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United States Department of Agriculture

Soil Conservation Service

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Subject: SOILS - Ground-Penetrating Radar (GPR) Trip Report - New York

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To: Paul A. Dodd, State Conservationist
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During the period of June 18-30, 1984, a field study was made in New York to familiarize personnel from the Soil Conservation Service, colleges and universities, and cooperating agencies with the ground-penetrating radar (GPR). The performance of the system was evaluated on a wide variety of soils throughout New York. Field studies and demonstrations were held in Columbia Oneida, St. Lawrence, and Allegany Counties.

Participants included: (Please see attached list.)

We were pleased that all commitments schedule in the initial itinerary report were met. Field soil scientist had made all necessary preparations for the GPR field work. Generally, depending on the complexity of soils, two to four sites were studied each day. Rain hampered field work on the first day of studies in Columbia County, but did not limit the results.

The equipment utilized during this field trip was the SIR System-8 with microprocessor, the ADTEK SR-8004H graphic recorder, the ADTEK DT-6000 tape recorder. The 80, 120, and 300 MHz antennas were used. The equipment operated well with one exception. A short developed in the Model 705DA transceiver after is was exposed to excessive vibrations and moisture during field work. This transceiver was shelved and a back-up transceiver from the 80 MHz antenna was utilized during the remainder of the field trip.

The performance of the GPR ranged from excellent to poor depending on site conditions. Generally, the radar probes deeper and provides the most detailed information in low conductivity earthen materials such as in areas of coarse and moderately coarse textured soils or limestone bedrock. In the moderately fine textured soils of the Ontario Lowlands, and Allegany Plateau, probings were generally less than 2 meters. The high conductivity and large surface area of shale have mitigating affect on the radar's performance. The probings in areas of moderately-fine textured soils, which had weathered from shale, were generally less than 1 meter. The present radar system is essentially ineffectual in areas of clayey soils having appreciable amounts of expanding 2:1 lattice clays. In an areas of Rhinebeck soil, the probing depth was less than 50 centimeters.

On the basis of limited field work, the GPR appears to be a very useful tool for differentiating bedrock from rock fragments in many areas of the Applachian Highlands and probably the Adirondacks. Each soil environment imposes limitations on the system's effective probing depth. Acknowledging these limitations, the radar can be used successfully in New York to study earthen material whenever the soil or depth of interest is within its capacity.

The enclosed report summarizes some of the major factors affecting the GPR's operation and interpretations in New York. As results from some areas were similar, this report does not address all sites or soils studied during this extensive investigation. Comments and observations from each site have been made on a complete record of the graphic profiles. This record has been returned to Fred Gilbert under a separate cover. As all transects were taped, additional copies of the graphic profiles are available upon request.

I wish to pass along my personnel thanks for the enthusiasm and cooperation that all members of your staff extended to me. The trip was enjoyable and exceptionally well organized and conducted.

James A. Doolittle

JAMES A. DOOLITTLE
Soil Specialist (GPR)

Enclosures

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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.

# SOILS INVESTIGATION

The New York field study of the ground-penetrating radar (GPR) included a wide geographic area and variety of soils. Representative soils were profiled with the GPR in areas of Columbia, Oneida, St. Lawrence, and Allegany Counties. Soils profiled and discussed in this report are: Blasdell (loamy-skeletal, mixed, mesic Typic Dystrochrepts), Caszenovia (fine-loamy, mixed, mesic Glossoboric Hapludalfs), Conesus (fine-loamy, mixed, mesic Glossoboric Hapludalfs), Farmington (loamy, mixed, mesic Lithic Eutrochrepts), Galwey (coarse-loamy, mixed, mesic Typic Eutrochrepts), Howard (loamy-skeletal, mixed, mesic Glossoboric Hapludalfs), Pittstown (coarse-loamy, mixed, mesic Typic Dystrochrepts), Rhinebeck (fine, illitic, mesic Aeric Ochraqualfs), Shaker (coarse-loamy over clayey, mixed, nonacid, mesic Aeric Haplaquepts), and Stockbridge (coarse-loamy, mixed, mesic Dystric Eutrochrepts).

In many of these soils, the utility of the GPR was reduced by (1) restricted probing depths and (2) the absence or week expression of horizons or pedogentic features.

Generally, the probing depth of the GPR was less than 2 to 3 meters in moderately-coarse textured soils, 1 meter in moderately-fine textured soils, and less than 0.5 meters in fine textured soils. For those who have read articles on the GPR, these results may appear discouraging. But the examples sited in the literature are mostly from areas in which the GPR has performed exceptionally well. It is uncertain whether many of the reported depths were consistently achieved, and the imagery was clear and usuable. Some reported probing depths may represent the lone or most significant exception to an otherwise more restricted trend in observable depths.

The maximum probing depth of the GPR is, to a large degree, determined by the effective conductivity of the soil. Soils having high effective conductivities rapidly dissipate energy and restrict the radar's probing depth. The principal factors which influence the conductivity of soils are: (1) the degree of saturation, (2) the amount and type of salts in solution, and (3) the amount and mineralogy of clays.

Moisture content is the primary determiner of conductivity. Conductivity is essentially an electrolytic process which takes place through moisture-filled pores. As the degree of saturation is increased, the rate of signal attenuation is increased and the probing depth is restricted. Many areas visited during this field trip had experienced above average precipitation and the soils were moist. Returning to many of these sites during a drier periods would probably increase the probing depth and the resolution of subsurface features.

Conductivity is directly related to the concentration of dissolved salts in the soil solution. Soils formed in sediments weathered from shale or carbonate rocks will contain more salts in solution that soils developed from acid crystalline rocks. Consequently, in similar soils with equal moisture contents, the probing depth of the GPR should be greater in the Adirondacks or Appalachian Highlands than in the Allegany Plateau or Ontario Lowlands.

Ions absorbed on the surface of clay particles can become partially dissociated or exchanged, and contribute to the conductivity of the soil. Generally, smectite and vermiculite clays have high cation-exchange capacities/(CEC) and will produce more conductive soils than will kaolinite or gibbsite. The electromagnetic properties of many soils, such as Rhinebeck, are strongly influenced by the amount and type of clay minerals present.

As a result of the shortness of time since the last glaciation, evidence of alteration is weakly expressed in many of the profiled soils. Though having a wide range in particle-size classes, and physiographic and topographic settings, these soils belong to only four suborders: Aquepts, Ochrepts, Aqualf, and Udalfs. All have ochric epipedons and either cambic or argillic horizons. Unfortunately, only the abrupt clay bulge of the argillic horizons is discerned by the GPR. As a general rule, the more abrupt an interface and the greater the electromagnetic gradient across an interface, the stronger the reflected signals. In the Inceptisols, the boundary of the surface or subsurface layers with the subsoil was too gradual and lacked sufficient contrast for the radar to detect. Cambic horizons are altered horizons, but the degree of alteration is generally too slight and the electromagnetic gradient too gradual for the radar to detect.

Argillic horizons were fairly well expressed on most graphic profiles of Alfisols. However, the high clay content of the argillic horizons and the underlying substrata caused the rapid and complete dissipation of the radiated energy in most moderately fine or fine textured soils. As a result of the high rates of signal attenuation in the argillic horizons, no further underlying, subsurface information was attained from most profiled Alfisols.

The GPR is a subsurface interface radar. It has been specially designed to provide information concerning subsurface conditions. Some surface conditions or features, such as the presence or absence of an organic root mat, barren soil, or shallow puddles of water have been inferred from the graphic imagery. In some areas, ochric epipedons have been distinguished from umbric or mollic epipedons. But in New York, most surface and near-surface features were masked by the strong amplitude of the surface reflection and its reverberated signals.

The shallowest depth at which an interface can be detected is controlled by the type and condition of the soil material and by the length of the transmitted pulse. With the 120 MHz antenna, the shallowest depth at which an argillic horizon has been discerned in moderately fine textured soil is approximately 7 to 10 inches.

In any GPR field study, 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 and able to penetrate to the desired depth. Provided sufficient energy is available to penetrate to the desired depth, a high frequency antenna will produce better resolution of subsurface features. For deeper depths of penetration or work in high-loss mediums, the lower frequency antennas are preferred because of their greater powers of radiation.

In most of the soils examined, the 120 MHz antenna provided ample depths of penetration and clear resolution of soil features. The 80 MHz antenna was tested at several sites and used extensively is areas of the finer textured Rhinebeck soils. Though the 80 MHz antenna displayed a greater potential to probe to deeper depths than the 120 MHz antenna, depth was not a critical factor when comparing the utility of these antennas for soil investigations. With the 80 MHz antenna, near surface or closely spaced interfaces were poorly resolved and many appeared to have been "averaged" together by its boarder bandwidths. However, in areas of Rhinebeck soil, the 80 MHz antenna provided the best balance of resolution and depth of penetration (generally less than 20 inches). As the 120 MHz antenna provided clear resolution of most subsurface features and the soils were recognized as being high loss medium, no attempts were made in this study to use to 300 to 500 MHz antennas.

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 uniform soil and 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 optimal settings.

The control and recording units are adjusted to achieve the most optimal settings at the beginning of each transect. No single combination of range gain or filtration settings is suitable for the diverse soil conditions encountered along transect conducted in areas of complex soilscapes. Along several transects, the poor quality of subsurface images can be attributed to wetter soil conditions, higher clay content, and the radar being temporarily out of optimal adjustment or pressed beyond its limits.

The SIR 4800 control unit and the ADTEK DT 6000 tape recorder were designed to satisfy the need for variable range gain and filtration settings. Transect recorded on magnetic tapes can be played back with range gain and/or filtration settings being continuously adjusted to cope with variations in soil conditions. Though time consuming, this procedure enhances the imagery on some graphic profiles.

The depth scale on all graphic profiles is a time scale. This time scale can be converted into a depth scale once the average rate of signal propagation through the soil has been determined or the depth to an interface is confirmed by auger borings.

Generally, the depth scales are accurate within each map unit provided the soils are similar and are on similar positions in the landscape. When extended across soil boundaries, drainage classes, or slope positions, depth scales can only be close approximations and should not be relied upon for highly precise measurements unless the number of ground-truth observations is increased.

The first soil examined with the GPR in New York was Pittstown. In Figure 2, the effective probing depth is limited to the upper part of the soil profile above the dense till. Moist soil conditions, high shale content, and heavier than expected soil textures were responsible for the rapid rates of signal attenuation and the restricted probing depth. With both the 80 and 120

MHz antenna, the radiated energy was completely absorbed and dissipated within the upper part of the dense till (A). In the lower part of Figure 2, only weak reverberated signals from near-surface features or random noise is visible on the graphic profile.

The lower part of Figure 2 represents a zone of no signal return. Similar zones have been referred to in the literature as "white-out" areas. White-out areas result from the complete dissipation of the radar signal, the absence of "significant" subsurface interfaces, or both.

The imagery of the interface (A) separating the solum from the dense till is not uniformly expressed across this profile. Lateral changes in electromagnetic and soil properties along interfaces 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. Abrupt changes in texture or bulk density across this interface would produce images having wide dark bands and narrow white bands (see A). At "B", the white bands are wider and the dark bands are narrower. Here, the electromagnetic gradient across this interface is less and has resulted in weaker signal amplitudes and wider white bands.

An auger hole is apparent about "C." The auger hole can be identified by its location at a reference site (dashed vertical lines), the draw-down of the interface's imagery at the auger hole, and the reverberated signal of the hole itself.

GPR imagery consists of both positive and negative signal components. In all of the enclosed figures, the signal components have been printed as black (positive) and hatchured (negative) bands. Differentiating or highlighting the signal components can, in many instances, assist the interpreter identify and trace the lateral extent of horizons and strata. With highlighting, it is apparent that several differing but closely spaced interface signals have been superimposed in the upper part of this figure. Note the sporadic occurrence of several thin, positive signal components above and to the left of "B." Superimpositioning can be either an additive or subtractive process.

An area of Blasdell soil is depicted in Figure 3. The Blasdell soil occurs on outwash plains and has formed in shaly glacio-fluvial deposits. In Figure 3, the stratified nature of these deposits are apparent. Variations in grain size and shale content are responsible for the strong electromagnetic gradients which produced these images.

On the basis of their graphic signatures, the underlying strata can be placed into three groupings: A, B, and C. The uppermost deposit of shaly alluvium, A, consist of multiple layers having strongly contrasting grain sizes or shale content. Though evidence of interfingering is apparent (D), these strata are essential horizontal. B represents an intermediate zone of closely similar strata. The images of the strata within this group are weakly expressed and are strongly inclined. The electromagnetic gradients separating the strata of this group are too weak or gradual for the radar to detect. A basal group, C, is continuous across the graphic profile. Group C is composed of inclined, strongly contrasting deposits.

The cancelation of two or more superimposed signals is responsible for the "white-out" area at "D." Similar areas of interference are evident on this graphic profile.

The GPR performed well in this area of Blasdell soil. The GPR identified an area that had been filled with dredge deposits from a near-by pond. The extent and thickness of the fill are interpretable from the graphic profile.

The usefulness of the GPR system in similar areas of glacio-fluival deposits will be restricted more by the quantity and quality of ground-truth measurements than by the medium. The numerous strata which appear on the graphic profile have created an interpretative nightmare. A large quantity of ground-truth data would be required to accurately identify each layer. As all interfaces appear in shades of gray to black and are closely similar in their graphic expression, identification is problematic. But, maybe, the identify of each strata is not germane to purpose of the investigation. Perhaps, only the general nature of the deposit or the depth to and the lateral extent of a major interface, such as the interface which separates areas A and B in Figure 3, is required.

In many areas of the Appalachian Highlands or the Allegany Plateau, it is exceedingly difficult to examine soil profiles with conventional soil surveying tools. Rock fragments limit the effectiveness of spades, bucket augers, and hand or mechanical probes. Soil scientists are tired and frustrated, and survey work is slowed when these tools are repeatedly stopped by cobbles or boulders. Often, an observation site consists of several holes of partial information with each hole being restricted by either a rock fragment or bedrock. At most sites and unless a backhoe is available, it is uncertain whether the probing was halted by a rock fragments or bedrock. In many areas inferences or broad assumptions must be made concerning the depth to bedrock and the composition of map units.

A more comprehensive, faster, and less labor intense method is needed to determine the depth to bedrock and its variability within map units or at specified sites. The GPR appears to have the potential to rapidly assess the depths to bedrock in many areas of the Appalachian Highlands.

Figure 4 is from an area of Farmington and Stockbridge soils. The limestone bedrock is easily identified by its multiple, sub-parallel bedding planes (A). The bedding planes appear to be strongly inclined and approach the surface at acute angles. The actual angle of inclination has been distorted by the vertical exaggeration of the graphic profile. In Figure 5, the vertical exaggeration is about 10 to 1. This distortion does not affect the accuracy of the depth measurements.

In Figure 4, parallelism of the bedding plane ends as the surface is approached and the influences of weathering becomes more intense. In response to the various processes of weathering, the bedrock layers can be observed to become fractured, segmented, and translocated parallel with the soil surface. The soil/bedrock interface can be delineated by connecting the closest points to which each subparallel bedding plane approach the soil surface prior to becoming segmented and moved downslope. Insular clusters of segmented rock. fragments (B) can be seen in the upper part of this graphic profile.

Figure 5 is from an areas of Cazenovia soil. The moderately fine texture (27 to 35 percent clay) and the high shale contents of the till restricted the probing depth of the GPR to less than 1 meter. The depth to the firm till (A) corresponds with the depth to the clay bulge in the argillic horizon. In Figure 5, the depth to this interface ranges from 24 to 37 inches. This interface can be continuously traced along the transect line. Variable not only in depth, but in expression, the image of this interface grades from gray to black. Colluvial deposits in a toeslope area near "B," are faintly expressed in the upper part of this section of the profile.

Cazenovia and Conesus soils belong to the same family: fine-loamy, mixed, mesic Glossoboric Hapludalfs. Profiles of these soils (Figure 5 and 6) accurately verified the presence, depth, and lateral extent of the argillic horizons; the principal diagnostic feature of all Alfisols. Generally, the GPR has not been effective in distinguishing the decrease in clay content which, by definition, occurs in some Hapludalfs. Often, as in Cazenovia soil, a decrease in clay content with increasing soil depth could not be verified with the GPR with a high degree of accuracy. In most GPR field studies, the decrease in clay content with increasing soil depth either did not occur or was too gradual for the GPR to distinguish.

Interfingers of albic material lack sufficient horizontal and vertical dimensions to be distinguished with the current system in high loss mediums. The area of Conesus soil lacked glossic characteristics.

Conesus soil consist of moderately fine textured till (A) overlying coarser texture outwash (B). In Figure 6, the contact between these two dissimilar deposits has been highlighted.

Till is composed of numerous rock fragments of all grain sizes. These rocks represent point reflectors and produce a unique appearance on graphic profiles (see A in Figure 6). The nonsorted, nonstratified characteristics of till produces a mottled appearance composed of numerous, randomly spaced, short, segmented images. With increasing soil depth, the radar will discern only the larger of these reflectors. The apparent absence of cobbles in the lower part of the till (C) is a result, in part, of these rock fragments passing below a critical size to depth ratio.

The outwash (B) is composed of stratified deposits. The strata are sorted and produce subparallel images. In Figure 6, the topography of the till/outwash contact is punctuated by two kettle holes.

Figure 7 is from an area of Howard soil. Although the Howard soil is similar to Cazenovia and Conesus soils, its graphic profile appears more uniform in expression. The argillic horizon (A) and a stone line (B) are the two strongly expressed subsurface layers apparent in this figure. This profile is distinguish by the exceptional uniformity of the graphic images. The GPR has verified the non-variable nature of the diagnostic layers and has documented the inferred similarities of soil type and characteristics across a delineated area.

A thin continuous stone line (B), a product of an earlier erosional cycle, parallels the soil surface and the argillic horizon. The stone line is composed of numerous, closely spaced point reflector. In portions of this profile, the reflections from several closely spaced stones have been superimposed and form a distinct plane. In other portions, the individual hyperbolic patterns from larger or more isolated rocks are evident.

A study was conducted to determine whether the GPR could locate drainage tiles in an areas of Minoa (coarse-loamy mixed, mesic Aquic Dystric Etrochrepts) fine sandy loam. Within the study area, soil type and soil characteristics are highly variable. The dominant soil along the transect was Shaker. In this area of Shaker soil, the GPR determined the depth to, and traced the lateral extent of the underlying clayey lacustrine sediments.

In Figure 8, the boundary (A) separating the coarse loamy and clayey lacustrine sediments has been highlighted. The three bands occurring below "A" are oscillation of the reflected signal form the same interface, the lithologic discontinuity. These bands usually occur in groups of three and limit the ability of the GPR to discriminate shallow or closely spaced interfaces.

The radar signal was rapidly dissipated by the underlying clayey lacustrine sediments of Shaker soil. In Figure 8, several widely spaced point reflectors (B) occur at a uniform depth of about 20 inches. These reflectors were, at first, believed to be the buried drainage tiles. After excavating several sites, the point reflectors were interpreted to be clusters of rocks. The inability of the GPR to distinguish buried drainage tiles was attributed to the high-loss nature of Shaker soil and the similar reflective qualities of cobbles and drainage tiles.

Figure 9 illustrates the inability of the present GPR system to penetrate highly conductive mediums. The epitome of an inhospitable soil environment for the GPR, Rhinebeck soil has an aquic moisture regime, is high base, and is fine textured with appreciable amounts of smectite clays.

In Figure 9, interpretations are very limited and at best, speculative. The soil/limestone bedrock (A) contact is weakly and intermittently expressed. Signal processing did not significantly enhance the imagery of this contact. The effective depth of penetration was less than 16 inches with the 80 MHz antenna.

In Figure 10, the soil/limestone bedrock interface (A and B) is apparent between depths of 1.7 and 8.3 feet. This transect was conducted in an area of coarser textured Galway soil which border the Rhinebeck soil. The affects of improved drainage and reduced clay content are readily apparent.

The intensity of the reflected signal from the soil/bedrock interface is reduced over time by the processes associated with weathering. As the bedrock surface weathers, this interface becomes less abrupt, more gradational, and more closely similar in electromagnetic properties with the overlying soil. Reflected images from deeply weathered zones of saprolite (B) appear on graphic profiles in less intense shades of gray. Deeper, essentially unweathered bedding planes (C) retain their contrasting properties and appear as distinct, black images.

In Figure 10, the soil/bedrock contact is fairly well expressed. However this contact was positively identified at only 64 percent of the observation sites. In the other 36 percent, interpretations were more difficult as a result of (1) the equipment being temporarily out of optimal adjustment for a particular site; (2) the equipment being pushed beyonds its limits; or (3) unfavorable ground conditions.

Ground-truth measurements provide the basic data on which radar imagery is scaled and compared. This data can and often does contain an inherent degree of measurement error. Measurement error can be attributed to the habit of rounding off numbers, nonvertical probing or measurements, and slight spatial discrepancies between the site of measurement and the track of the radar.

Antennas have a fairly broad radiation pattern within the ground and average the depth to an interface across the area of radiation. Theoretically, the radiation pattern is conical in shape with the apex of the cone at the center of the antenna.

Slight discrepancies often exist between soil boring data and the depth scaled on the graphic profile. In order to document the accuracy of the GPR system a site was selected (near Figure 10) to compare the scaled radar imagery with ground-truth auger data.

The measured depth to the soil/bedrock interface, the scaled depth of the radar imagery, and the difference between these measurements are listed in Table 1. The average deviation between soil boring data and scaled radar imagery is 0.3 foot (3.5 inches). The deviation between scaled radar imagery and ground-truth auger data are: within 12 inches at all sites; within 6 inches in 70 percent of all sites; and within 1.3 inches in 60 percent of all sites. The match between ground-truth data and scaled radar imagery conforms with observations made in areas of irregular soil horizons or layers in other states.

Results similar to these obtained with the GPR in the Ontario Lowlands were achieved in the soils profiled in the Allegany Plateau. In the Allegany Plateau, probing depths were less than 1 meter and were restricted by essentially the same factors, high shale contents and moderately fine textures.

TABLE 1

Deviation Between Measured Depths and Scaled Radar Imagery

| | Reference Points (in feet) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Method of Measurement | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Depth to Rock | 3.25 | 1.65 | 1.45 | 0.8 | 1.0 | 0.8 | 0.8 | 1.6 | 1.6 | 1.3 |
| Scaled Depth | 3.25 | 2.20 | 1.56 | 0.8 | 0.9 | 0.8 | 0.8 | 2.1 | 2.3 | 2.3 |
| Absolute Deviation | 0.0 | 0.55 | 0.11 | 0.0 | 0.1 | 0.0 | 0.0 | 0.5 | 0.7 | 1.0 |

Average Deviation: 0.30

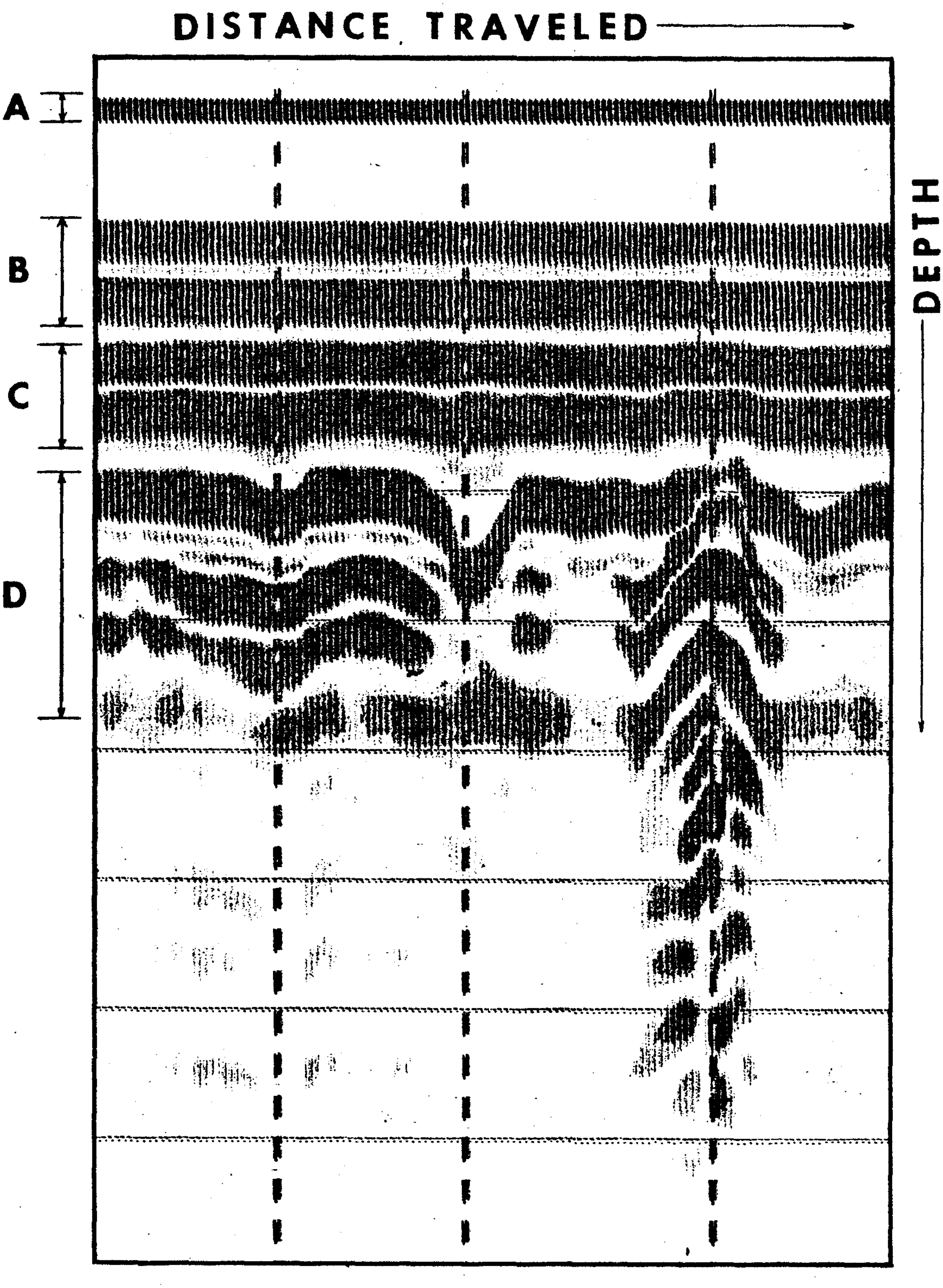
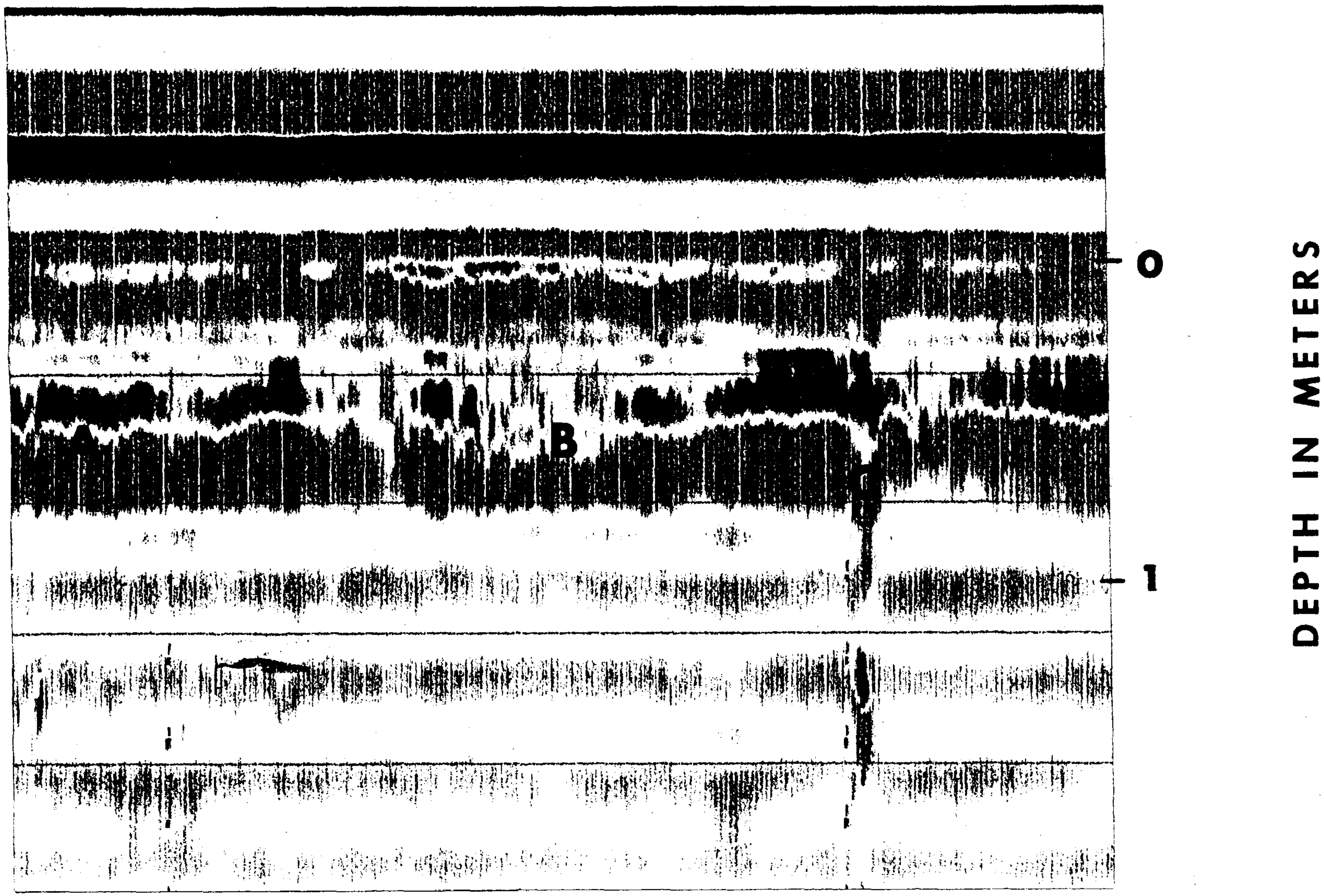



FIG. 1

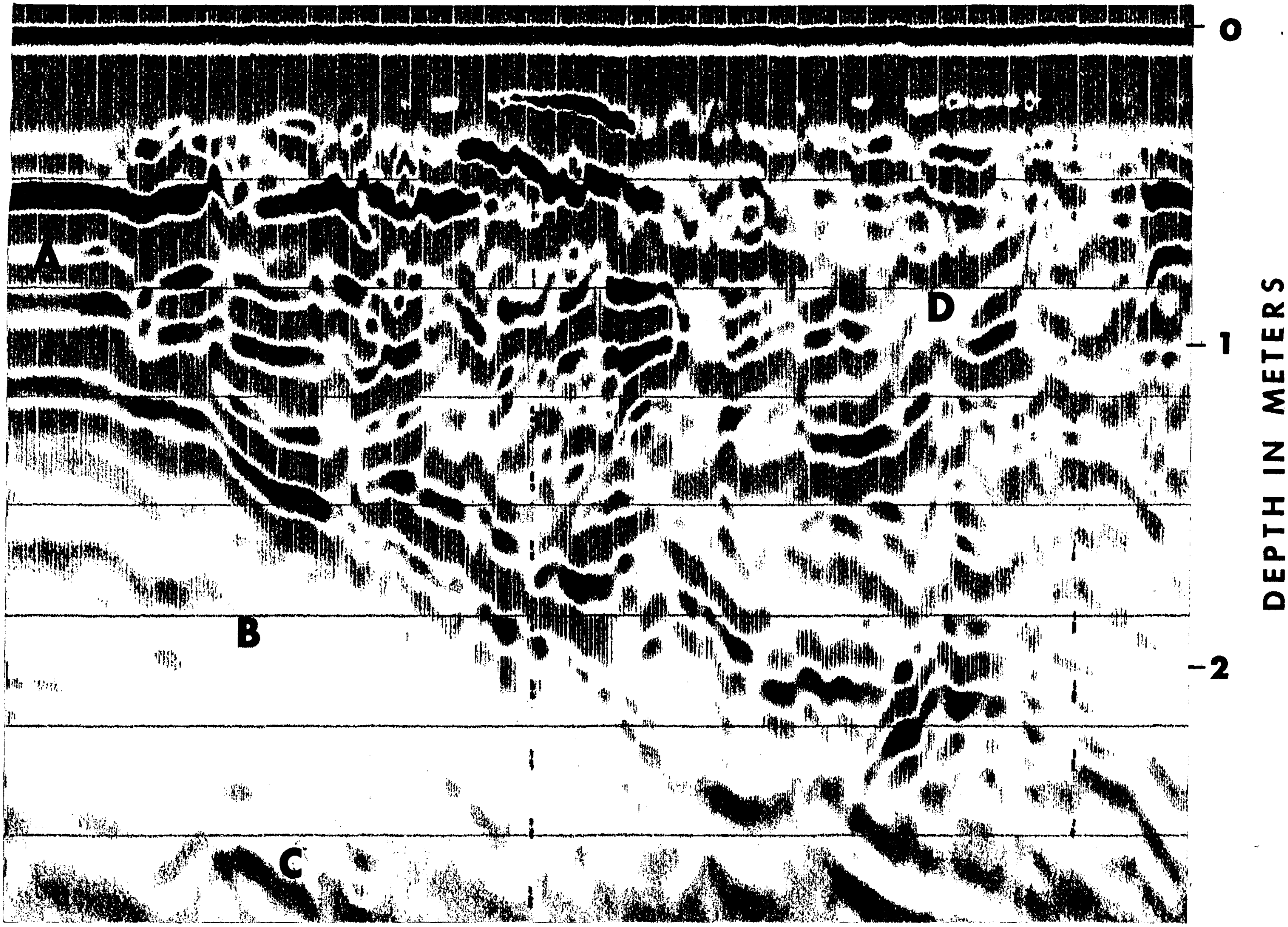
A GRAPHIC PROFILE

FIG. 2



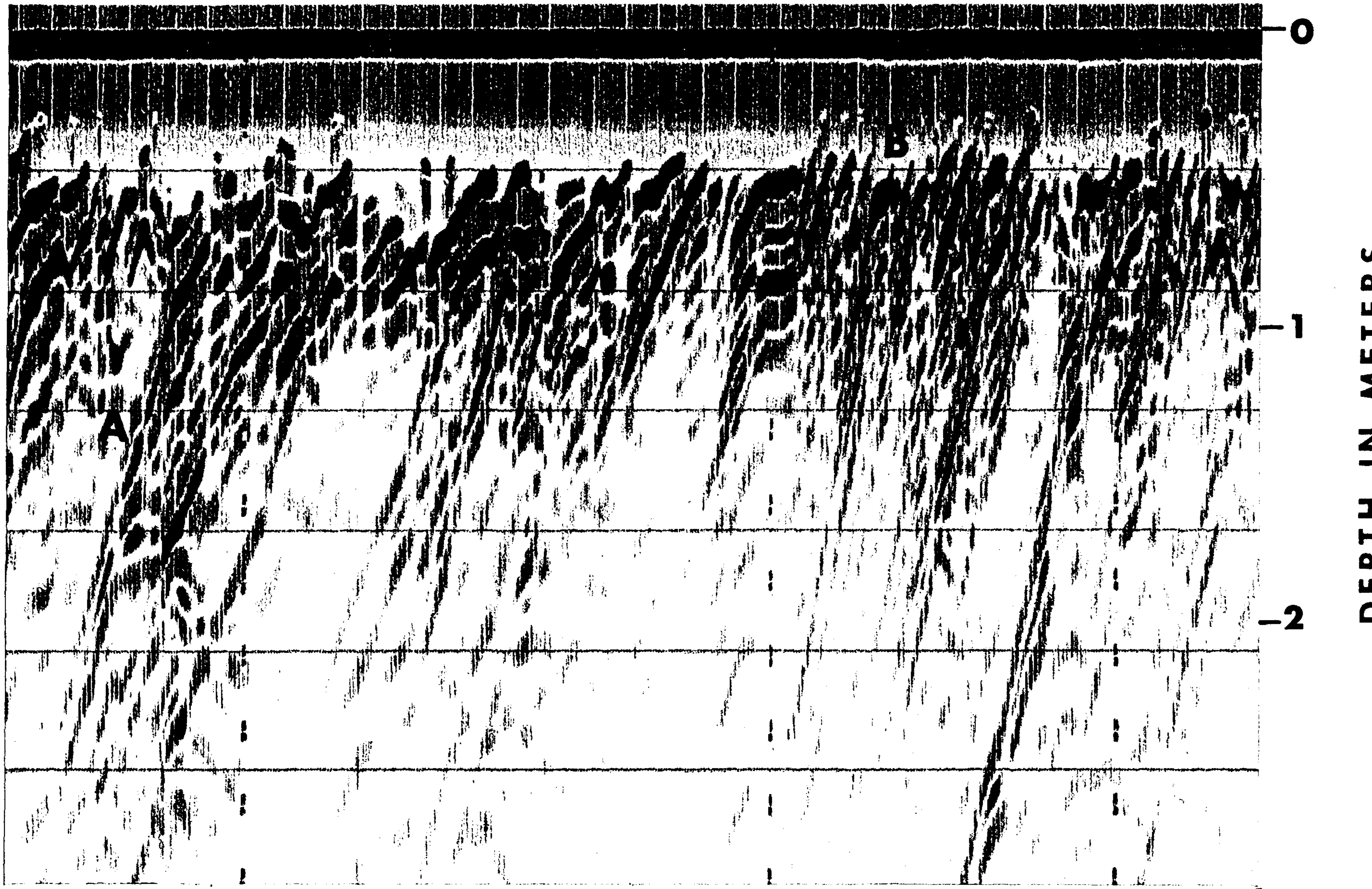

DEPTH TO DENSE TILL
PITTSTOWN SOILS

FIG 3



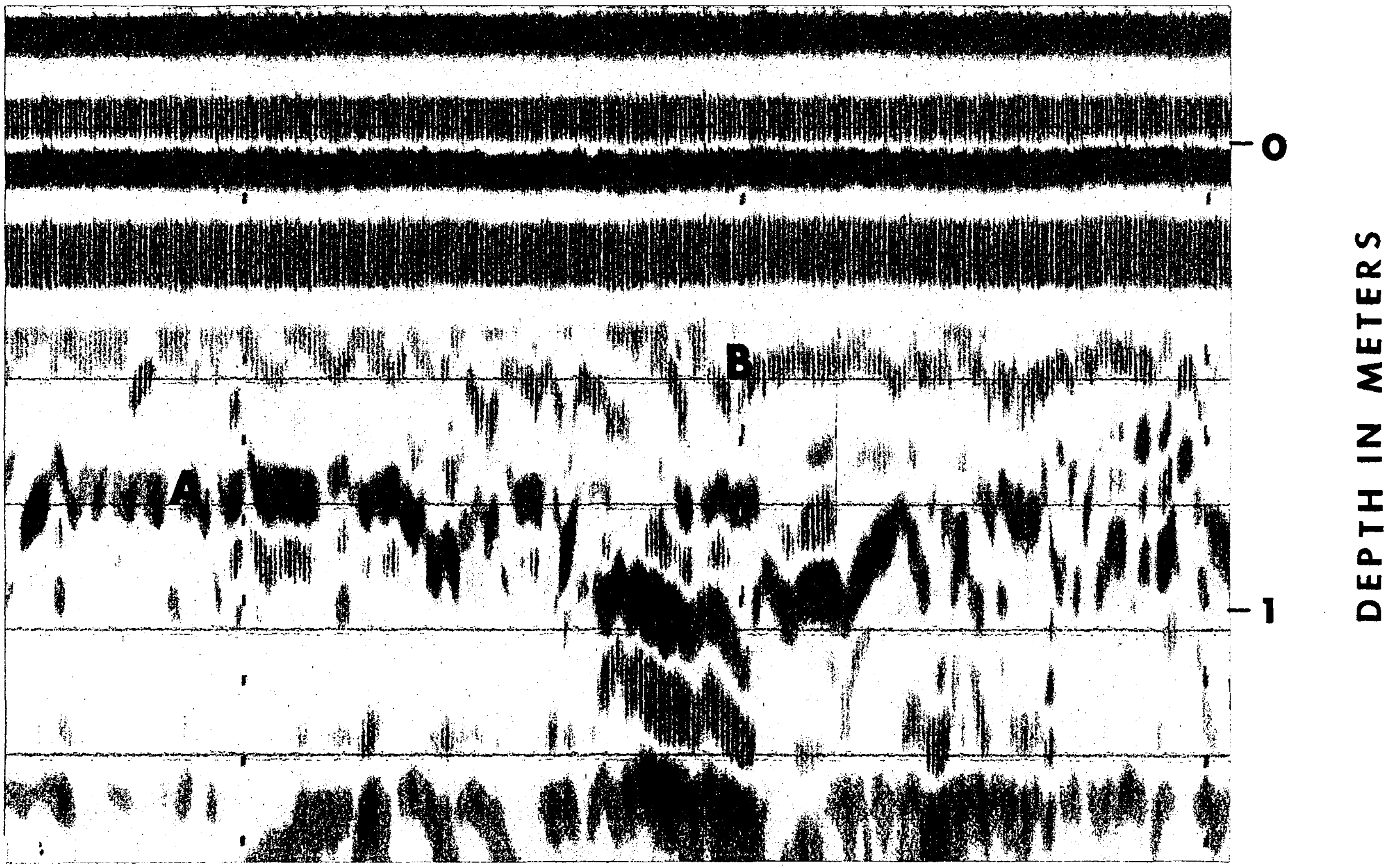

SHALY ALLUVIAL DEPOSITS
BLASDELL SOILS

FIG. 4




LIMESTONE BEDROCK
FARMINGTON-STOCKBRIDGE SOILS

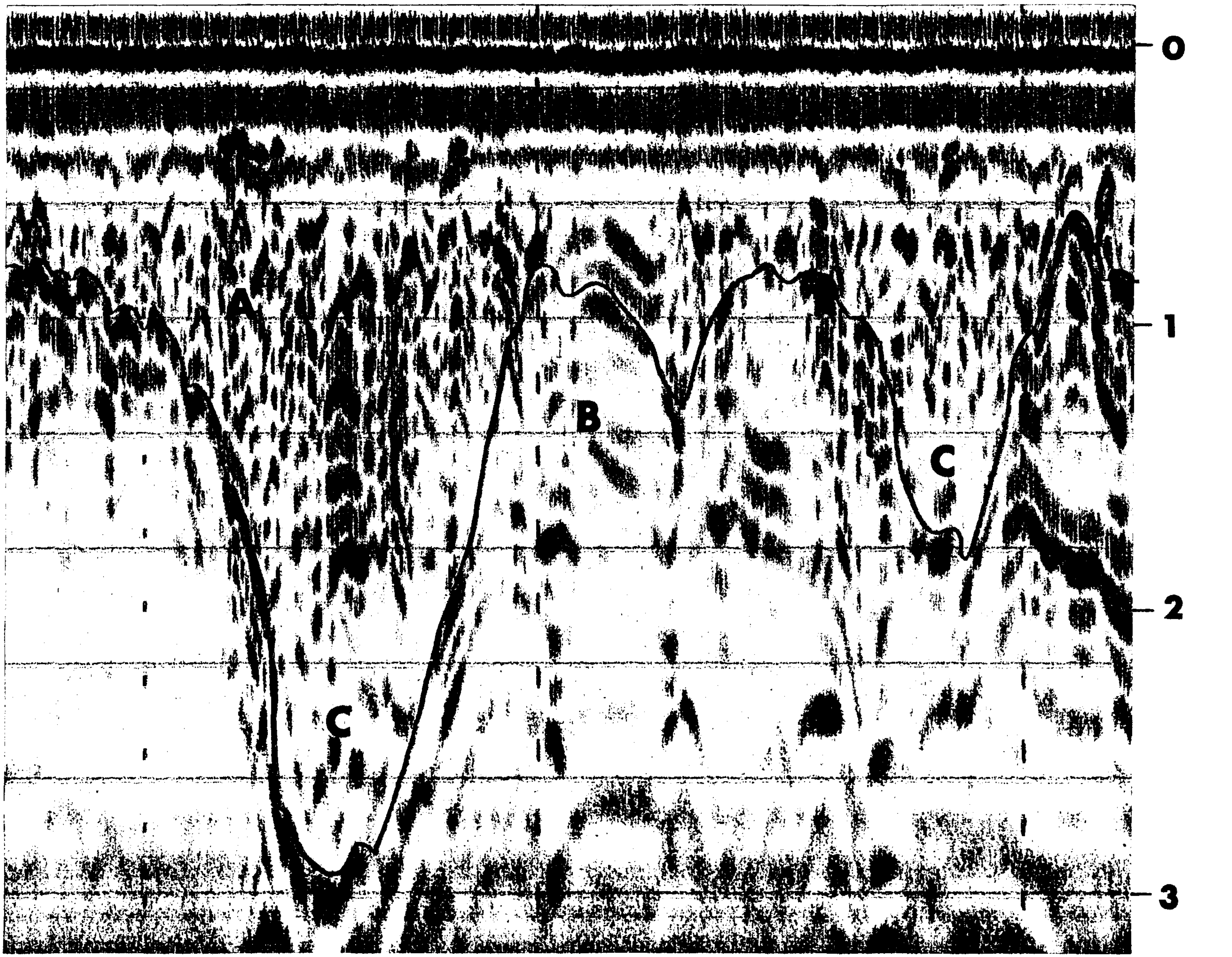
FIG. 5




DEPTH TO FIRM TILL

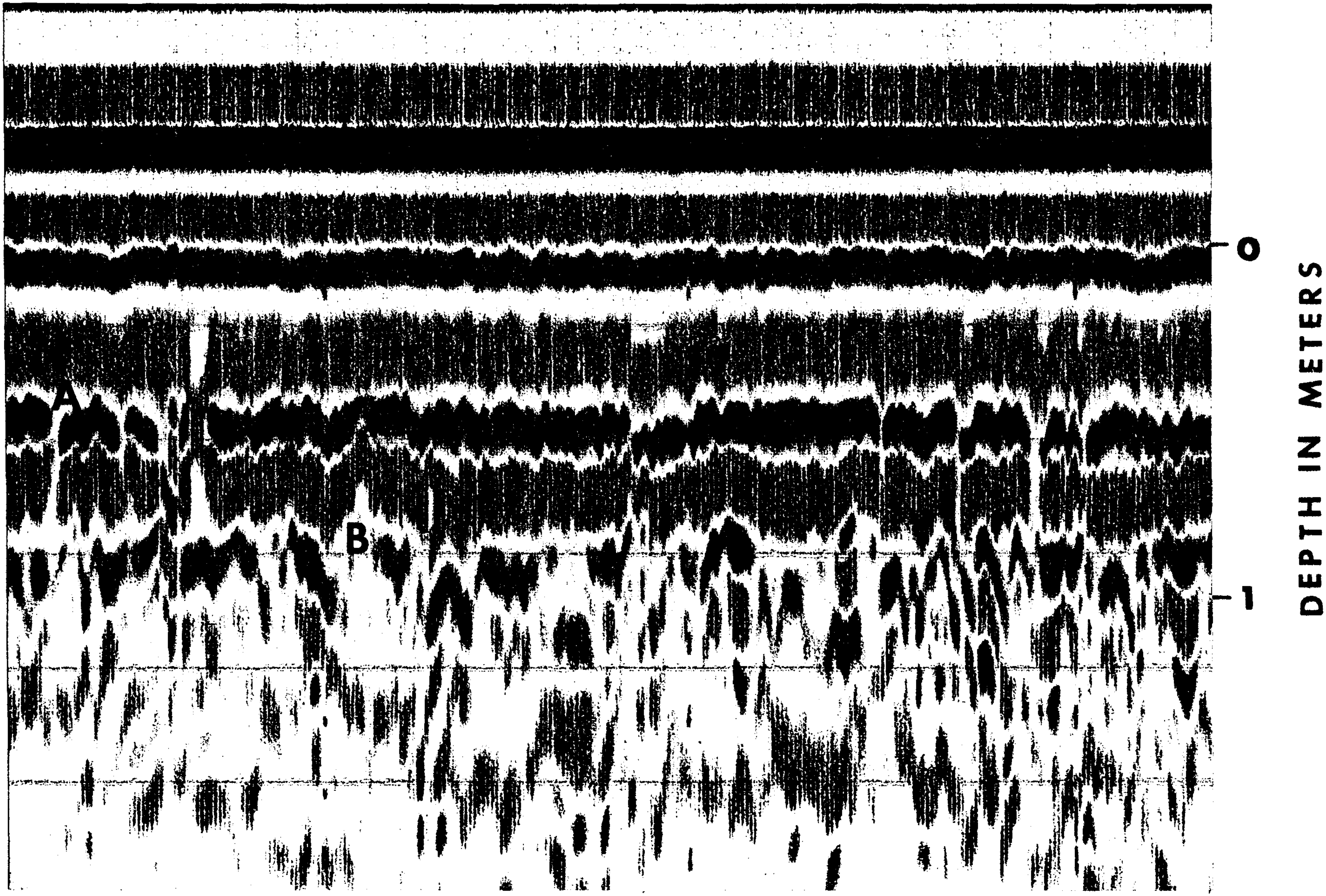
CAZENOVIA SOIL

FIG. 6



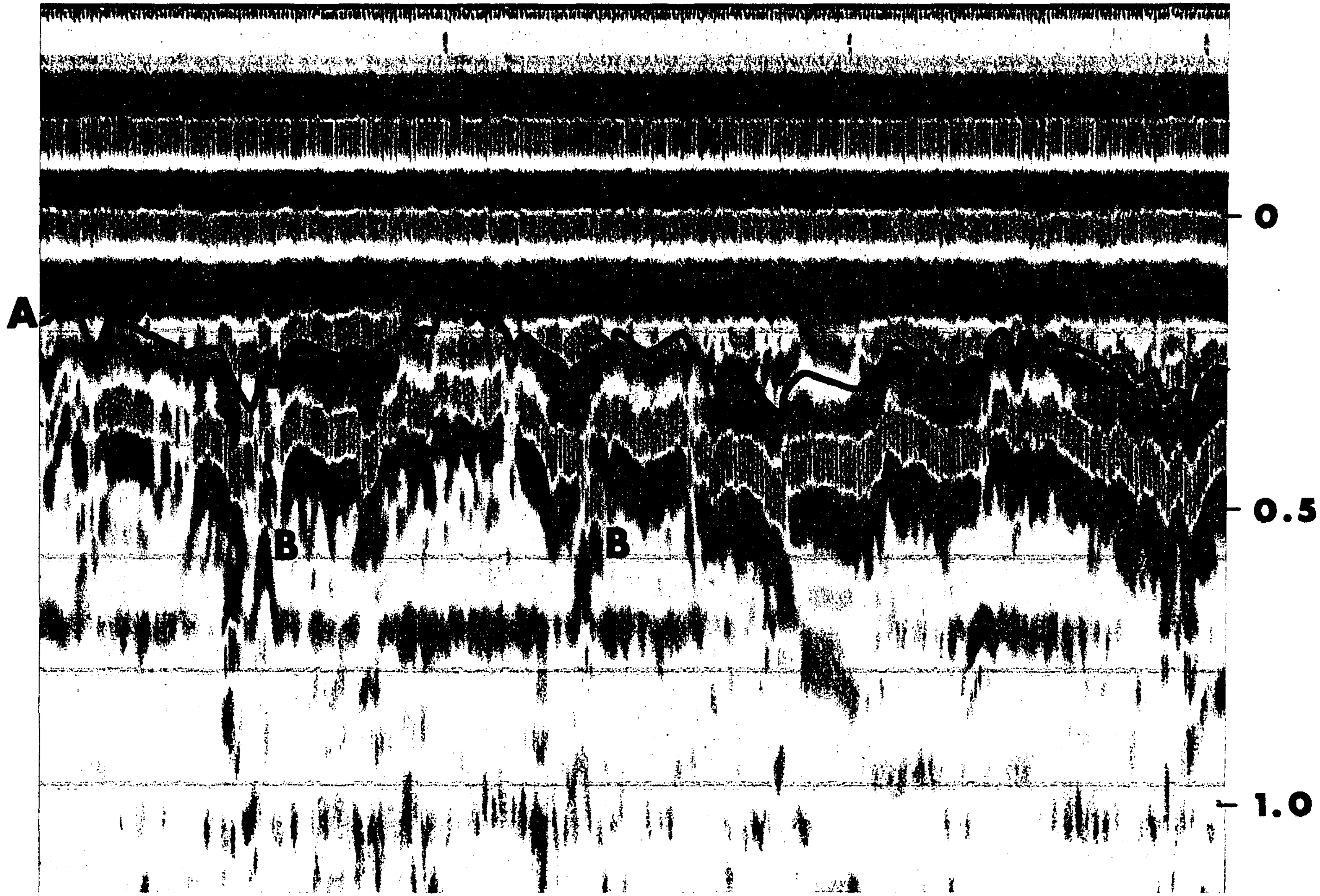

DEPTH TO GRAVEL
CONESUS SOILS

FIG. 7



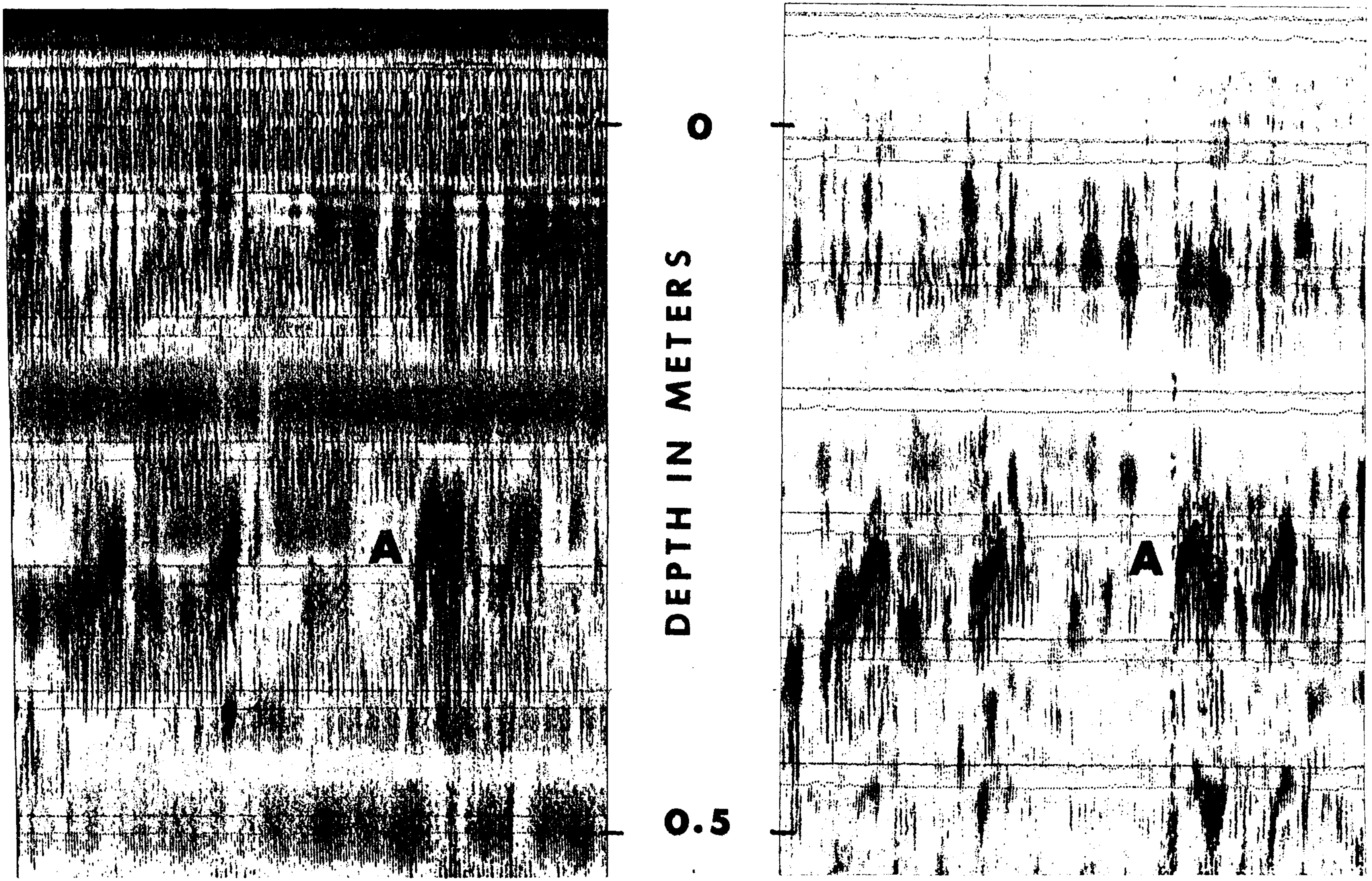

DEPTH TO GRAVELLY MATERIAL
HOWARD SOIL

FIG. 8




DEPTH TO CLAYEY SEDIMENTS
SHAKER SOIL

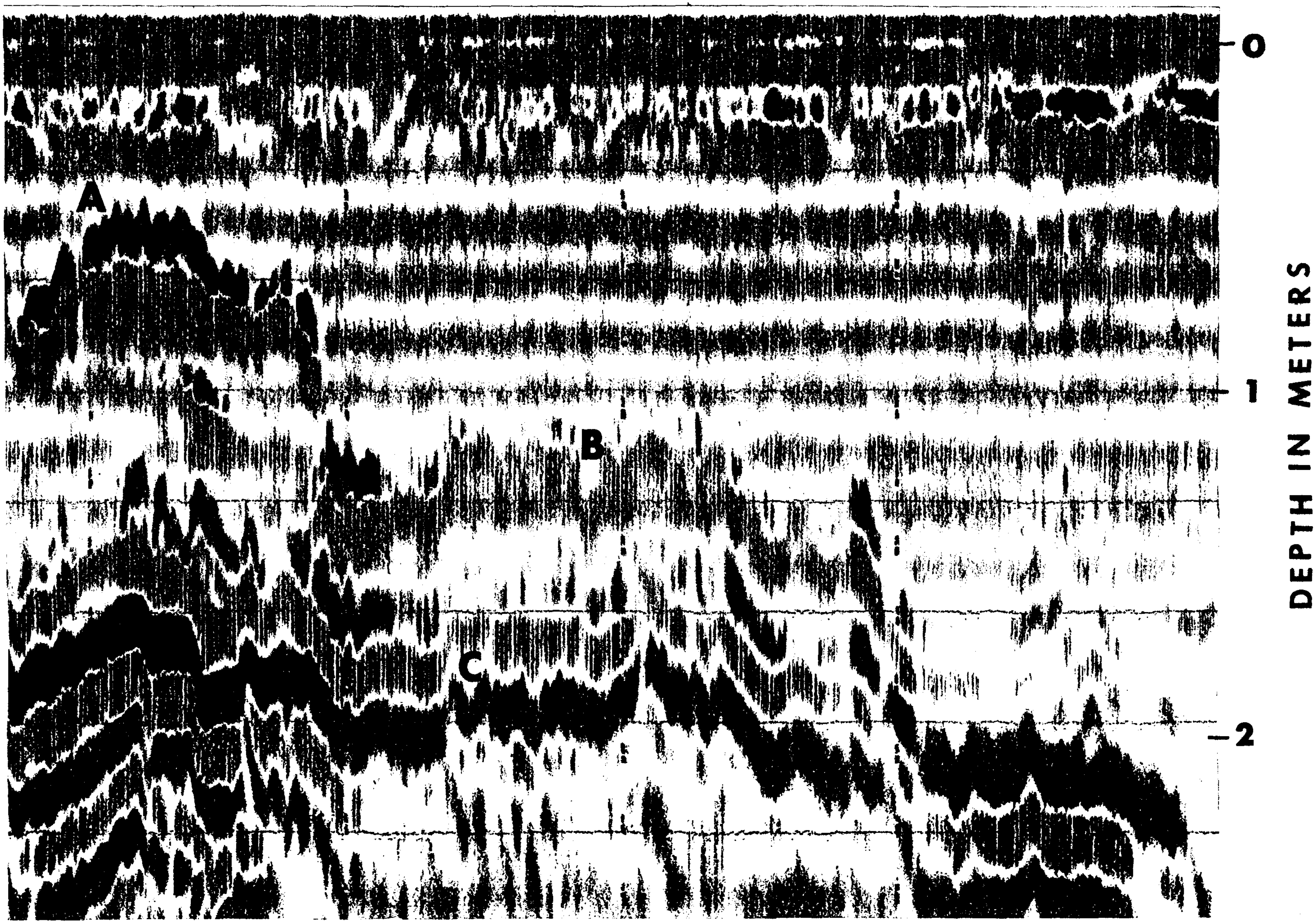
FIG. 9




UNPROCESSED PROCESSED

AREA OF RHINEBECK SOIL

FIG. 10




DEPTH TO LIMESTONE BEDROCK