United States Department of Agriculture

Soil Conservation Service

401 S.E. First Avenue, Room 248
Gainesville, Florida
32601

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

Date: June 11, 1984

To: Robert R. Shaw, State Conservationist
SCS, Columbus, Ohio

File Code: 430-5

The ground-penetrating radar (GPR) system was field tested in Ohio during the period of May 13-26, 1984. The study was conducted at the ARS Hydrologic Station near Coshocton, and at the OARDC, Wooster. The purpose of this investigation was to evaluate the GPR's performance under variable soil conditions, and to determine its potential application in the Ohio soil survey program. A copy of the trip report indicating the results of this investigation is enclosed.

Participants include:

Dick Amerman, Director, Hydrologic Station, Coshocton
Dick Christman, Administrator, ODNR-DSWC, Columbus
Tom D'Avello, Soil Scientist, SCS, Coshocton
Bill Edwards, Soil Scientist, Hydrologic Station, Coshocton
Jon Gerken, Soil Specialist, SCS, Columbus
Tom Graham, Soil Scientist, SCS, Millersburg
Margaret Griffith, Soil Scientist, SCS, Zanesville
George Hall, Professor, OSU-OARDC, Columbus
Keith Huffman, State Soil Scientist, SCS, Columbus
Paul Jenny, Soil Scientist, SCS, Cambridge
Mark Johnson, Soil Scientist, SCS, Newark
John Lyons, Assistant Professor, OSU-OARDC, Columbus
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Joe Steiger, Soil Scientist, SCS, Zanesville
Larry Tornes, Assistant State Soil Scientist, SCS, Columbus
Ted M. Zobeck, Assistant Professor, OSU-OARDC, Columbus

We were pleased that all commitments scheduled in the itinerary report were met. Rain delayed field work only one morning, but did not hamper or limit the results.

During field work the GPR was introduced to each participant. A slide presentation on the GPR was given before the staff of the USDA-ARS Hydrologic Station, Coshocton, on May 18, 1984. A conference summarizing the GPR's activities and results was held at the close of field work on May 25, 1984. In attendance were Tom Graham, John Lyons, Rex Mapes, Larry Milliron, Bob Ritchie, Ted Zobeck, and myself.

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, and the 80, 120, and 500 MHz antennas. The equipment operated well with one exception. On the last day of GPR field work, two hours were spent troubleshooting and correcting a defective stylus belt on the graphic recorder. The ADTEK DT-6000 tape recorder, having been recently received from the manufacturer, was taken and used in the field for the first time.

The GPR provided useful soil data at all investigated sites. Though site specific and weather dependent, it appears to have good potential in eastern Ohio for most investigations involving the upper 1 to 2 meters of soil.

At Coshocton the radar performed well and provided ample data to a depth of about 2 meters; the desired depth for the purpose of this investigation. As a reconnaissance tool the GPR displayed its ability to rapidly provide a detailed graphic profile of subsurface conditions and document the variability and complexity of soils across the landscape. Though the radar operated well, interpretations were restricted by the complexity of soil and bedrock conditions, the inexperience of the operator in this environment, and the quantity of graphic data.

The GPR is more depth restricted in the glacial drift which typifies the Wooster area. Wet spring like conditions and the general nature of the soils combined to restrict the effective depth of penetration to about one meter. With drier soil conditions, depths as great as two meters may be attainable in the moderately fine-textured soils of the till plains.

I am pleased with the results of this trip. Much has been learned. Obviously more work needs to be done to define the range and the nature of GPR applications in Ohio. To be useful, we must understand the systems limitations and apply this technology to areas in which it will work well. Each environment imposes a limitation on the system's effective depth of penetration. Acknowledging these limitations, the radar can be successfully used in Ohio to study earthen materials whenever the area or depth of interest is within its capacity.

All pertinent graphic profiles have been turned over to Ted Zobeck. All transects have been taped. Copies of these tapes are available or the tapes themselves may be borrowed upon request.

I wish to pass along my personal thanks for the enthusiasm and cooperation that all members of your staff and of the cooperating agencies extended to me. Thank you for the opportunity to work in Ohio.

Sincerely,

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 narrów 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.

DISCUSSION OF RESULTS

A. Coshocton

The USDA-ARS hydrologic station near Coshocton was selected as the first site for evaluating the performance of the ground-penetrating radar (GPR) in Ohio. The purpose of this phase of the investigation was to evaluate the GPR's potential in areas having interbedded layers of sedimentary rocks. Specifically this study would assess the potential of the GPR to determine the depth to soil horizons and to paralithic contacts.

The research station is situated in an area characterized by irregular topography which is underlain and often controlled by essentially horizontal beds of sedimentary rocks. The subsurface lithology is exceedingly complex and variable. Thin multiple interbedded layers of clays, coal, sandstone, and shale intersect the surface at all elevations. Though generally covered by a thin veneer of coluvium or loess deposits, bedrock has exerted a strong influence on the evaluation of soils. The variability of soils over seemingly short distances can often be explained by variations in bedrock lithology.

Within the research station two principal transects were laid out. Later two minor transects were established within representative map units. Each of the initial transects crossed complex soilscapes which included areas of Berks (loamy-skeletal, mixed, mesic Typic Dystrochrepts), Coshocton (fine-loamy, mixed, mesic Aquultic Hapludalfs), Dekalb (loamy-skeletal, mixed, mesic Typic Dystrochrepts), Keene (fine-silty, mixed, mesic Aquic Hapludalfs), and Raynes (fine-loamy, mixed, mesic Typic Hapludulfs) soils. During reconnaissance work areas of Rarden (clayey, mixed, mesic Aquic Hapludults), Rigley (coarse-loamy, mixed, mesic Typic Hapludults), Steinsburg

(coarse-loamy, mixed, mesic Typic Dystrochrepts), and Westmoreland (fine-loamy, mixed, mesic Ultic Hapludalfs) soils were observed along proposed transect routes.

Each initial transect was laid out perpendicular to slope contours. These transects crossed complex slopes which ranged from 6 to 25 percent. Flags were placed at 50 or 100 foot intervals along each transect line and served as reference points.

The first step in any GPR field operation 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 depth of interest. In any medium the higher the frequency of the antenna the better the resolution of subsurface features; provided sufficient energy is available to penetrate to the desired features. As the application of this study was soils, the desired depth of penetration was about 2 meters. No attempts were made at Coshocton to evaluate the GPR's maximum depth of penetration.

At Coshocton the 120 MHz antenna provided ample depth of penetration and adequate resolution of soil and bedrock features. The 80 MHz antenna was field tested at one site. Although the 80 MHz antenna has the 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 investigation. Each appeared more than capable of investigating soils to depths greater than 2 meters. With the 80 MHz antenna near surface or closely spaced interfaces were often poorly resolved and many appeared to have been "averaged" together by its broader band widths. Based on previous field work in areas of moderately-fine textured soils, it was decided that the 300 and 500 MHz antennas would not be used in this study.

The majority of the transects were conducted with a scanning time of 83 nanoseconds (ns). It was assumed that the average relative dielectric

constant of the soil was 19. This figure is based on a tabled value for wet loamy soils. Based on this approximation a time window was established on the control unit sufficient to probe to a depth of about 2.8 meters. Variations in moisture and clay contents, lithology, and the number and thicknesses of interfaces will cause the actual depth of penetration to vary with soil type and slope position.

The depth scale on all graphic profiles is initially a time scale. The time scale can be converted into a depth scale after the depth to a known interface has been confirmed by ground-truth measurements or the assumed velocity of propagation has been approximated. Unfortunately, the velocity of signal propagation is inversely related and strongly dependent upon the moisture content of soils which, in the study area, appeared to be quite variable.

Within map units depth scales are generally accurate provided the soils are similar. When extended across the boundaries of soils, drainage classes, or slope positions depth scales can only serve as close approximations and should not be relied upon for highly precise measurements unless supported by ground-truth observations.

The second step in any field operation is the calibration of the GPR to achieve optimal signal returns. This procedure is relatively simple in areas of similar soils and uniform soil conditions. In areas of similar soils readjustments are generally unnecessary once the proper settings on the control unit have been achieved. Continuous readjustments of the settings are often required as the complexity of soils and soilscapes increase.

At the beginning of each transect the radar was calibrated and the range gain and filtration settings adjusted to achieve the most optimal setting at that particular site. No single combination of range gain or filtration setting was suitable for each of the diverse soil conditions encountered

along the transects. Settings must change in response to change in soils and soil properties; especially degrees of saturation and clay content.

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

On some slope segments the graphic profiles appear to be exceedingly depth restricted. In Figure 2A, soil information appears to be discontinuous and restricted to the upper meter of the graphic profile. In most places restricted soil depth was caused by the range gain and/or filtration being temporarily out of optimal adjustment. In some areas the restricted soil depth was caused by the radar signal being rapidly and completely dissipated by the high clay content of the soil.

A microprocessor can be used to enhance radar imagery. The microprocessor has seven programs; each with a unique filtration bypass. Though each program is unique, all have been designed to either remove background noise, "stack" weaker subsurface signals, or both. In Figure 2B, the identical transect segment was played back with increased range gain and processed through the microprocessor. Higher gain settings increase unwanted random system noise which, especially in deeper studies, can mask the desired interface signals. In Figure 2B, a running average algorithm program was selected and used to remove most of the unwanted system noise.

Signal enhancement and processing with the microprocessor was generally unnecessary in the study area. In most places establishing optimal range gain and/or filtration settings sufficed. Deeper geologic investigations often require high gain settings and are more likely to benefit from the use of the microprocessor.

In Figure 3, the complexity of the slopes is clearly expressed. The multiple dark bands represent soil horizons and rock layers. No single interface can be traced for more than a couple hundred feet. As all interfaces appear in shades of gray to black and are closely similar in expression, their proper identification is problematic and would require a large number of ground-truth observations.

Several general observations can be made concerning the information contained in Figure 3. The radar has verified the complexity of the soilscape and has provided more information than we can possibly digest. We are limited by our ability to interpret this data.

In Figure 3, images of bedrock interfaces appear as subparallel bands which approach and intersect the surface at distinct angles. The angle of inclination appears to be greater on the graphic profile than it is in reality. This distortion does not affect the accuracy of depth measurements. It is caused by the vertical exaggeration which is common to all graphic profiles, by our failure to account for the inclination of the ground surface (the surface regardless of slope is always horizontal), and by the speed of antenna advance. Recording data on the graphic recorder at faster speeds of paper advance will stretch out the horizontal scale and correct some of the distortion caused by these factors.

The parallelism of the bedrock images breaks down in Figure 3 as the surface is approached and the influence of mass wasting becomes more evident. The shallower portions of bedrock layers can be observed to either bend downslope (B) or to become segmented in response to the process of mass wasting. Insular clusters of segmented rock fragments are inferred in some areas (C).

Soil horizons tend to be more nearly parallel with the soil surface. Also responding to the pull of mass wasting, the irregular upper boundary of

an argillic horizon (A) can be traced laterally between observation sites 7 and 9.

Figure 4 is a portion of a graphic profile taken from a convex shoulder slope. Processes of mass wasting has disrupted the orderly sequence of soil horizons and rock layers. It is exceedingly difficult to identify and to trace the lateral extent and continuity of each layer. The soil horizons and rock layers are discontinuous and appear to be intersecting. Several interface signals appear to be superimposed and have cancelled each other out at "A." As all images appear in shades of gray to black and are similar in graphic expression, identification of each interface and the differentiation of rock layers from soil horizon is exceedingly difficult.

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 errors 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 profiles. In order to document the accuracy of the GPR system, a site was selected (Figure 5) to compare the scaled radar imagery with ground-truth auger data.

In Figure 5, the image of the soil/bedrock interface is denoted by "A." The image is generally clear and continuous across the graphic profile from observation site 1 to 4. Near observation site 5 the bedrock becomes segmented. No soil/bedrock interface is apparent on the graphic profile at

observation site 6. This observation was confirmed in the field. A cluster of rock fragments is evident at "B." A lower lying interface is identified at "C."

The measured depth to the soil/bedrock interface, the scaled depth of the radar imagery in Figure 5, and the difference between these measurements are listed in Table 1. The average deviation between soil boring depths and scaled radar imagery is 0.7 inches. The deviation between scaled radar imagery and ground-truth auger data are as follows: within 2.1 inches at all sites; within 1.0 inches in 80 percent of all sites; and within 0.5 inches in 60 percent of all sites. The match between ground-truth data and scaled radar imagery conforms with observations made in areas of uniform horizons or layers in other states.

B. Mine Spoil Area

An attempt was made to use the GPR to measure the thickness of "top soil" or "top dressing" which was spread across the surface of mine spoil during reclamation processes. "Top dressing" consists of intermixed soil material from surface and subsurface layers and the upper part of the subsoil. This material is removed and stockpiled prior to mining.

Nine plots, each suposedly having a distinct thickness of "top soil," were located within the study area. Thickness of "top soil" varied between plots and ranged from 0 to 12 inches. A transect line was established crossing the nine plots. Along the transect line the "top soil" was observed to vary from 6 to 12 inches. The soil was Fairpoint (loamy-skeletal, mixed, nonacid, mesic Typic Udorthents).

The 500 MHz antenna was used in this study. The narrower band width of the 500 MHz antenna provides the briefest clear time and the most improved resolution of near surface features. At this site the 500 MHz antenna possessed sufficient energy to probe to an established depth of about 30 inches and deeper depths of penetration are possible.

Near surface reverberations and signal superpositioning in the upper part of the graphic profiles caused the top dressing/spoil interface to be masked. Later various methods of signal processing were used to improve the resolution of near surface interfaces. The best resolution was attained by printing only one polarity; either the positive or negative pulse. As seen in Figure 6A, this procedure resulted in the resolution of a fairly distinct and uncomplicated interface (A) in the upper part of the graphic profile. This interface is believed to be the contact between the overlying, friable top soil and spoil material and the underlying, firm spoil material. Below this interface numerous point objects, possibly larger rock fragments, are evident.

In Figure 6B, the hyperbolic patterns of a buried metal bar is apparent. The bar was buried at a depth of 13 inches in the spoil material. Both polarities have been printed in this figure. At "B," the superpositioning of desired and reverberated signals have masked the subsurface interface signal caused by variations in degree of compaction (A in Figure 6A).

C. Wooster

The GPR was used on glacial drift at the Ohio Agricultural Research and Development Center near Wooster. In addition to the possibility of providing data on the variability of the soils, an opportunity was seen to field test the radar on glacial deposits.

The dominant soils in the study area were Canfield (fine-loamy, mixed, mesic Aquic Fragiudalfs) and Riddles (fine-loamy, mixed, mesic Typic Hapludalfs). Most soil profiles had a lithologic discontinuity; loess in the upper part and dense till in the lower part. In many areas fragic properties or fragipans had developed at the contact of these two dissimilar deposits. During field work an abrupt change in soil consistency from friable to firm marked the boundary of these materials. Generally the soils were moist and, in some pedons, water was perched above the dense till.

Both the 80 and 120 MHz antennas were used at Wooster. The maximum depth of consistent penetration for both antennas was approximately 1 meter. The 80 MHz antenna provided slightly greater depths of penetration, but the difference was considered insignificant. Though deeper depths of penetration were achieved with both antennas in some areas, these depths appear to be exceptions to an otherwise more restrictive trend. Deeper penetration was probably caused by drier soil conditions on higher lying positions, lower clay content, or a thinner loess cap.

The GPR is not only highly site specific but is also weather dependent. Attenuation of the radar signal is directly proportional to the moisture content. The maximum depth of penetration is inversely related to the attenuation of the radar signal in a medium. Returning to this study area when the soil is drier would undoubtedly increase the depth of penetration and the resolution of subsurface features. Regardless of the time of

year, it is considered unlikely that depths in excess of 2 meters can be consistently achieved.

Two transects were established in the study area. Each crossed delineated bodies of several map units. Flags were placed at 50 foot intervals along each transect line and served as reference points.

Since most of the discernable information obtained with the GPR was in the upper 1 meter of the soil profile, transects were conducted with a scanning time of 32ns. This adjustment provided sufficient scanning time to probe to a depth of slightly greater than 1 meter in wet loamy soils. As a procedure, reducing the scanning time increases the printing space available on the graphic recorder per unit depth scanned. This enlargement process increases the detail and the accuracy of shallow depth measurements.

Figure 7 is a segment of a graphic profile obtained from a transect conducted with the 80 MHz antenna. The roughness of the surface, the depth to and the lateral extent of a subsurface interface (A), and the occurrence of a zone of sedimentary rocks (B) are apparent.

The subsurface interface is believed to represent the contact between loess and till. The identity of this interface is speculative and will require further correlation between ground-truth observations and scaled radar imagery. Additional features were observed in the upper part of the soil profile which could have caused this electromagnetic response. These features include: an argillic horizon, a perched water table, a zone of mottling and ferrous oxides, and layers of dissimilar consistency. Alone or in combination these soil conditions undoubtedly affected and may have caused this interface signal.

In Figure 7, the signature of the subsurface interface appears uniform. The black band describing this interface appears consistent in intensity. The width of the black and white bands along the interface are variable and can be used to infer change. Lateral changes in electromagnetic properties

along this interface can be inferred from changes in the widths of the light and dark bands on the graphic profile. As a general rule: the more abrupt or contrasting the interface separating layers or horizons, the stronger the amplitude of the reflected signal, the blacker and wider the dark bands, and the narrower the width of the white bands. Abrupt changes in consistency, texture, or moisture across this interface should result in wide dark bands and narrow white bands.

Later the 120 MHz antenna was used along the same transect line. Figure 8 is a reproduction of the graphic profile taken from the same area that was seen in Figure 7. The same settings on the control unit were used for each transect. The more rapid absorption of the signal emitted by the 120 MHz antenna has restricted its depth of penetration. The rock interface seen in Figure 7 was not apparent in the lower part of the graphic profile in Figure 8.

In Figure 8, the subsurface interface appears more variable. Lateral changes in the electromagnetic gradient across this interface can be inferred from changes in the expression of its graphic signature. In some areas the negative component (A) of the signal is apparent above the strongly expressed positive component. The occurrence and strength of expression of both signal components suggests a strong electromagnetic gradient across the interface. At "B" the negative signal component is absent and the signal is gray or is nonexistent. It is inferred that the interface is more diffuse and gradual at "B."

The speed of antenna advance is critical. The number of scans per unit area and consequently the level of detail can be increased on all graphic profiles by conducting transects at slower speeds. In Figure 9, a more detailed graphic profile was produced by slowing the rate of antenna advance. Note the increased levels of detail along the subsurface interface. At "A," the interface signal is diffuse and is intermediate gray in expression. A

gradual clay increase and ill-defined argillic horizon is inferred from this graphic signature. At "B," the positive band appears darker and wider and the interface is more strongly expressed. A stronger electromagnetic gradient across the subsurface interface occurs at "C." Here the negative and positive signal components are strongly expressed. The positive pulse is at its widest and darkest expression. Possibly this area is characterized by a strongly expressed fragipan. It is realistic to believe that with experience greater and more confident interpretations can be made.

A pipe was buried at various depths in a wall of a soil pit to confirm the depth scales calculated for these GPR observations. The 120 MHz antenna was pulled across the area with the identical settings which were used on all previous transects conducted at Wooster. In Figure 10, an air filled cavity at a depth of 20 inches is apparent at "A." A pipe buried at a depth of 40 inches is evident at "B."

The buried pipe experiment was conducted after a period of heavy rains. The increased moisture content of the soil slowed the signal and limited the depth scanned in the established time interval. A pipe, buried at a depth of 40 inches, is still shallow enough to be included in the graphic profile. On the basis of this observation it is most probable that the GPR was effectively scanning to a depth of greater than 1 meter in the transects conducted at Wooster.

Although the pipe was buried at a depth of 40 inches, none of the soil horizons observed in the soil pit between a depth of 30 to 40 inches was apparent on the graphic profile. This can be attributed to the greater reflection magnitude of the pipe than the soil interfaces. The interfaces were either too gradual or subtle in electromagnetic properties, or the gradient had been dampened by the additional soil moisture.

TABLE 1

Deviation Between Measured Depths and Scaled Radar Imagery

Method of Measurement	Reference Points					
	1	2	3	4	5	6
Depth to rock	24.0"	20.0"	20.0"	23.0"	23.0"	-
Scaled depth	24.0"	20.2"	22.1"	22.7"	22.1"	
Absolute deviation	0.0"	0.2"	2.1"	0.3"	0.9"	

Average deviation - 0.7"

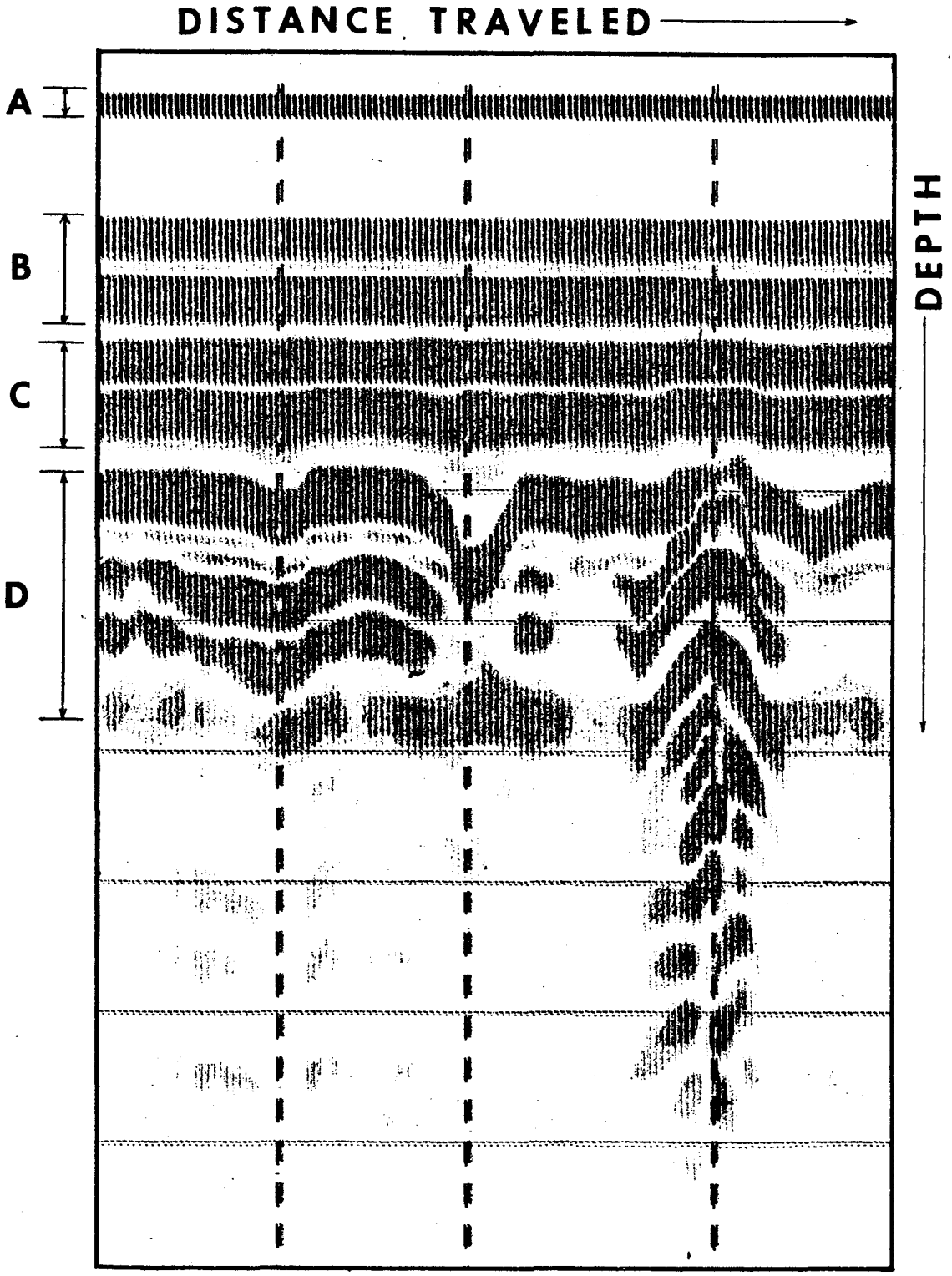


FIG. 1

A GRAPHIC PROFILE

FIG. 2
SIGNAL ENHANCEMENT

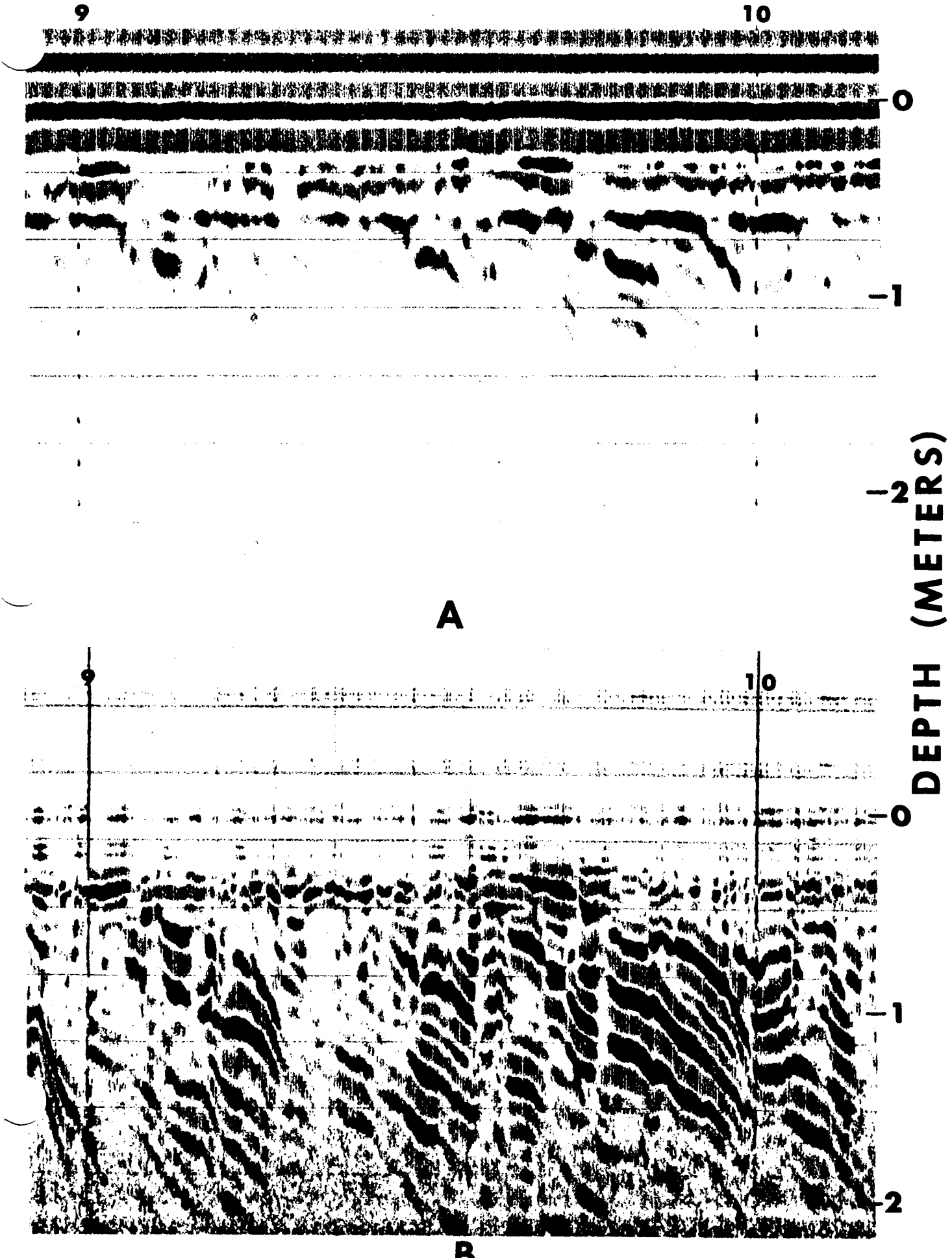
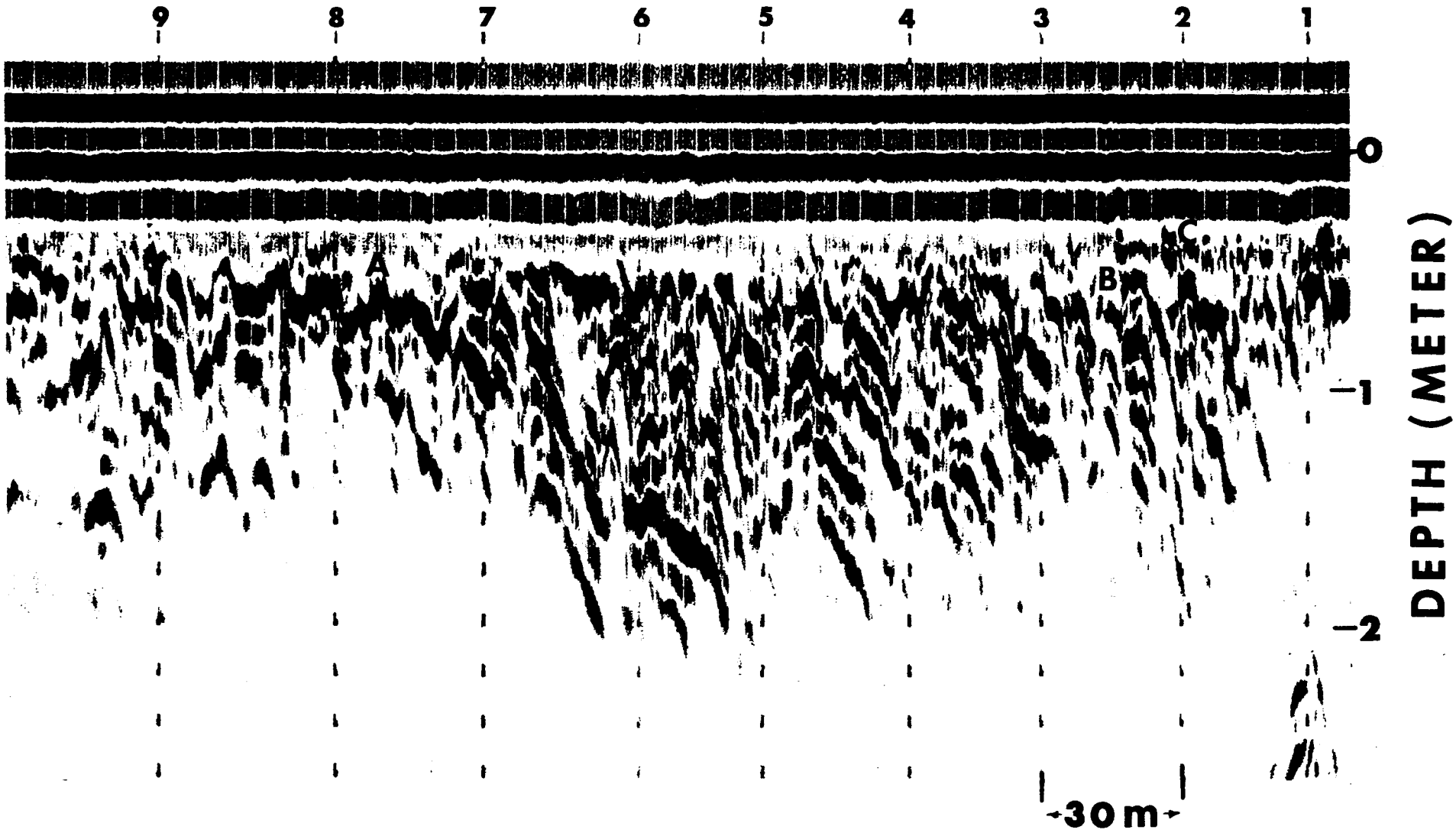
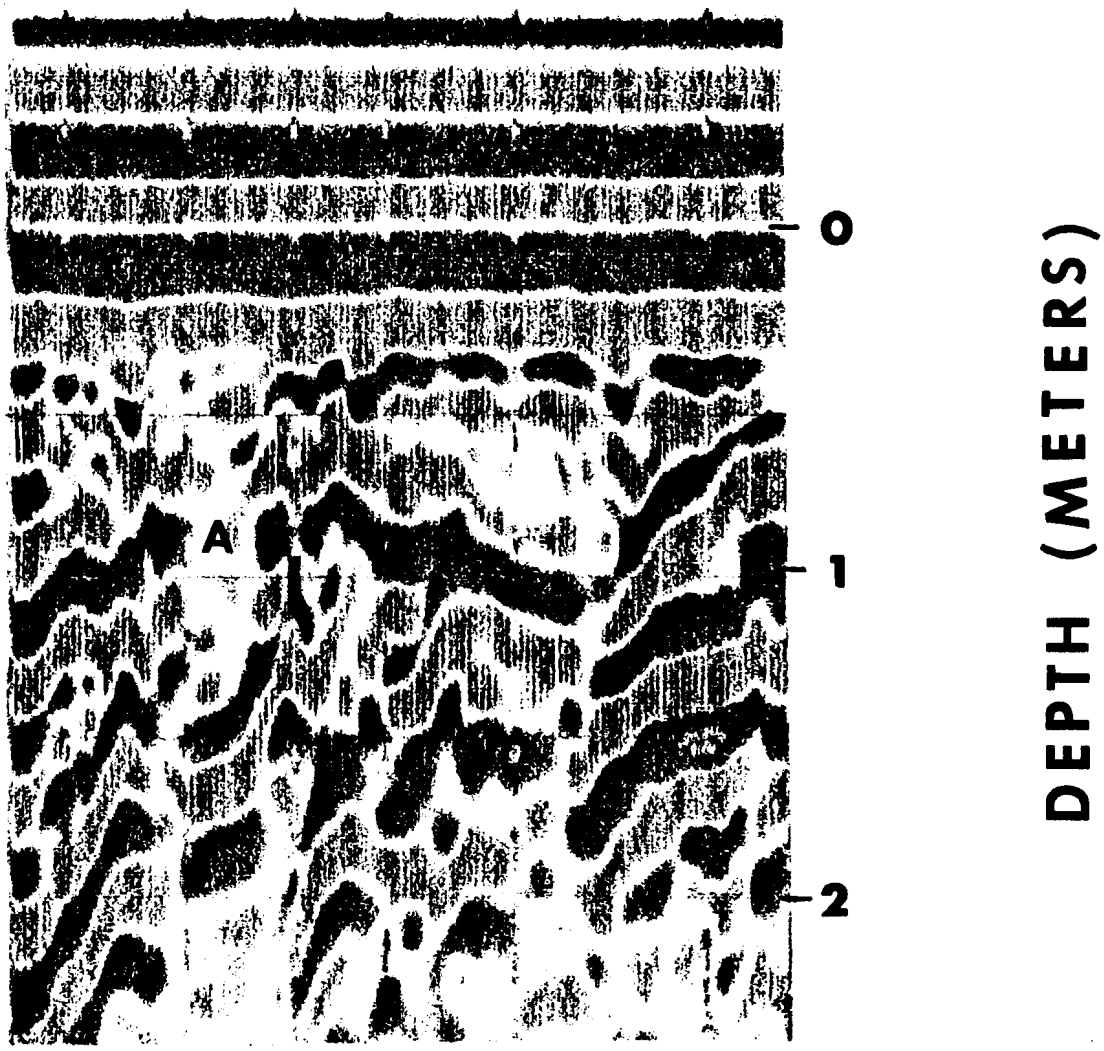


FIG.



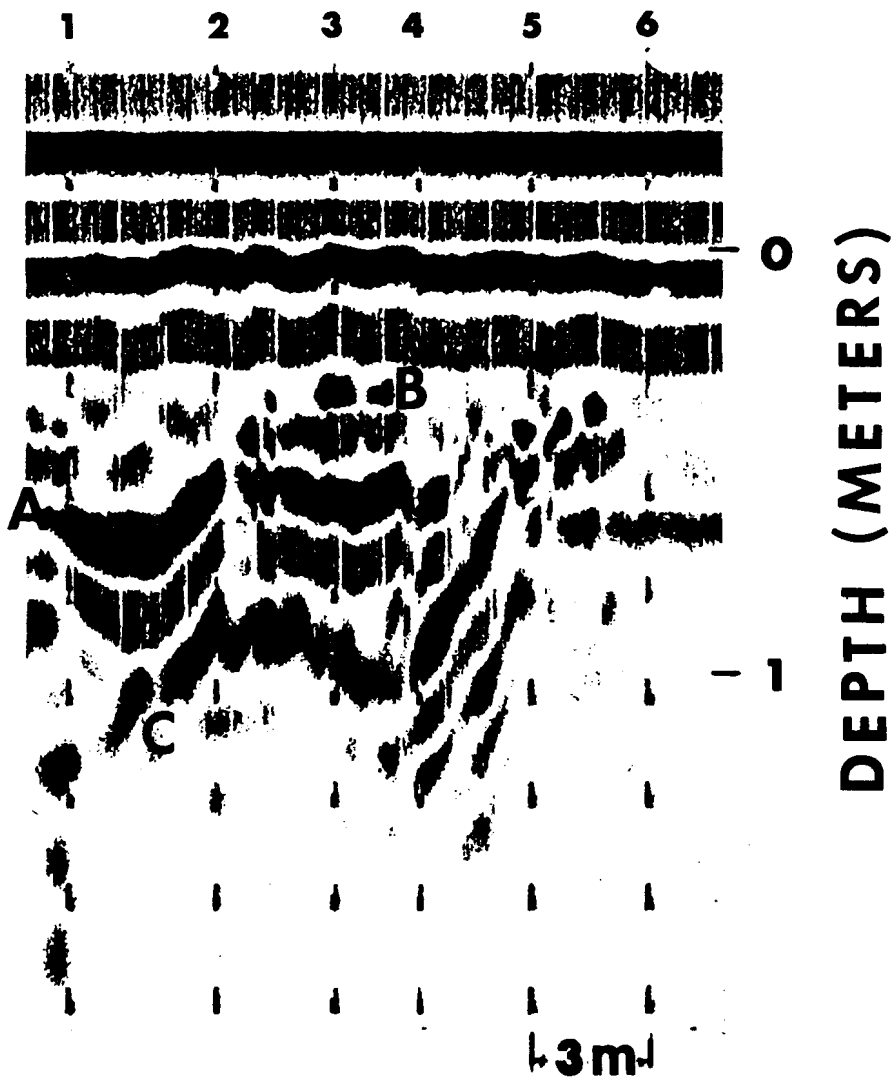
TRANSECT IN AREA OF COSHOCTON AND RIGLEY SOILS

FIG. 4



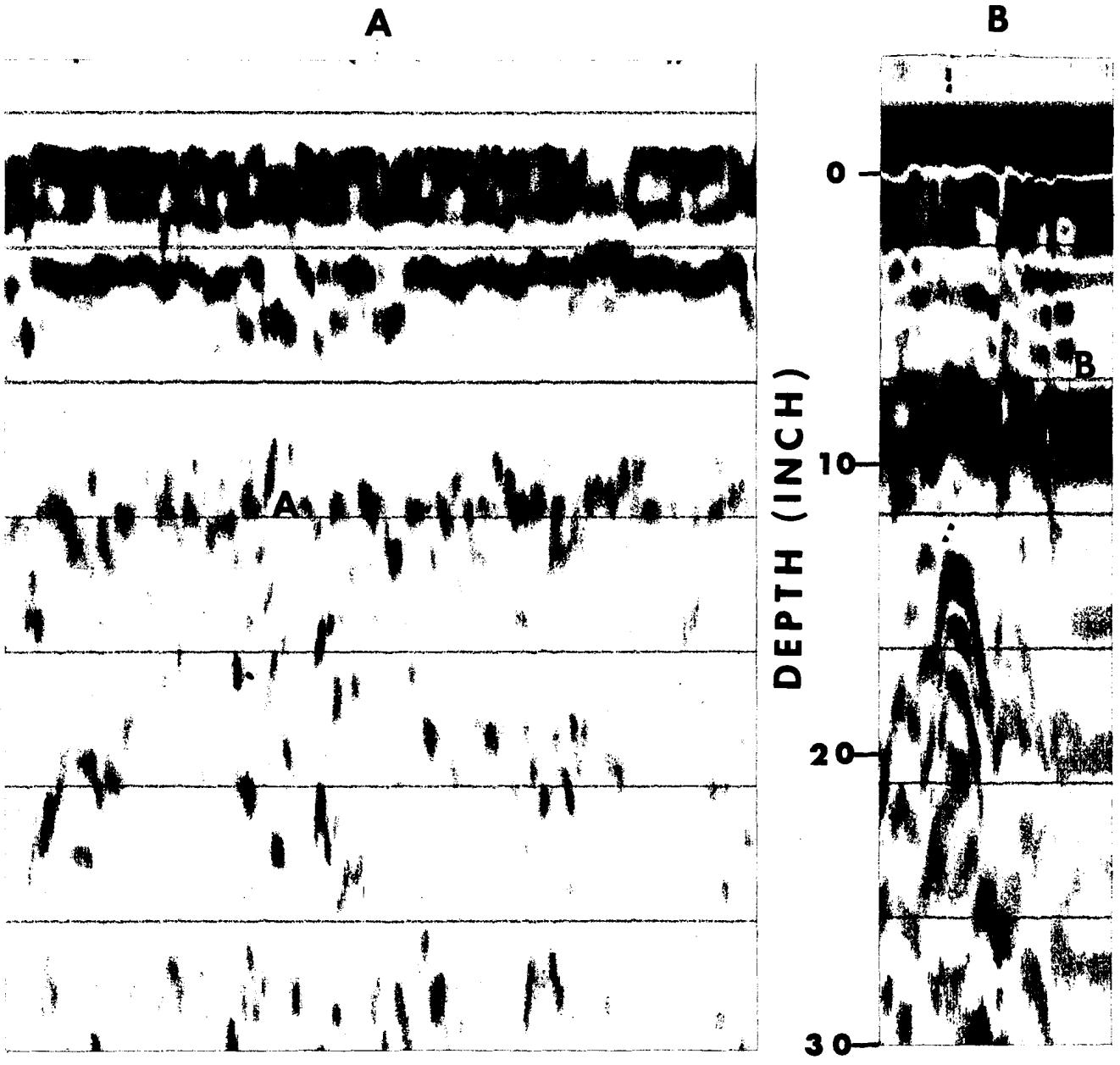
GRAPHIC PROFILE OF MULTIPLE, THIN, SEGMENTED, HORIZONS AND STRATA OF BEDROCK

FIG. 5



VARIATIONS IN THE DEPTH TO SANDSTONE

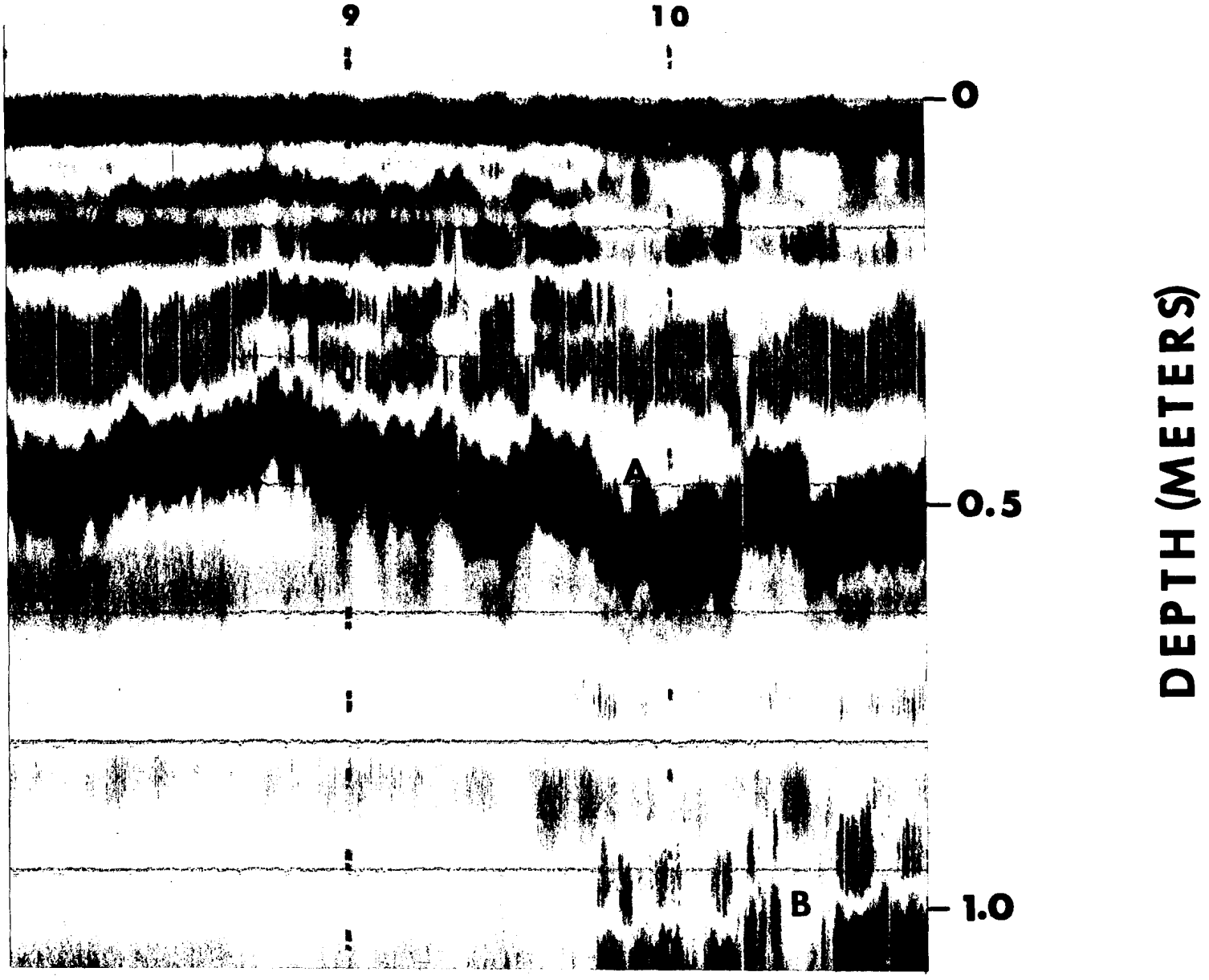
FIG. 6



MINE RECLAMATION AREA

500 MHz

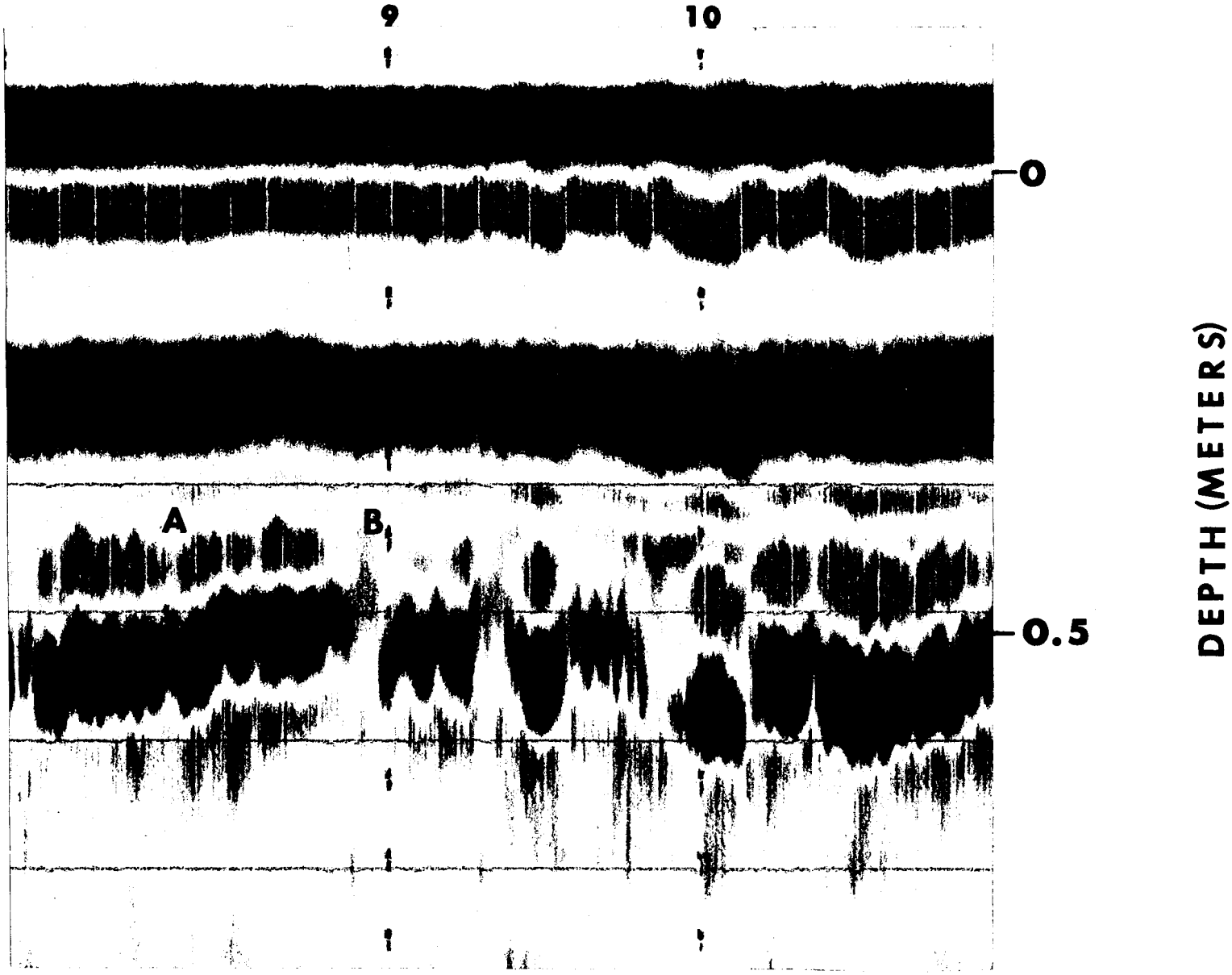
FIG. 7



GPR TRANSECT IN AN AREA OF RIDDLES–CANFIELD SIL

80 MHZ

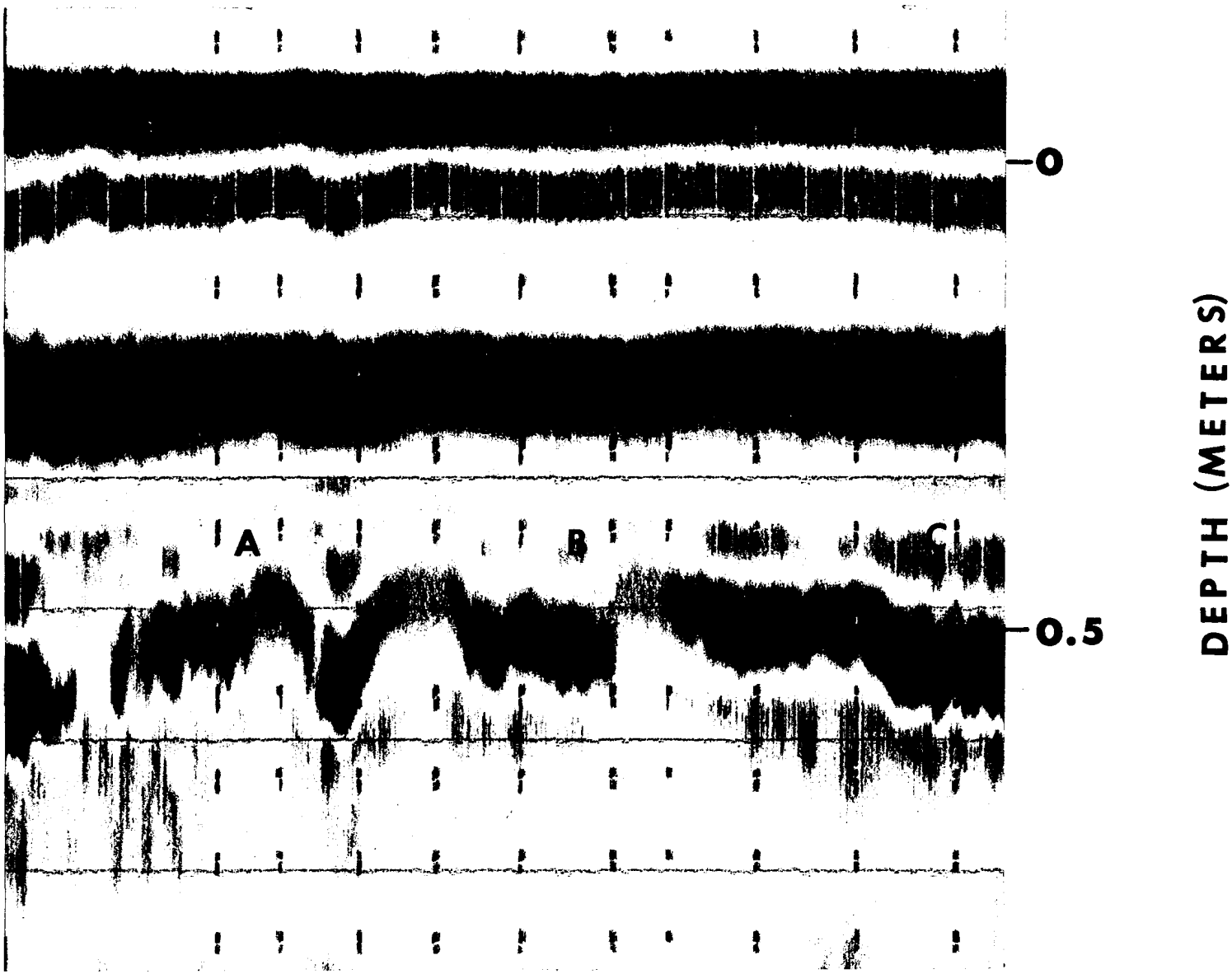
FIG 8



GPR TRANSECT IN AN AREA OF RIDDLES–CANFIELD SIL

120 MHZ

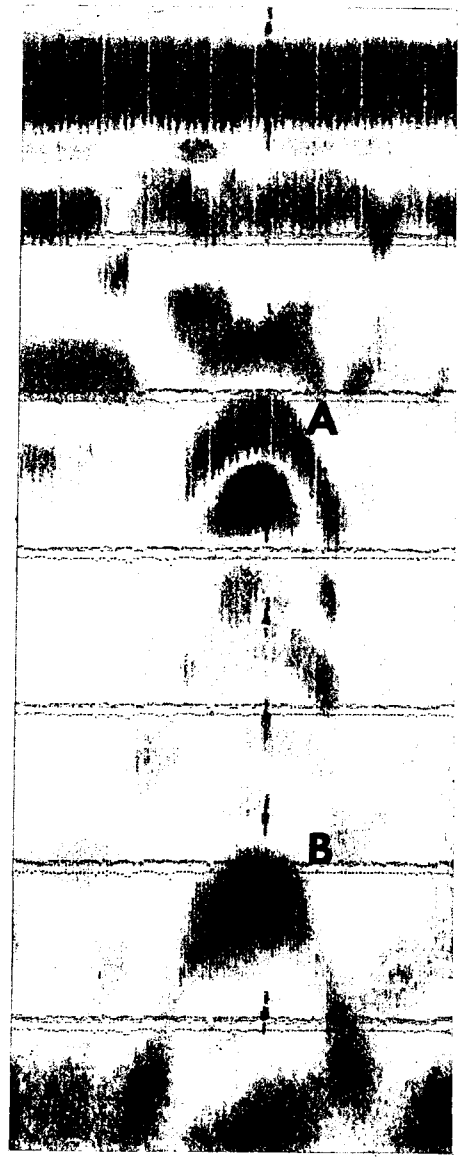
FIG 9



GPR TRANSECT IN AN AREA OF RIDDLES-CANFIELD SIL

120 MHZ

FIG. 10



GPR PROFILE OF A CAVITY AND A BURIED PIPE