United States Department of Agriculture

Soil Conservation Service

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Gainesville, Florida
32601

Subject: SOILS - Ground-Penetrating Radar (GPR) - Trip Report - North Carolina

Date: May 24, 1984

To: Coy A. Garrett, State Conservationist
SCS, Raleigh, North Carolina

File Code: 430-5

A ground-penetrating radar (GPR) unit was field tested in North Carolina during the period of April 23-27, 1984. The purpose of this field study was to assess the GPR's potential in North Carolina. It was tested as an expedient reconnaissance tool for on-site investigations, and as an economical, quality control tool providing detail soil data for soil survey updates and for progressive soil surveys. Multiple GPR transects were conducted at selected sites in Duplin, Pender, and Wake counties.

Participants included:

- William Leslie Barnhill, Soil Survey Party Leader, SCS
- R. Wade Biddex, Soil Conservationist, SCS
- Gina Boccetti, Soil Scientist, SCS
- Boyce W. Boyette, Soil Conservation Technician, SCS
- David Clapp, Soil Scientist, SCS
- David Combs, Area Conservationist, SCS
- Cecil C. Conners, Construction Inspector, Duplin County
- Tommy Cutts, Assistant State Conservation Engineer, SCS
- Frank Evans, Construction Inspector, Wake County
- Kenneth R. Futreal, District Conservationist, SCS
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- Donnie Ray Harris, Soil Conservationist, SCS
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- Ernest Hayhurst, Assistant State Soil Scientist, SCS
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- Jay S. Milan, Soil Conservationist, Pender County
- Darwin Newton, State Soil Scientist, SCS
- John M. Ray, Jr., District Conservationist, SCS
- Herman O. Riggs, Civil Engineer Technician, SCS
- Plummer Vines, Civil Engineer Technician, SCS
- Jimmy R. Vinson, Soil Conservation Technician, SCS
- Robert Williams, Project Engineer, SCS

All commitments scheduled in the itinerary report of April 9, 1984 were met. A slide presentation and general discussion on the use and application of the GPR was given before members of the state office staff on April 23, 1984. Each day Ernest Hayhurst conducted a discussion summarizing the activities for that day.

The equipment utilized during this field trip was the SIR System-8 with microprocessor and the ADTEK SR-8004H graphic recorder. The equipment operated well with no serious malfunction. The ADTEK DT-6100 tape recorder was undergoing corrective maintenance and was unavailable during this field trip. The unavailability of the tape recorder necessitated a greater number of transects to be taken at each site, but did not inhibit observations or results.

The 80, 120, and 300 MHz antennas were utilized during this field trip. The 120 MHz antenna provided the best balance of signal resolution and depth of penetration, and appears to be the most suitable antenna for engineering and soils investigations in North Carolina. The 80 MHz antenna provided the poorest resolution of subsurface features, and its potential depth of penetration was not significantly greater than that experienced with the 120 MHz antenna. The 300 MHz antenna is severely depth restricted in loamy Coastal Plain and Piedmont sediments.

I am pleased with the GPR's performance in North Carolina. The radar provided meaningful and usable information at all sites visited; though the amount and quality of information varied at each site.

The GPR demonstrated its weather, site, and interpreter dependency during the geologic studies. Wetness and higher clay contents in the overburden were factors contributing to the high levels of unwanted "system noise" on the graphic profiles; which confused interpretations at site 23, Crabtree Watershed. I personally have not had the opportunity to complete many geologic investigations with the GPR, and my interpretive skills and techniques in this area are lacking. Improved and more confident interpretations can and will follow additional experiences and exposure.

To the geologist depth of penetration is critical. In areas of Piedmont, the GPR has probed to depths of 7 meters. Depending on site and weather conditions, the GPR appears capable of producing clear, continuous, and detailed information to depths as great as 10 meters. Working with the North Carolina Department of Transportation in Pender County, the GPR produced consistent and clear images to depths of 4 meters; intermittent and clear images from 4 to 6 meters; and occasional and poor images from 6 to 8 meters. In Pender County wetness and high concentrations of ions in solution were most likely the cause for restricted range of the GPR.

The GPR performed exceptionally well on all soils examined. The potential of the present GPR system to define the occurrence, strength, depth, and extent of soil horizons in Coastal Plain areas of North Carolina has been established.

The ground-penetrating radar is a new tool, a product of advancing technology, but it is not the panacea for the study of soils or for site assessments. No single tool or geophysical technique will solve all site problems. The GPR has proven to be highly weather, site, and interpreter dependent. It is depth restricted. Generally the present GPR system should not be expected to give clear, continuous, and detailed information to depths greater than about: 30 feet in course-textured material and bedrock; 15 feet in moderately fine-textured material; and about 5 feet in fine-textured material.

Even with the aforementioned restrictions, the GPR is a viable tool in many areas of North Carolina. When applied to sites that are variable in composition, the continuous spatial measurements provided by the GPR have significant benefits; completing the partial information obtained from individual site measurements. Used properly, the GPR will help to assist users minimize and select only those measurement sites which will provide the maximum amount of information.

I am pleased by the performance of the GPR in North Carolina as well as in all investigated areas of the Coastal Plain. Hopefully the future will witness an expanded use and diversified application of the ground-penetrating radar.

I wish to pass along my special thanks to Ernest Hayhurst for his enthusiasm and support in the field during this trip.

Adam Hyde for

James A. Doolittle
Soil Specialist (GPR)

Attachments

cc: w/attachments
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PRINCIPLES OF OPERATION

The GPR is a broad-band width, 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 electronmagnetic 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. By towing the antenna along the ground surface, a continuous profile of subsurface conditions is "burned" onto the paper by the graphic recorder.

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). With the exception of the start of scan image, all of these components 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.

GEOLOGIC INVESTIGATIONS

The first area selected to study the feasibility of using the GPR for engineering site assessment was at site 23 of the Crabtree Watershed in Wake County. The study area consisted of a 130 foot, gently sloping segment along a cleared trail near the upstream cross-sectional edge of the center section. Due to heavy rains the area was inaccessible by vehicle and the equipment was carried in by hand. The saturated soil produced unfavorable ground conditions for the GPR and seriously reduced the radar's effective depth of penetration.

The unavailability of the tape recorder necessitated multiple transects across the study area. With each transect the gain and filtration settings were adjusted on the control unit, and various programs available with the microprocessor were selected in an attempt to enhance the quality of the graphic profiles. The 80 MHz antenna, having greater average and peak powers of radiation, was selected for this study because of its greater potential penetrating powers.

Assuming a dielectric constant of 19.0 for saturated loamy soil material, an initial scanning time window was set on the control unit to provide a scanning depth of approximately 7.8 meters; the depth scale was expanded to 9 meters.

Generally the performance of the GPR at this site was poor. Figure 2 is representative of the graphic profiles obtained at this site. A running average algorithm program was used to enhance this graphic profile. This program has removed much of the random system noise which tended to clutter the unprocessed graphic profiles. But background noise remains high, especially in the lower part of this profile.

Although numerous interface signals are evident in Figure 2, the graphic profile is generally unclear and difficult to interpret. Interface signals can be observed throughout the approximated scanning depth (7.8 meters). Broad zones of similar material can be inferred from similarities in the graphic signatures and texture. These broad zones were associated in the field with several distinct strata following comparisons with the core data.

The second site selected for GPR studies was along sideslopes leading to the emergency spillway at site 25, Crabtree Watershed. This study site was noticeably drier and was accessible along cleared trails with a 4-wheel drive vehicle. The use of the vehicle and generally more favorable site conditions enabled a larger area to be surveyed, in a shorter period of time, and with less intense labor.

Even at this site the graphic profiles from transects conducted with the 80 MHz antenna were unclear and poorly resolved. Profiles collected with the 120 MHz antenna were remarkable clear and provided consistent imagery to depths of 6.5 meters.

Figure 3 is a portion of a transect taken with the 120 MHz antenna. The depth scales used in geologic site studies are generally approximations based on the "averaged" relative dielectric constant of the earthen material. Admittedly, it is difficult to accurately approximate the depth scales along transects which do not have core data. Most earthen materials are ansiotrophic and each layer may have differing electromagnetic properties which affect the rate of signal propagation. The assumed, relative dielectric constant of the entire profile is used to calculate the depth scale according to the formula:

$$T(ns) = d(m) \times \frac{\sqrt{Er}}{0.15}$$

where:

T(ns) = scanning time in nanoseconds

d(m) = distance in meters

Er = relative dielectric constant

In Figure 3, the scanning depth was scaled on the graphic profile based upon the depth to bedrock at several coring stations and an assumed dielectric constant of 10. The contact between the overlying weathered sediments (B) and the bedrock (A) is distinct and easy to interpret in some areas while being obscure in others. The broad horizontal line (C) in the lower part of this figure is clutter caused by metallic interference which was due to the close proximity of the vehicle to the antenna. Using a suitable program on the microprocessor will effectively remove this clutter as evident in Figure 4.

In Figure 4, the contact of consolidated bedrock with detached bedrock fragments and weathered loamy sediments has been highlighted with a black line. Unquestionably it is difficult to accurately follow this contact in some areas. The bedrock has a distinct lithology. This lithology provides an identifiable, characteristic signature on the graphic profile consisting of multiple bands which slope at an approximate 60 degree angle from upper left to lower right. It is felt that with greater experience and research, interpretations can be made in many similar sites in North Carolina with a higher degree of confidence.

SOILS INVESTIGATION

Table 1 lists the soil series and soil families studied with the GPR in Duplin and Pender Counties. These soils formed in loamy Coastal Plain deposits on marine and stream terraces and interstream divides. These soils range from very poorly drained to well drained. Generally the underlying materials are stratified and variable textured. These soils are representative of the Coastal Plains, but have fairly shallow subsurface features which historically have not been easily discerned or defined by the GPR. Major diagnostic soil properties occurring within the upper 16 inches of the soil profile are often not properly interpreted as strong surface reflections will mask changes in the upper part of the soil.

Figure 5 is a segment of the graphic profile from a transect that was conducted in an area of Goldsboro soil with the 120 MHz antenna. In this figure, the polarity control on the graphic recorder was set so that all positive pulses would be printed full black while all negative pulses would only be highlighted. This procedure facilitates the differentiation of near surface and closely spaced subsurface interfaces.

The range scale was adjusted to provide sufficient scanning time to probe to a depth of approximately 1 meter. Deeper penetration was possible at this and other sites in Duplin and Pender Counties, but was considered impractical to the objectives of this study. As a procedure, reducing the depth of GPR penetration increases the available printing space per unit depth scanned on the graphic recorder. This enlargement process increases the detail and accuracy of shallow depth measurements.

In Figure 5, features within the upper 20 inches of the soil have been compressed into a vertical distance of approximately 2 inches on the graphic profile. This compression of data has produced significant overlapping and superpositioning of the radar signals in the upper part of the graphic profile.

The argillic horizon is represented by three distinct bands. These characteristic triple bands are caused by oscillation in the reflected radar signals, and often limit the ability of the GPR to discriminate shallow or closely spaced interfaces. The upper most band of the argillic horizon has been labeled "B" and was used for all depth measurements.

Lateral changes in electromagnetic properties along the argillic horizon can be inferred from changes in the width of the dark and light bands on the graphic profiles. As a general rule: the more abrupt or contrasting the interface, the stronger the amplitude of the reflected signal, the blacker and wider the dark bands, and the narrower the width of the white bands. An abrupt change in textures across the eluvial/illuvial interface should produce wide dark bands and narrow white bands.

In areas of eroded soil, the upper part of the argillic horizon has been mixed with the plow layer. In eroded areas (see "C" in Figure 5), the GPR discerns the argillic horizon as being near the surface. On the graphic profile, contrast across the eluvial/illuvial interface is diminished and the width of the white bands is increased in the areas of eroded soils (C). Theoretically, in similar soils erosion can be measured with the GPR on the basis of the depth to the argillic horizon, and the relative strength (lightness or darkness) of the black bands and the width (to the exclusion of the dark bands) of the white bands.

In Figure 5, the thin discontinuous interface (A) is a dark gray, dark grayish brown, or grayish brown subsurface layer. This interface signal is only apparent where the subsurface layer is present and greater than 4 inches thick. A lower gleyed horizon within the subsoil is evident at "D."

The capillary fringe in most medium textured soils is too gradual and diffuse to be detected with the GPR. Though the water table was observed in the field, its reflected signal is too weak to be recognized in this figure.

Presently, 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, and slight spatial discrepancies between the site of measurement and the track of the radar scan.

The antenna has a fairly broad radiation pattern within the ground and "averages" 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 depths scaled on the graphic profile. In order to document the accuracy of the GPR system at this site, a study was conducted comparing scaled radar imagery with ground-truth auger data.

The measured depth to the argillic horizon, the scaled depths of the radar imagery, and the difference between these measurements are listed in Table 2. The average deviation between soil boring depths and scaled radar imagery is 1.5 inches. The deviations between scaled radar imagery and ground-truth auger data are as follows: within 4.0 inches at all sites; within 2.0 inches in 67 percent of all sites; and within 1.0 inches in 44 percent of all sites. The match between the ground-truth data and the scaled radar imagery for the argillic horizon is considered remarkable. Greater variations are often observed between scaled and ground-truth measurements with each consecutively lower lying subsurface interface.

The delay time of the reflected signals and consequently the depth scale is determined by both the velocity of propagation and the depth to the interface. Often a horizontal gradient in the permittivity of a horizon will affect the velocity of signal propagation and cause the reflected signal to be delayed, making the horizon appear to slope to a greater depth.

To test this observation, a second comparison of the scaled radar imagery with the ground-truth data was made. The measured depth to the gleyed portion of the subsoil, the scaled depth of the radar imagery, and the difference between the measurements are listed in Table 2. In this example, the average deviation between the soil boring depths and scaled radar imagery is 3.4 inches. It is correct to assume that with increasing soil depth, wider disparities will exist between scaled radar imagery and ground-truth data in soils having multiple and strongly contrasting layers or horizons.

Similar transects were conducted in the area of Goldsboro soil with the 300 MHz antenna. Images from the 300 MHz antenna (Figure 6) were severely weak and depth restricted. The 120 MHz antenna, based on field testing in Alabama, Florida, Louisiana, and South Carolina, provides the best balance of resolution and penetrating depth, and is the most suitable antenna for soil investigations on the Coastal Plain. The 80 MHz antenna, though having slightly better powers of penetration, produced images that were less distinct than the images that were produced with the 120 MHz antenna.

In Figure 7, the images of loamy sand argillic horizons (A) are clearly expressed beneath the fine sand and sand surface and subsurface layers of Autryville soils. This graphic profile was complicated by the superpositioning of reflected signals from a perched water table which occurred immediately above the lower and more continuous argillic horizon. In a drier state, the imagery would probably have been more distinct. "B" identifies a third, more discontinuous argillic horizon. This deeper horizon is most likely composed of interstratified lenses of loamy and sandy materials.

In time and with added field experience and technological developments, it is probable that individual horizons and layers will be routinely identified by their unique signal characteristics or "signatures" on the graphic profile. Presently, in some areas, this prediction is a reality.

Figure 8 is an example of the potential of the GPR to characterize the type, depth, and lateral extent of soil horizons. Confirmed by detailed ground-truth observations, each horizon is delineated by distinct interface signals and possess unique signatures which distinguishes it from adjoining horizons. The composite average variation between ground-truth and scaled data across the graphic profile was only 1.8 inches.

Figure 9 is from an area of Rains and Pantego soils. Most major diagnostic features used to classify and separate these soils are evident in this profile: the presence or absence of the umbric epipedon (A), and depth to and lateral extent of the argillic horizon (B).

Areas of Pantego soils having an umbric epipedon were not readily apparent in the field, but were quite distinct and readily observed on the graphic profile. Areas of Pantego soil appear to be filled depressions. Though specifically designed for subsurface investigations, interpretations can be made concerning surface conditions and epipedons.

Buried tree stumps and roots are numerous in the upper part of this profile. These features are best described as point objects having limited lateral extent. They are identified by their characteristic hyperbolic or inverted "V" pattern.

The subsurface layer (C) that extends midway across Figure 9 is a stratified Cg horizon. At first glance this layer appears to be continuous across the entire graphic profile, but a closer examination reveals that it is irregular in depth, diffuse, and ill-defined. The absence of distinct, continuous multiple bands and the occurrence of numerous random, segmented patterns are believed to represent a zone of segmented clay layers interstratified with lenses of sand. The credibility of these observations was confirmed by field observations.

Many people have inquired into the ability of the GPR to discern coarser textured materials underlying moderately fine or fine textured materials. To date most examples drawn from the field have come from Florida where coarser textured materials commonly overlie fine textured material. As illustrated in Figure 9, the GPR has the potential in some areas of picking up abrupt changes from moderately fine textured to coarser textured materials at depth ranging from 1 to 2 meters. Generally the GPR has not been effective in distinguishing Hapludults from Paleudults. Often the decrease in clay content with increasing soil depth could not be verified with a high degree of accuracy with the GPR. In most GPR field studies, the decreasing clay content either did not occur or was too gradual a transition for the GPR to discern.

Figure 10 is a portion of a transect that was conducted in an area of Liddell soil. This soil is coarse-silty. A light gray silty clay loam horizon (A) occurs below the control section in the left-hand portion of this profile. The abrupt textural change from silty loam to silty clay loam along this horizon's upper boundary provided a strong reflected signal and a dark subsurface image. Approximately midtransect this moderately fine textured subsurface horizon became segmented (B) and ended near "C." A weakly expressed brittle layer (C) can be traced with some difficulty across the entire graphic profile at an average depth of approximately 1 meter.

TABLE 1

Soil Name	Description
Autryville	loamy, siliceous, thermic Arenic Paleudults
Goldsboro	fine-loamy, siliceous, thermic Aquic Paleudults
Liddell	coarse-silty, siliceous, thermic Typic Haplaquepts
Pantego	fine-loamy, siliceous, thermic Umbric Paleaquults
Rains	fine-loamy, siliceous, thermic Typic Paleaquults
Torhunta	coarse-loamy, siliceous, acid, thermic Typic Humaquepts

TABLE 2

Deviation Between Measured Depths and Scaled Radar Imagery to Argillic Horizon in Goldsboro Soil

Reference Site	Depth to Argillic (inches)	Scaled Depth (inches)	Absolute Deviation (inches)
1	11	10.5	0.5
3	14	15.5	1.5
5	14	10.0	4.0
7	10	9.0	1.0
9	9	9.3	0.3
11	7	7.5	0.5
13	4	6.8	2.2
15	4	6.8	2.2
17	6	7.5	1.5

Average deviation: 1.5 inches

TABLE 3

Deviation Between Measured Depth and Scaled Radar Imagery to Gleyed Part of Argillic Horizon in Goldsboro Soil

Reference Site	Depth to Gleyed Layer (inches)	Scaled Depth (inches)	Absolute Deviation (inches)
11	38	34.9	3.1
13	24	22.0	2.0
15	24	25.5	1.5
17	28	35.0	7.0

Average deviation: 3.4 inches

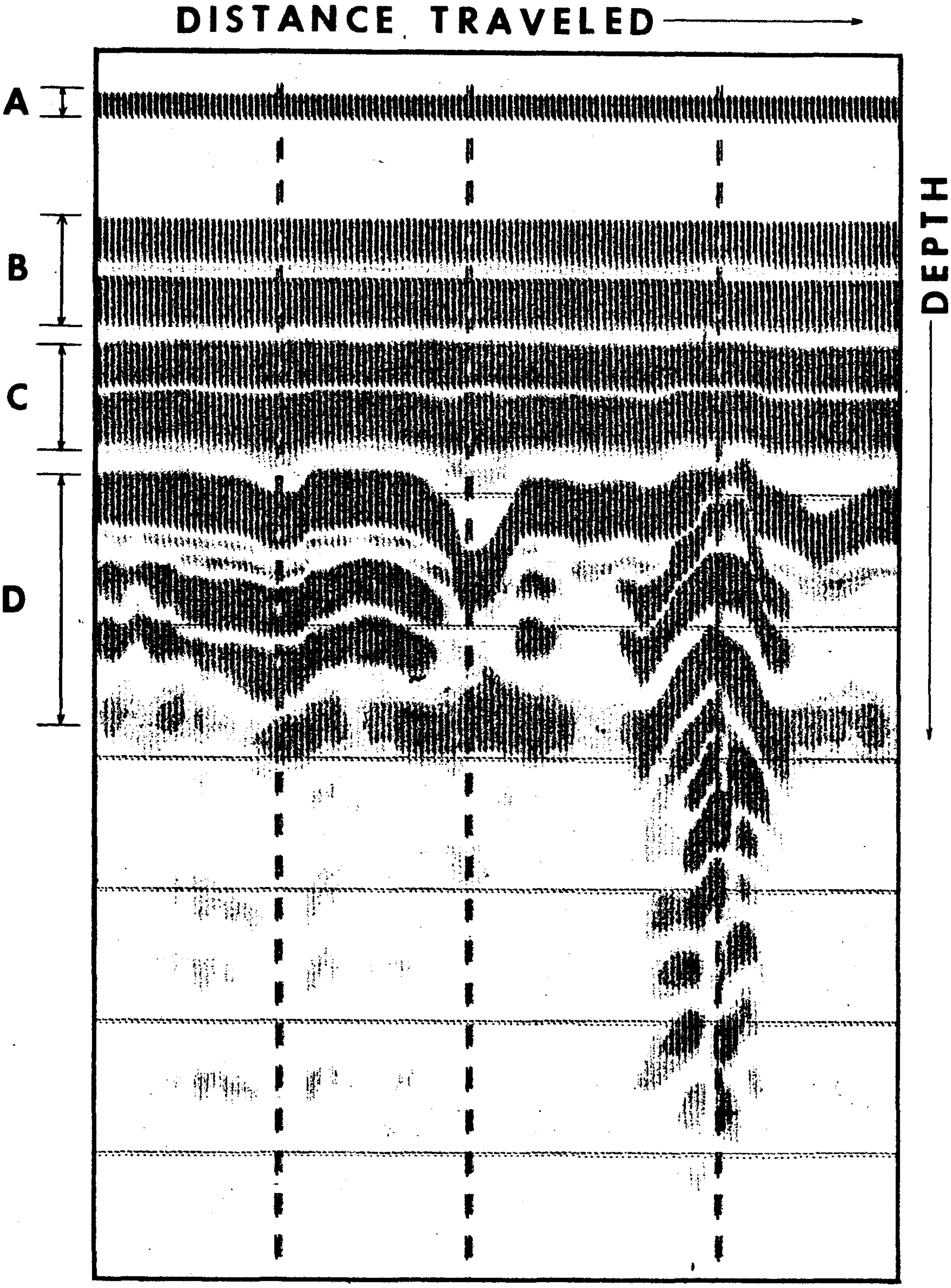
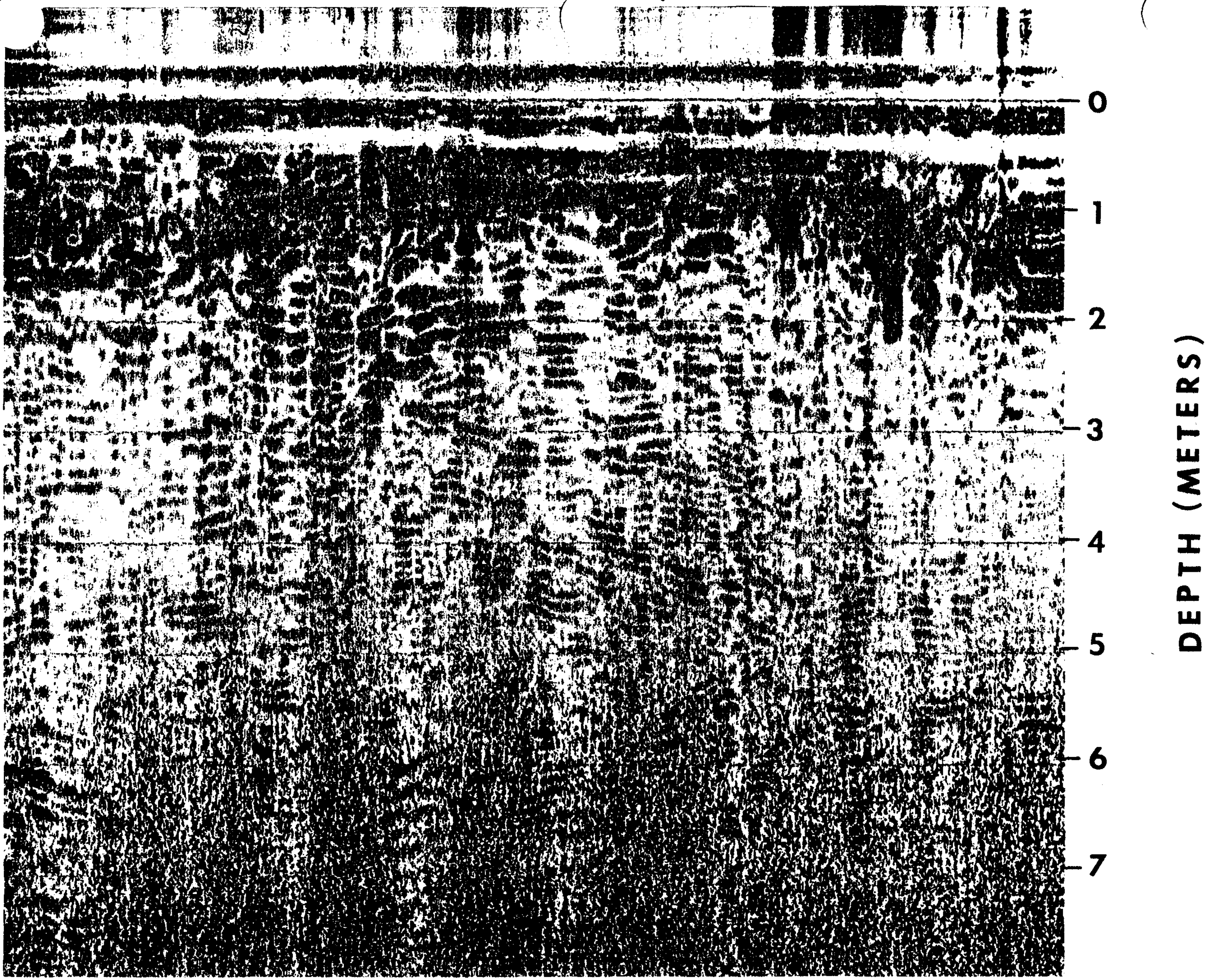


FIG. 1

A GRAPHIC PROFILE

FIG. 2



GPR PROFILE AT SITE 23, CRABTREE WATERSHED

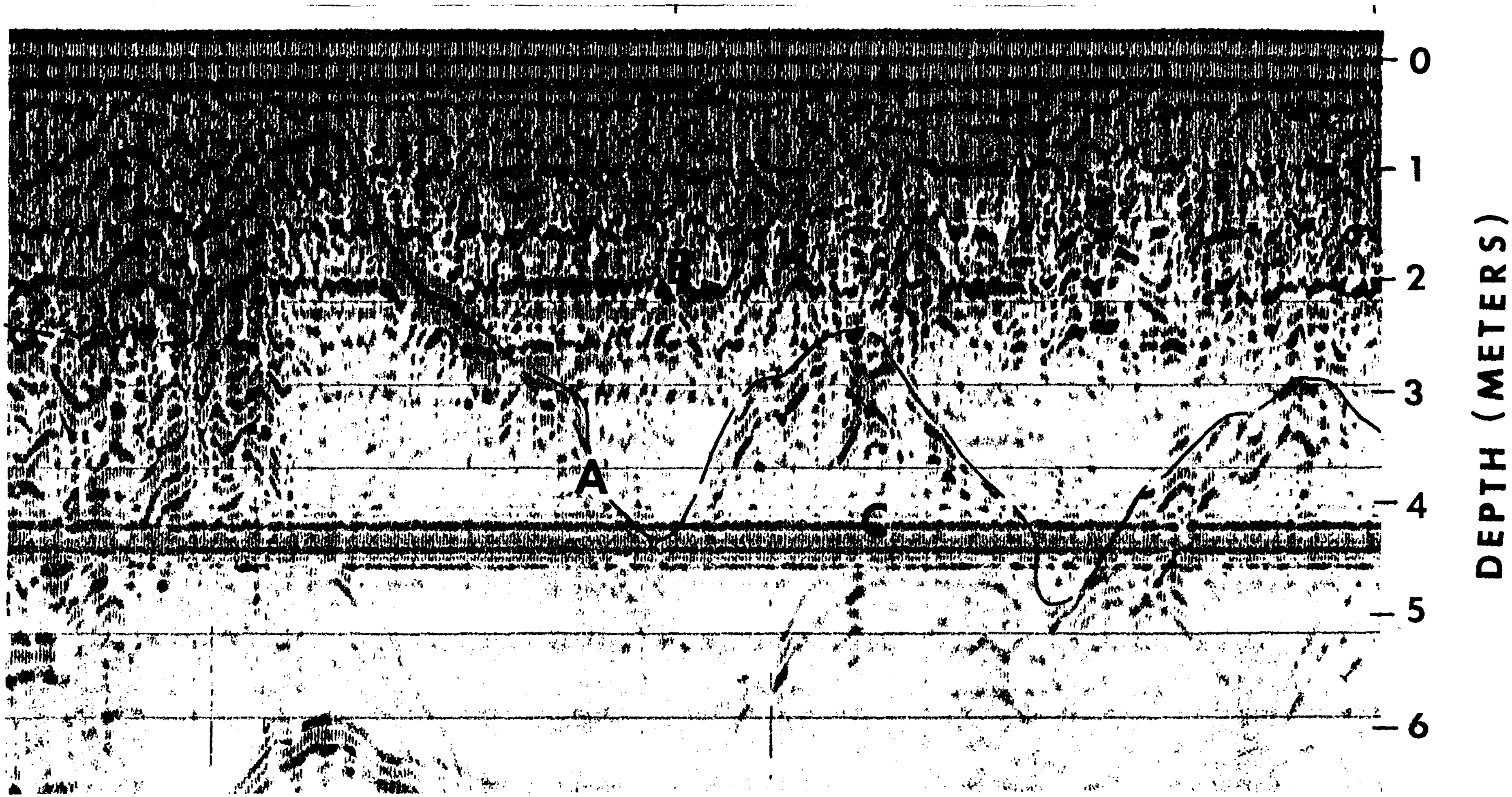
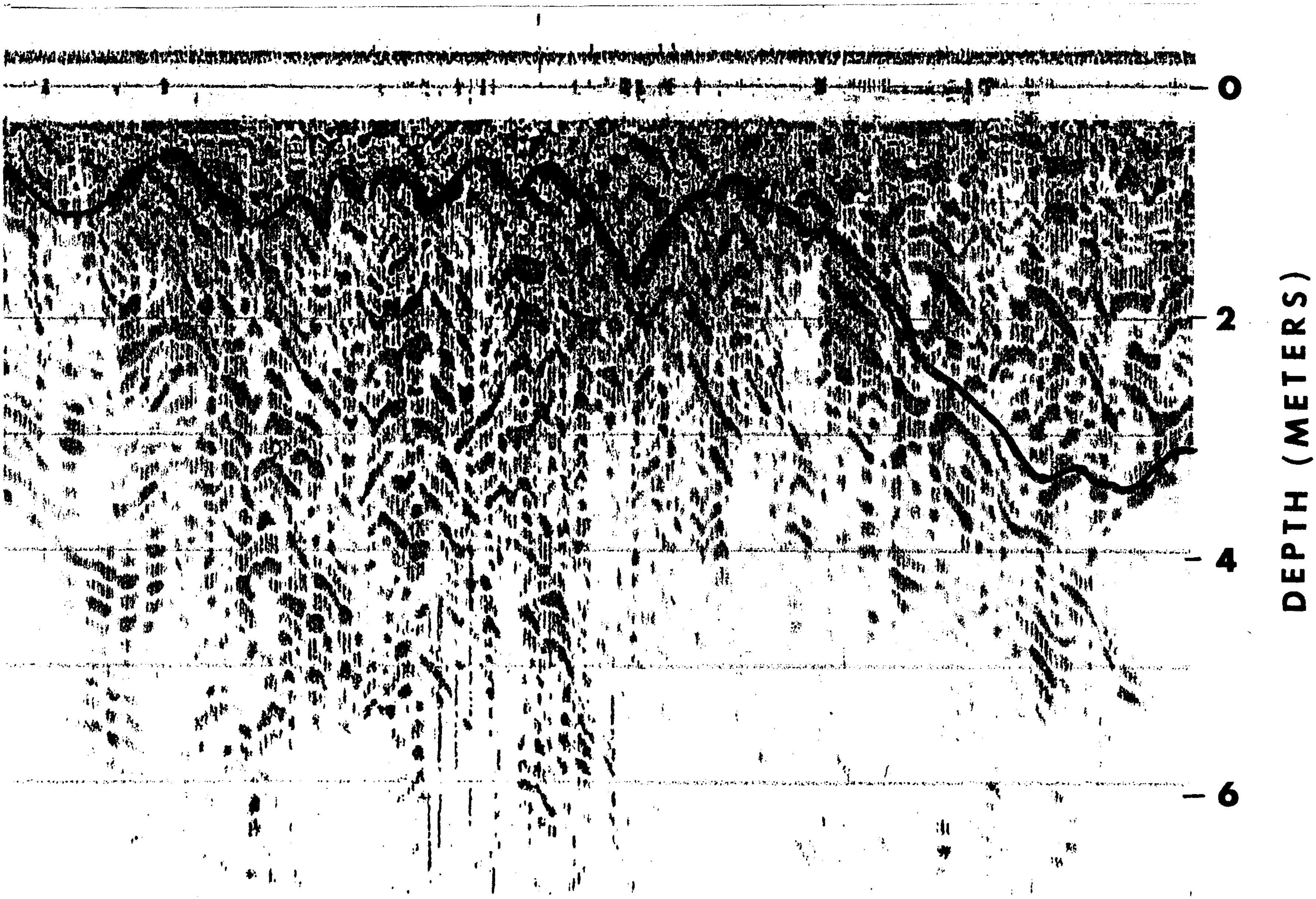


FIG. 3

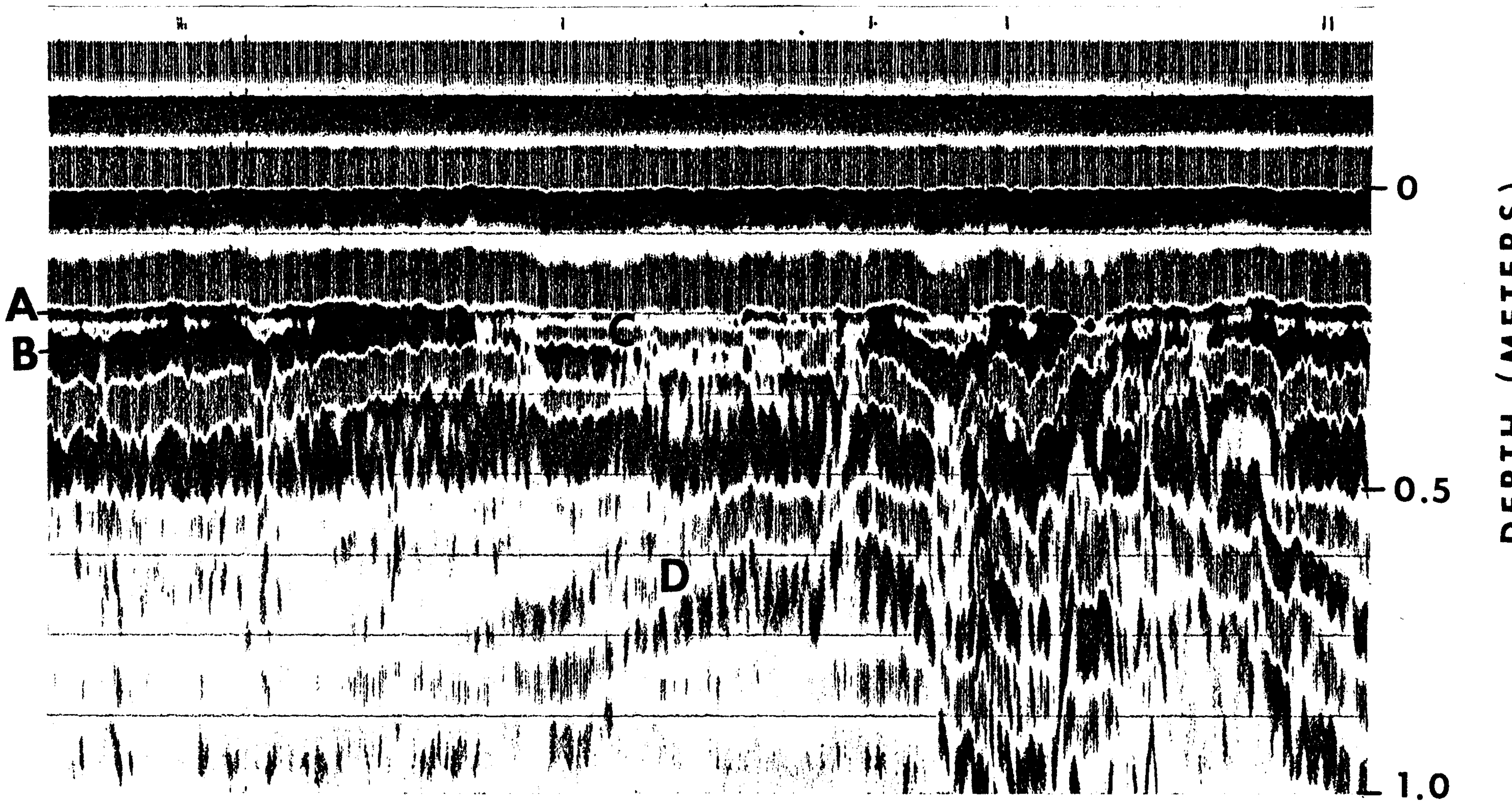
GPR PROFILE AT SITE 25 CRABTREE WATERSHED

FIG.



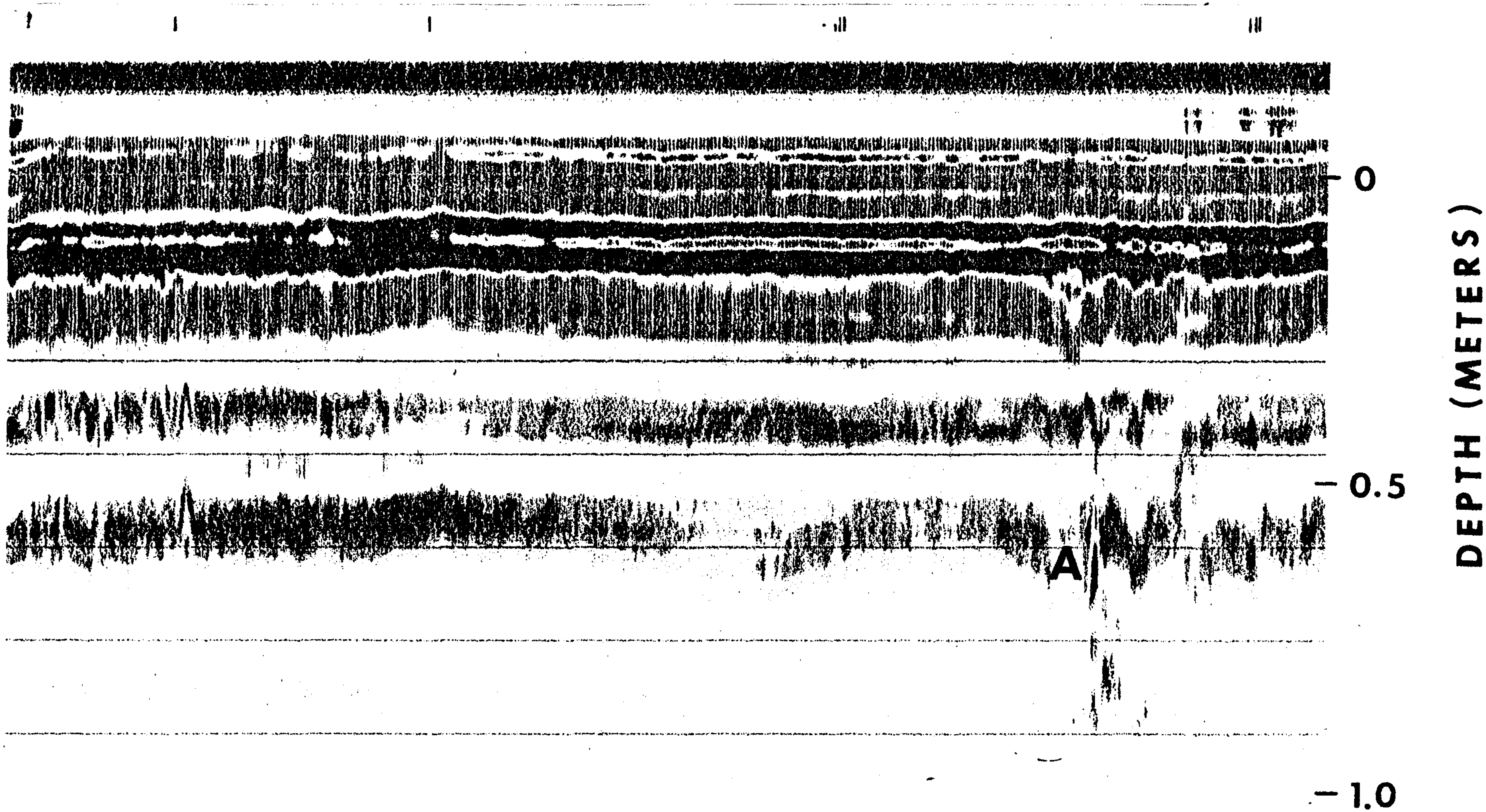
GPR SIGNATURES IN BEDROCK

FIG. 5



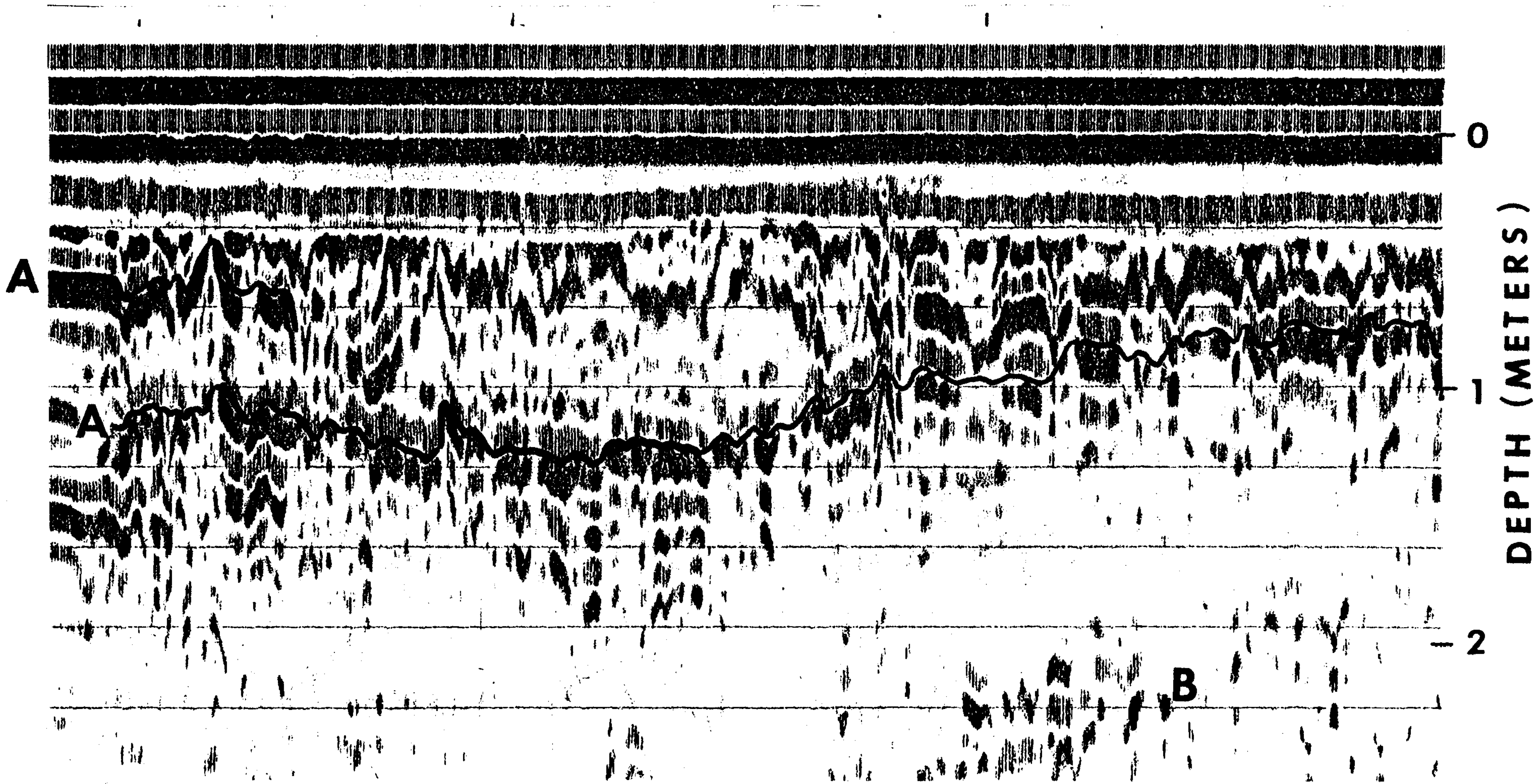
GPR TRANSECT IN AREA OF GOLDSBORO SOILS

FIG. 6



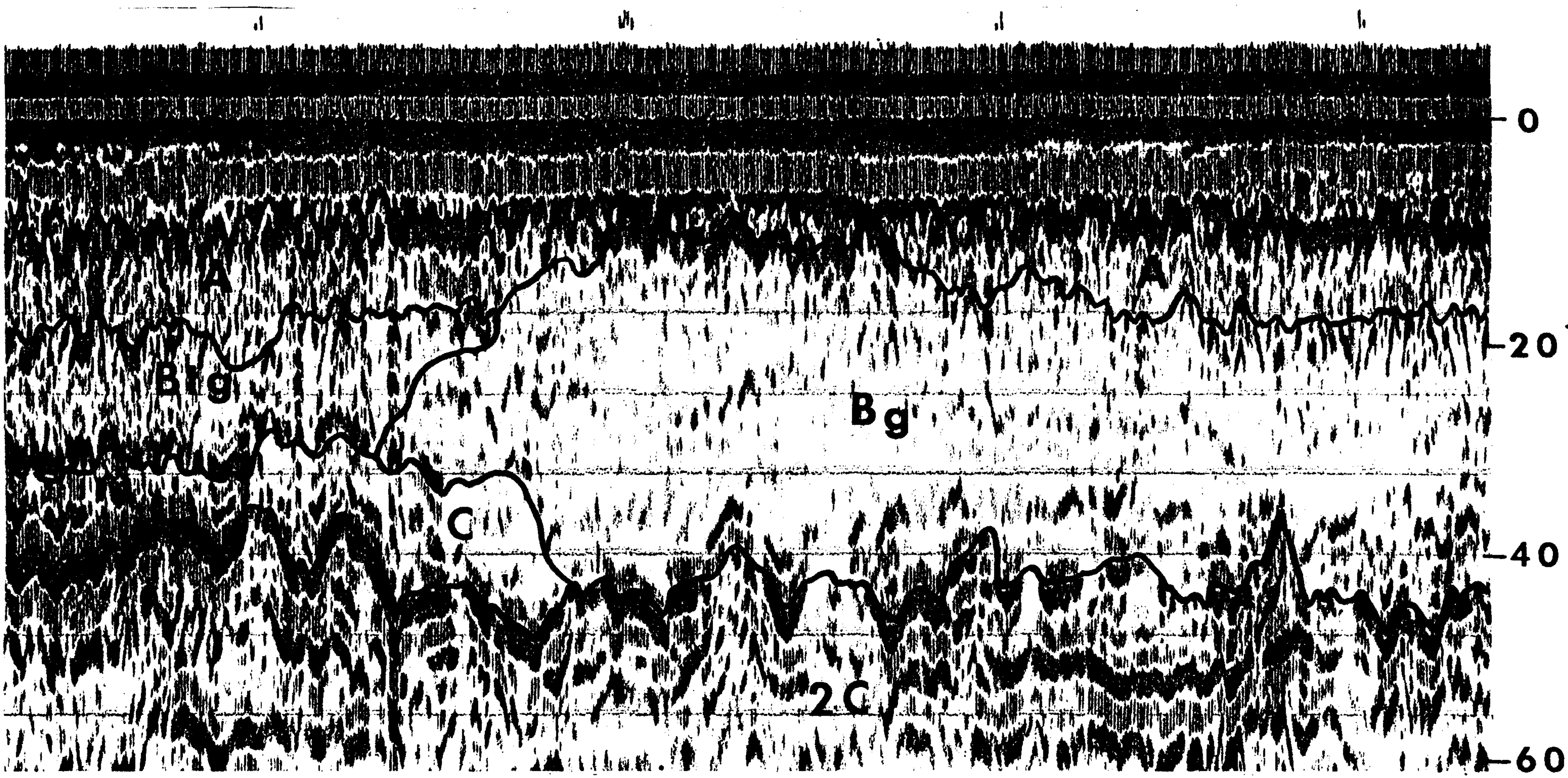
GRAPHIC PROFILE OF GOLDSBORO SOILS TAKEN WITH THE 300 MH_z ANTENNA

FIG. 7



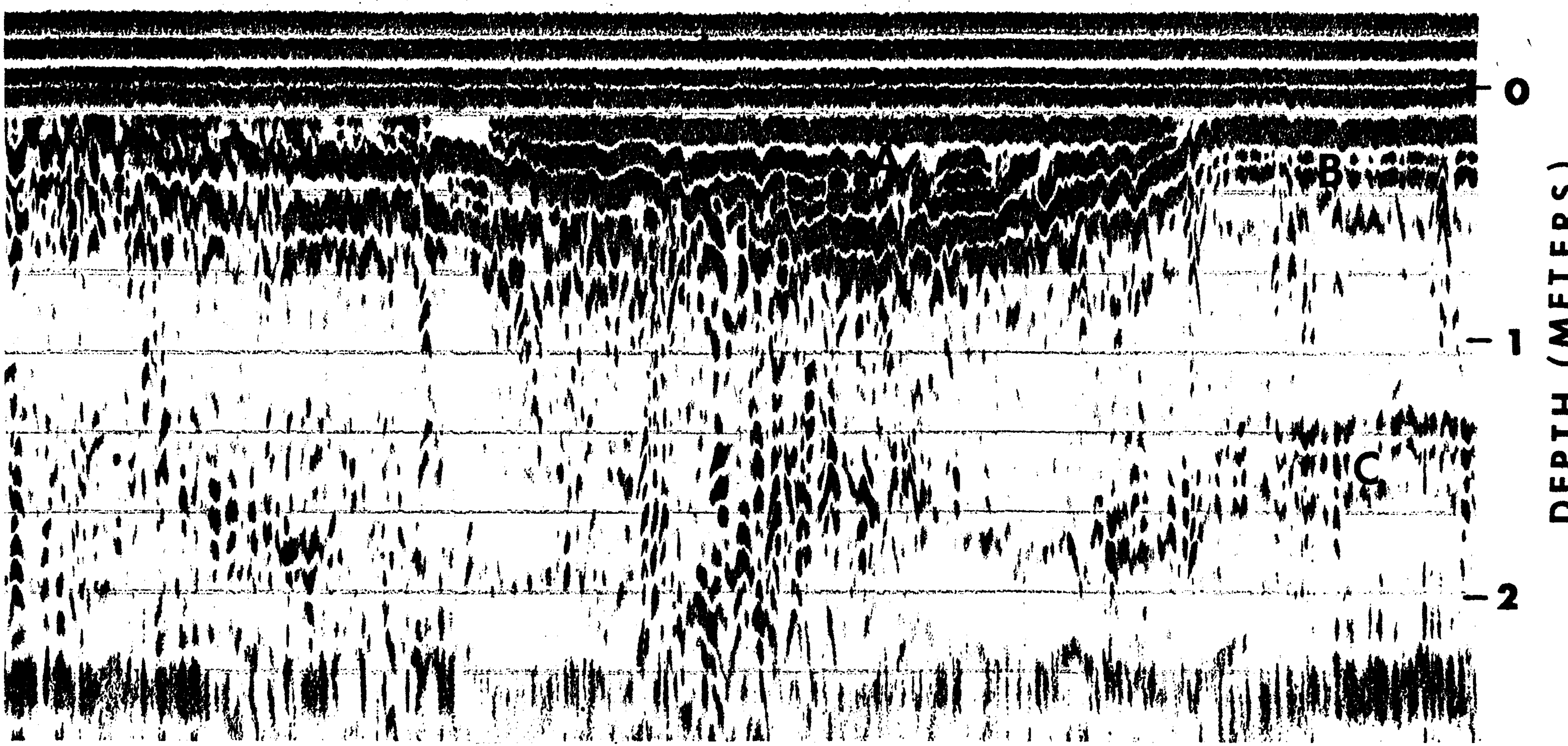
GPR TRANSECT IN AN AREA OF AUTRYVILLE SOILS

FIG. 8



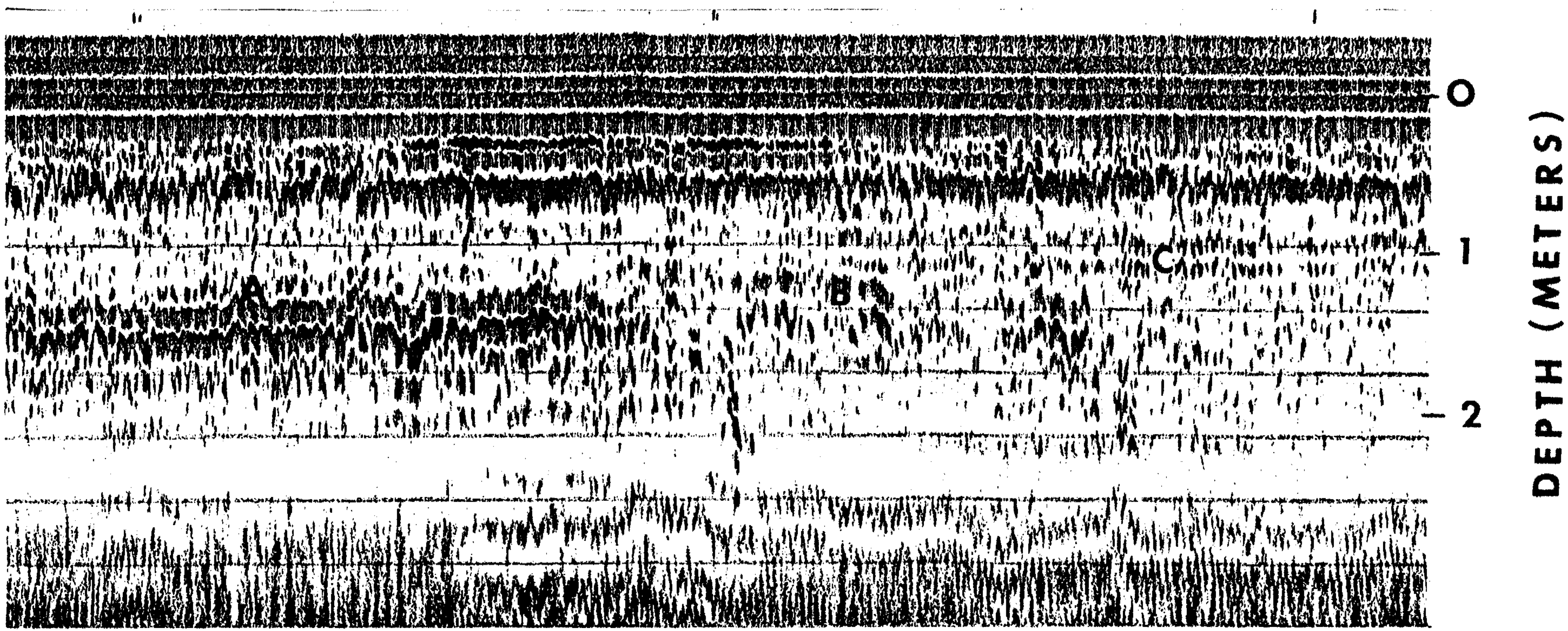
HORIZONATION IN AN AREA OF PANTEGO AND TORHUNTA SOILS

FIG. 9



GPR PROFILES OF TYPIC AND UMBRIC PALEAQUULTS

FIG. 10



GPR PROFILES IN AN AREA OF COARSE-SILTY TYPIC HAPLAQUEPTS