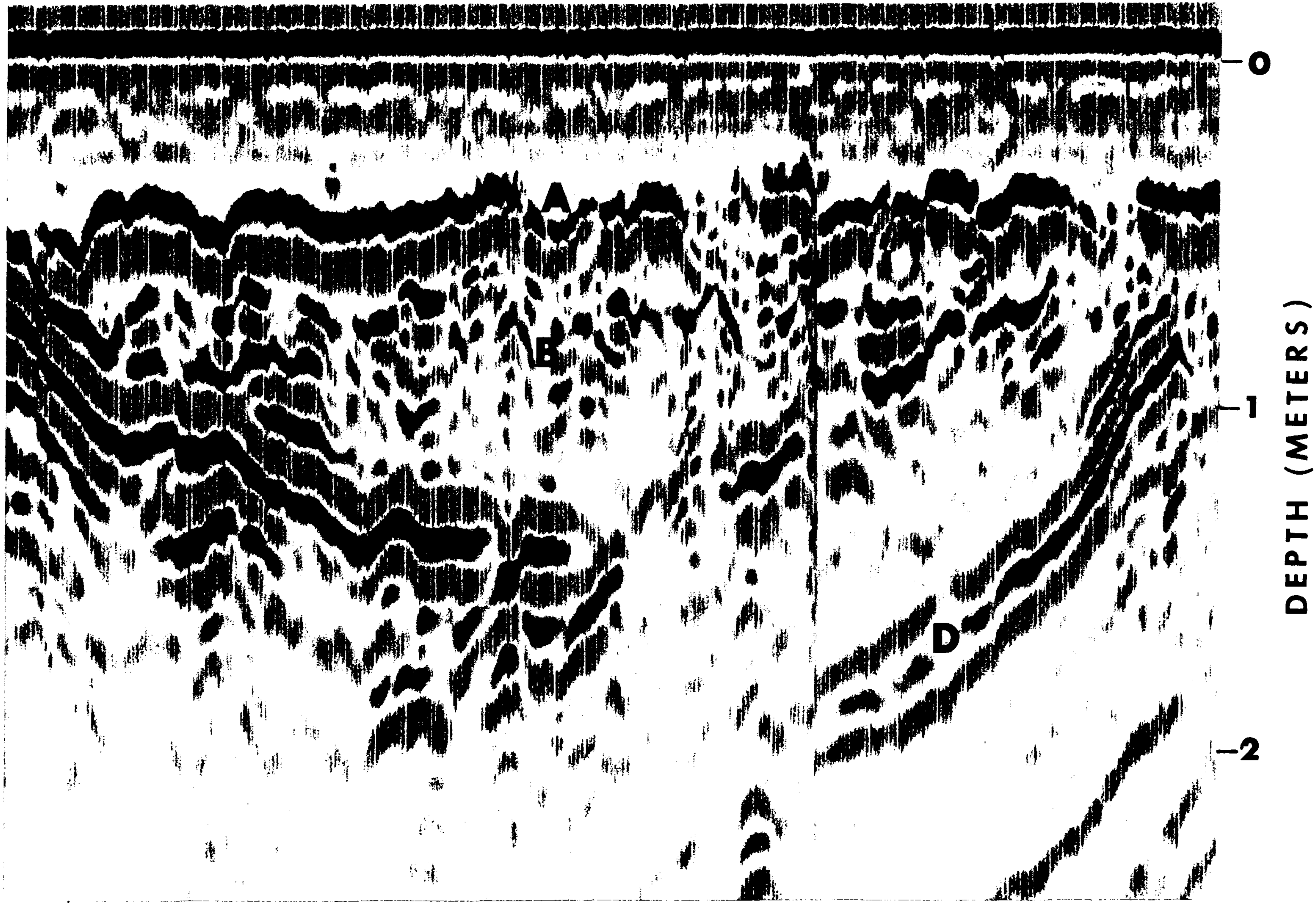
FREEHOLD FINE SANDY LOAM

FIG. 9



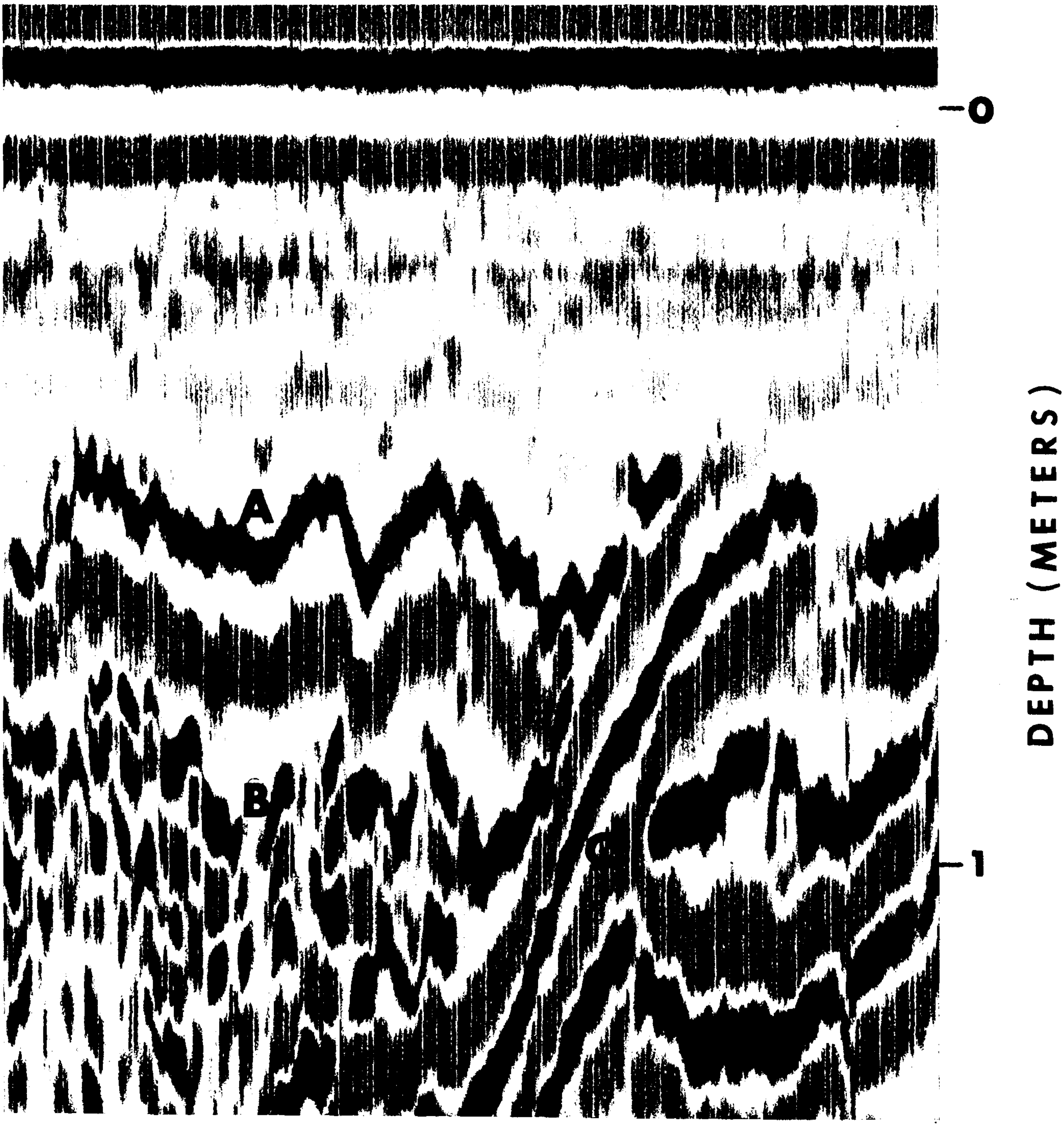
AN AREA OF ATSION SOILS

FIG. 10



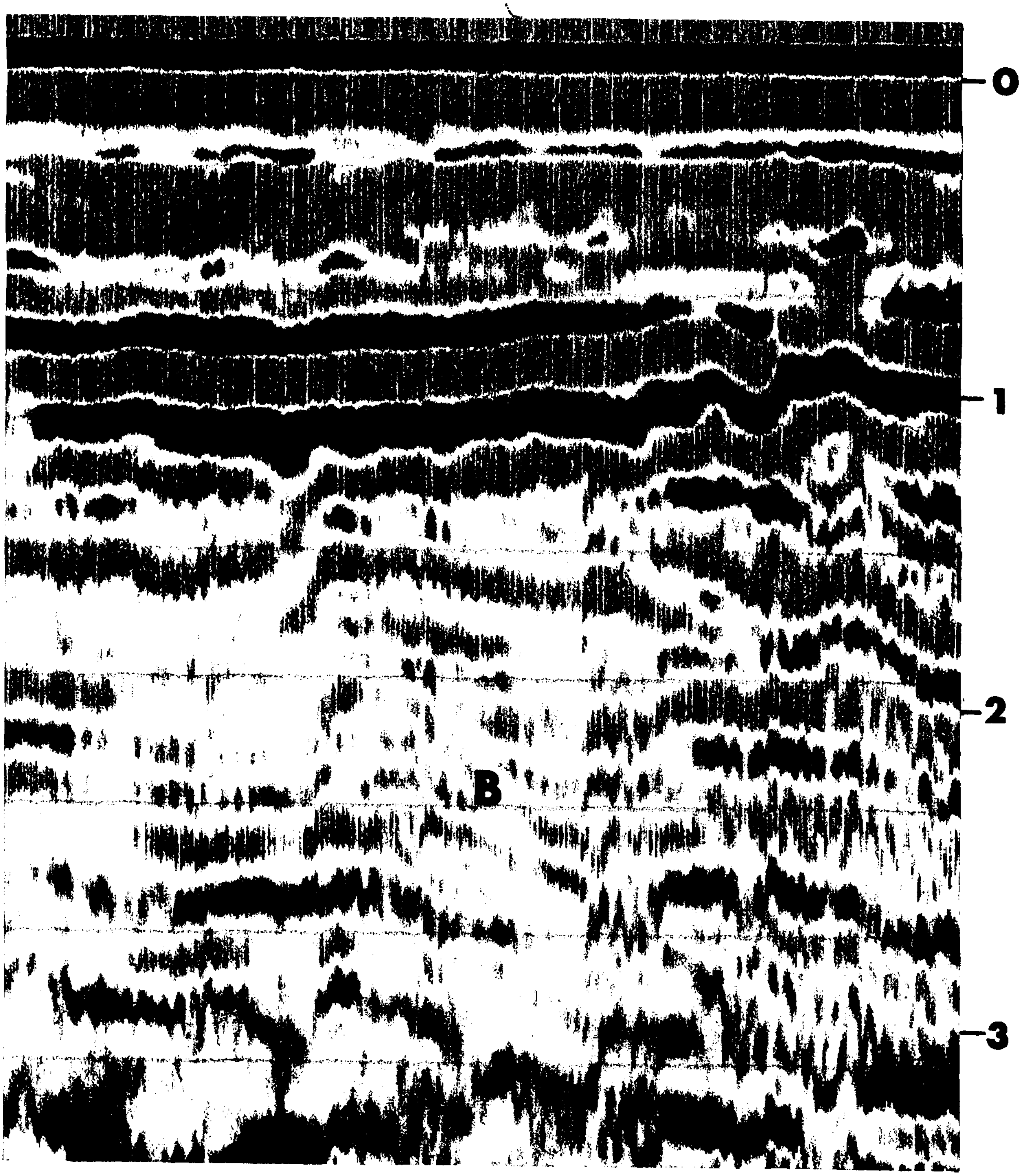
GRAPHIC PROFILE OF A KNOLL

FIG. 11



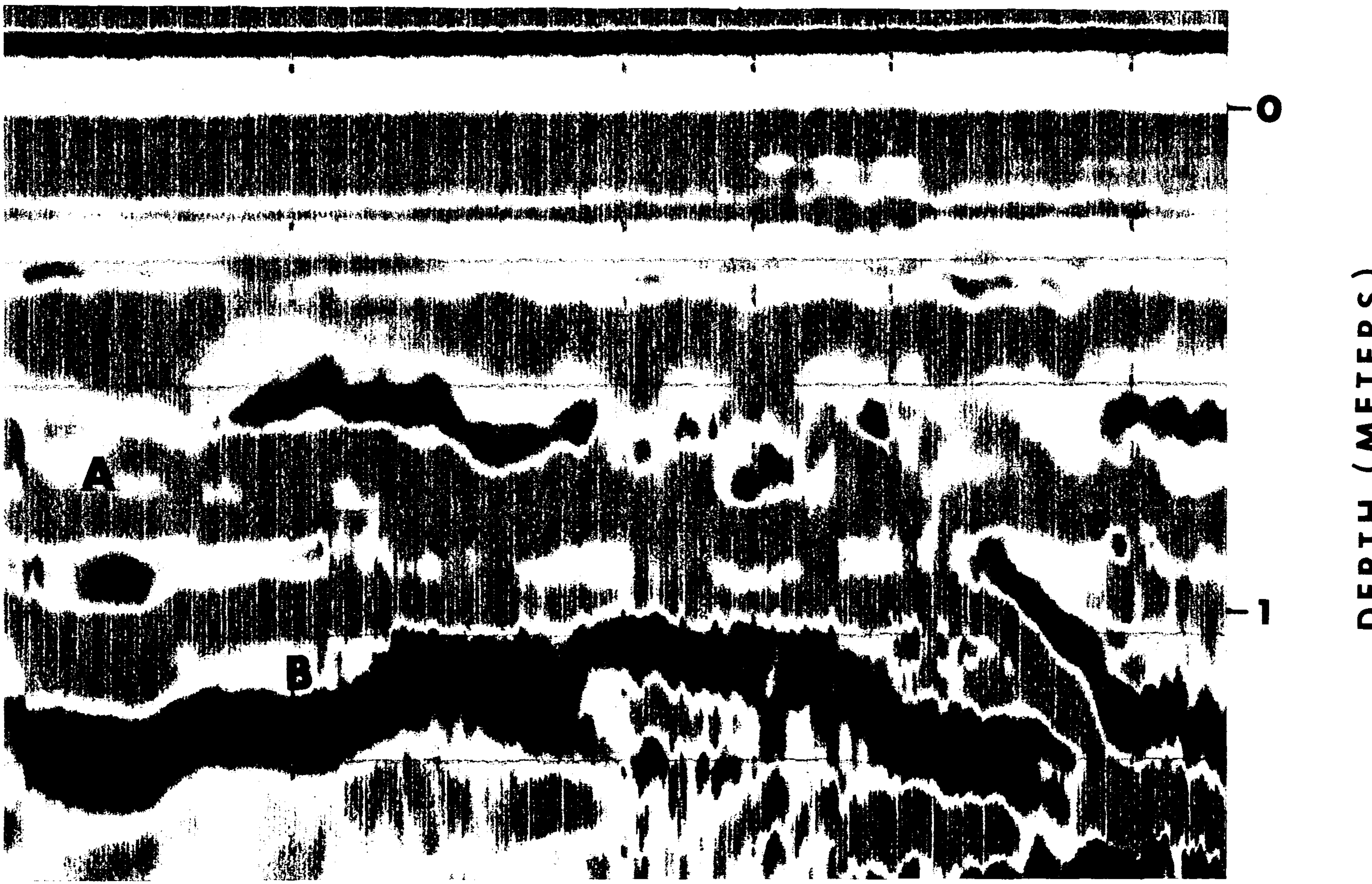
AREA OF DOWNER AND SASSAFRAS SOILS

FIG. 12



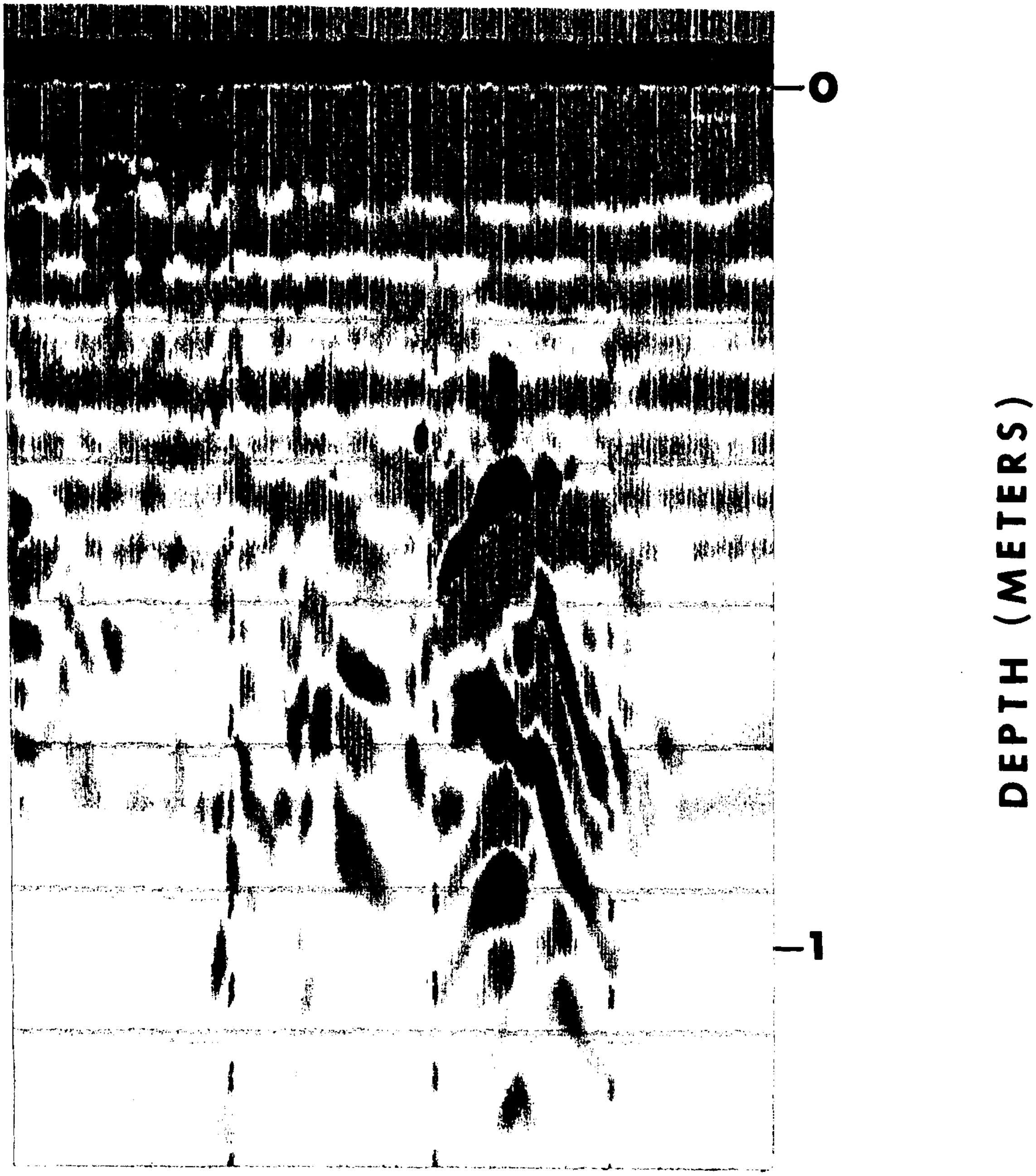
AREA OF CHILLUM SOILS

FIG. 13



AREA OF KEYPORT SOILS

FIG. 14



BURIED FOUNDATION