United States Department of Agriculture

Soil Conservation Service

401 S.E. First Ave., Rm 248
Gainesville, Florida
32601

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

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To: Dr. Carolyn G. Olson
U. S. Geological Survey
National Center, Mail Stop 431
Reston, Virginia 22092

File Code: 430-5

During the period of October 15-17, 1984, a GPR field study was made by personnel of the U. S. Geological Survey and the Soil Conservation Service in the Massanutten Mountains of Virginia. The purpose of this field study was to evaluate the effectiveness of the GPR as a reconnaissance tool for determining the depth to bedrock and characterizing soils and surficial materials in forested terrain. The specific site of this investigation was the Mill Run Watershed, Massanutten Mountains.

Participants included:

Owen Bricker, Hydrologist, USGS-WRD, Reston, VA
Louis W. Heidel, Soil Survey Party Leader, SCS, Woodstock, VA
Carolyn G. Olson, Geologist, USGS-WRD, Reston, VA
Dean Rector, Soil Specialist, SCS, Richmond, VA
Michael Shackelford, Hydrologist, USGS-WRD, Reston, VA

The equipment utilized during this study was the SIR System-8 manufactured by Geophysical Survey Systems, Inc. (Trade names have been used to provide specific information. Their mention does not constitute endorsement.) The SIR System-8 consists of a control unit with microprocessor, a power distribution unit, an ADTEK SR 8004H graphic recorder, and an ADTEK DT 6000 tape recorder. The system was powered by either a 12-volt battery or a portable 500 watt generator.

The GPR performed well in the study area. Generally, the radar probed deeper and provided the most detailed subsurface information in the coarse to moderately-fine textured soils which formed in residium weathered from sandstone. In most soils, the GPR provided exceptional profiles of such subsurface features as: fragipans, argillic horizons, boulders, and lithologic discontinuities. In the moderately fine to fine textured soils formed in colluvium or alluvium weathered from shale, the effective probing depth was about 3 meters. From summit to lower backslope, the GPR provided a near complete profile of the depth to bedrock. The soil/bedrock interface was clear and interpretable in 80 percent of all observation sites. In the other 20 percent, the surface of the bedrock was obscured or uninterpretable.

These results are encouraging. As a rapid reconnaissance tool for site assessment, the GPR appears to offer a highly reliable and comprehensive method for differentiating soil horizons and near-surface discontinuities under similar conditions in the Valley and Ridge Physiographic Province.

The enclosed report summarizes the major interpretations of the field work. All pertinent graphic profiles have been returned under a separate cover letter. As all transects were recorded on magnetic tapes, additional copies are available upon request.

James A. Doolittle

James A. Doolittle
Soil Specialist (GPR)

Attachment

cc: w/attachment
Richard W. Arnold, Director, Soils Division, SCS, Washington DC
A.B. Holland, Director, NENTC, SCS, Chester PA
Manly S. Wilder, State Conservationist, SCS, Richmond VA
James W. Mitchell, State Conservationist, SCS, Gainesville FL

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.

Discussion of Results

This report summarizes the major observations of this field study. Ten transects were established in the Mill Run watershed to study the feasibility of using GPR to determine the depth to bedrock and to characterize soils and surficial materials in forested terrain. With the exception of one transect (transect x), each was about 300 meters in length. All were located on trails which provided access for a 4WD vehicle into an otherwise inaccessible area. At regular intervals (30m) along each transect line, flags were placed in the soil and functioned as observation points. As the antenna passed by each of these observation points, the operator depressed an event marker on a remote control. This procedure impressed a vertical mark(s) on the graphic profile which corresponded with the observation point. Each transect contained 10 observation points. Transects were conducted by towing the 120MHz antenna in a sled at a very slow walking pace.

The vertical scale, or depth scale, on graphic profiles is dependent upon the two-way travel time of the electromagnetic pulse. To depth scale the radar imagery, either the depth to a particular interface or the relative dielectric constant of the medium must be known. For most soil investigations, the depth scale is easily determined by a few ground-truth auger borings. Unfortunately, numerous boulders and cobbles limited the effectiveness of spades and augers within the study area. Attempts to determine the depth to bedrock or soil horizons with conventional surveying tools were slowed and eventually thwarted by the rock fragments.

The depth scales used in this study were based on approximations of the relative dielectric constant of the earthen material. This procedure provides close but not precise approximations of the depth scale. Admittedly, it is difficult to accurately estimate the depth scales for transects which do not have ground truth boring data. Most earthen materials are ansiotrophic and

each layer has unique electromagnetic properties. The approximated relative dielectric constant of the entire profile is used to calculate depth scales on radar imagery according to the formula:

$$T = d \times \sqrt{\frac{Er}{0.15}}$$

where: T = scanning time in nanoseconds

d = probing depth in meters

Er = relative dielectric constant

All depth scales used in this study were based on a dielectric constant of 13.

Figure 2 is from a special transect in which the antenna was hand-towed across a summit area of the watershed. The Wallen (loamy-skeletal, siliceous, mesic Typic Dystrochrepts) soils are moderately deep over Massanutten sandstone. In this figure, the soil/bedrock interface has been highlighted by a dark line. The sandstone, characterized as being massive, displays a lack of reflected signals except along some fracture or bedding planes. On graphic profiles, a lack of subsurface reflections signifies the absence of subsurface interfaces, the complete dissipation of the radar signal, or both. It is inferred from the graphic profiles that only the larger and more near surface bedding or fracture planes are discerned by the radar. Moisture is free to circulate in these planes, to more intensively weather the rock, and to fill the spaces with dissimilar and more electromagnetically contrasting materials.

In Figure 2, the sandstone bedrock is identified by multiple, sub-parallel bedding planes (A) in the upper part of the profile. The massiveness and electrical homogeneity of the sandstone is inferred from the lack of subsurface interfaces in the lower part of this profile. The inclined parallelism of the bedding or fracture planes ends as the surface of the ground is approached and the influences of weathering processes become more intense. In response to weathering processes, the orderly inclination of the

bedding planes is altered, segmented, and translocated parallel with the surface of the soil.

In Figure 2, the soil/bedrock interface (dark line) was drawn by connecting the closest points to which the parallel planes approach the surface prior to becoming segmented or truncated. Insular clusters of rock fragments (B) are evident in the upper part of the profile.

Transect B (see Figures 3 and 4) was made across the upper backslope. The scanning time, and consequently the probing depth, was adjusted and two runs of this transect were made; one at 140 nanoseconds (Figure 3) and one at 252 nanoseconds (Figure 4). In Figure 3, the GPR provides an exceptional profile of the bedding planes within the sandstone to a depth of 5.5 meters and a clear representation of the soil/bedrock contact. Though in Figure 4 the GPR appears to probe to depths in access of 8 meters, high levels of induced resonances interfere with reflections from desired signals and make interpretations exceedingly difficult below a depth of about 7 meters. The multiple bands of induced resonances, or background noise, become noticeable at higher gain settings on the control unit. High gain settings are often required to amplify weak subsurface signals.

In both of these figures, the bedding or fracture planes appear to be strongly inclined and approach the surface at an extremely acute angle. Though strongly dipping, the actual angle of inclination may have been distorted somewhat by the vertical exaggeration of these graphic profiles. Compare the horizontal scales with the vertical scales. This distortion does not affect the accuracy of the depth measurements.

In many mid and lower backslope areas (see Figures 5 and 6) the colluvium/bedrock interface was obscured by large concentrations of rock fragments. The quantity, size, and shape of these rock fragments affect the quality of interpretations. As the number of rock fragments (see B in Figures 5 and 6) increase in the overlying colluvium, the boundary separating bedrock

from soil may appear too irregular or indistinct on the graphic profiles to be easily distinguished. While the imagery of the area immediately above the colluvium/bedrock interface may be too cluttered with rock fragments, the imagery of the underlying bedrock is generally free of random interfaces.

Resolution of point objects, such as rock fragments, is generally limited to one-half the wavelength of the antenna in a particular medium. With increasing soil depth, rock fragments must be increasingly larger or clustered to be discerned by the GPR. In Figure 6, observe the decrease in the apparent number of rock fragments immediately above the surface of the bedrock. In this zone, the majority of the rock fragments have most likely passed below a critical size to depth ratio and can no longer be profiled by the GPR.

The shape of a rock can contribute to spurious reflections. Spurious reflections are reflections directed away from the antenna. These reflections account for a portion of the lost imagery in some areas.

Qualitative observations concerning the interpretability of the soil/bedrock interface are listed in Table 1. This table was prepared by rating the clarity of the soil/bedrock interface at evenly spaced intervals along each graphic profile. Ground truth observations would verify the imagery and increase the accuracy of most interpretations. In 80 percent of the observation sites, the clarity of the soil/bedrock interface was good or fair. In the other 20 percent, the surface of the bedrock was obscured or uninterpretable. The poor quality of the images in some areas is attributed to: (1) unfavorable ground conditions, (2) the equipment being out of optimum adjustment for a particular site, or (3) the equipment being pushed beyond its limits.

As a rule, images of the bedrock surface were clearer and more easily discerned on summit and upper backslope positions. Images of the bedrock surface were generally of poorer quality on mid to lower backslope positions

TABLE 1

Interpretability of the Soil/Bedrock Interface

Transect	A	B	C	D	Aug.
Good	89%	64%	34%	34%	55%
Fair	11%	20%	28%	40%	25%
Poor	-	16%	32%	24%	18%
Very Poor	-	-	6%	2%	2%

where the colluvium was thicker, rock fragments more numerous, and the bedrock surface more irregular.

The GPR was an effective tool for determining the depth to and tracing the lateral extent of major subsurface horizon within the study area. Figure 7 is from a transect conducted with the GPR in an area of Sequoia (clayey, mixed, mesic Typic Hapludults) soils. The upper boundary of a major subsurface horizon (A), perhaps the argillic horizon, is evident across the upper part of this profile. Sequoia soils are moderately deep over acid shales. Inclined bedding planes of the underlying shale bedrock are apparent at B. Though depths as great as 3 meters were obtained in areas of Sequoia soil, the depth of consistent and interpretable imagery was about 2 meters. These depths are considered remarkable, considering the high clay and shale contents of Sequoia soils.

Figure 8 is from an area of Laidig (fine-loamy, mined, mesic Typic Fragiudults) soil. Although the GPR profiled to depths of 6.8 meters along this transect (transect E), the effective depth of continuous and detailed data was about 4 meters. A fragipan (A) can be traced across this profile. In some areas (as near B), the image of the fragipan loses expression and becomes segmented. In these areas, the fragipan appears to have weaker expression and the boundary (or lithologic break) separating older from younger colluvium has become more gradational and less distinct. Isolated clusters of rock fragments are evident at B.

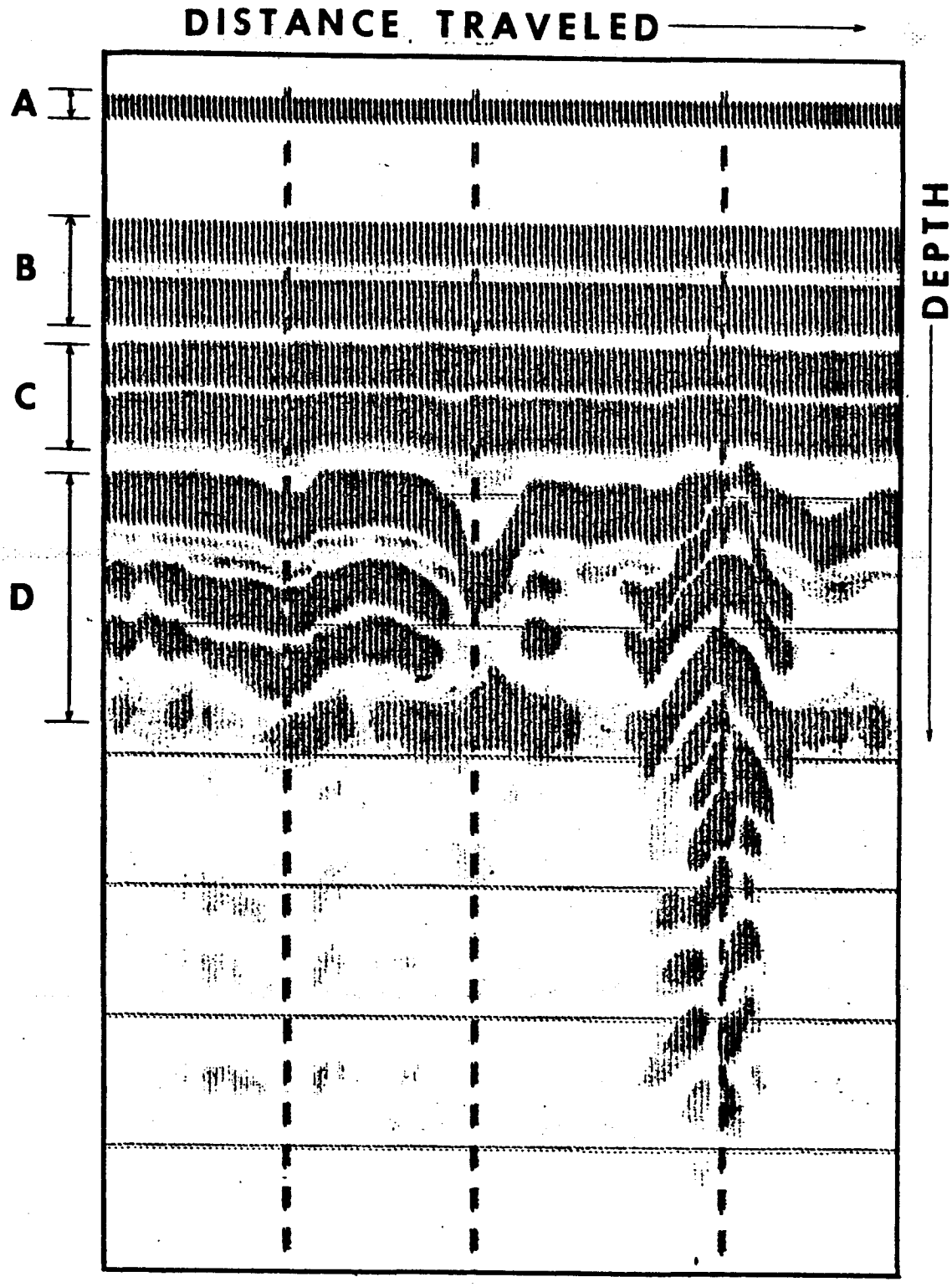
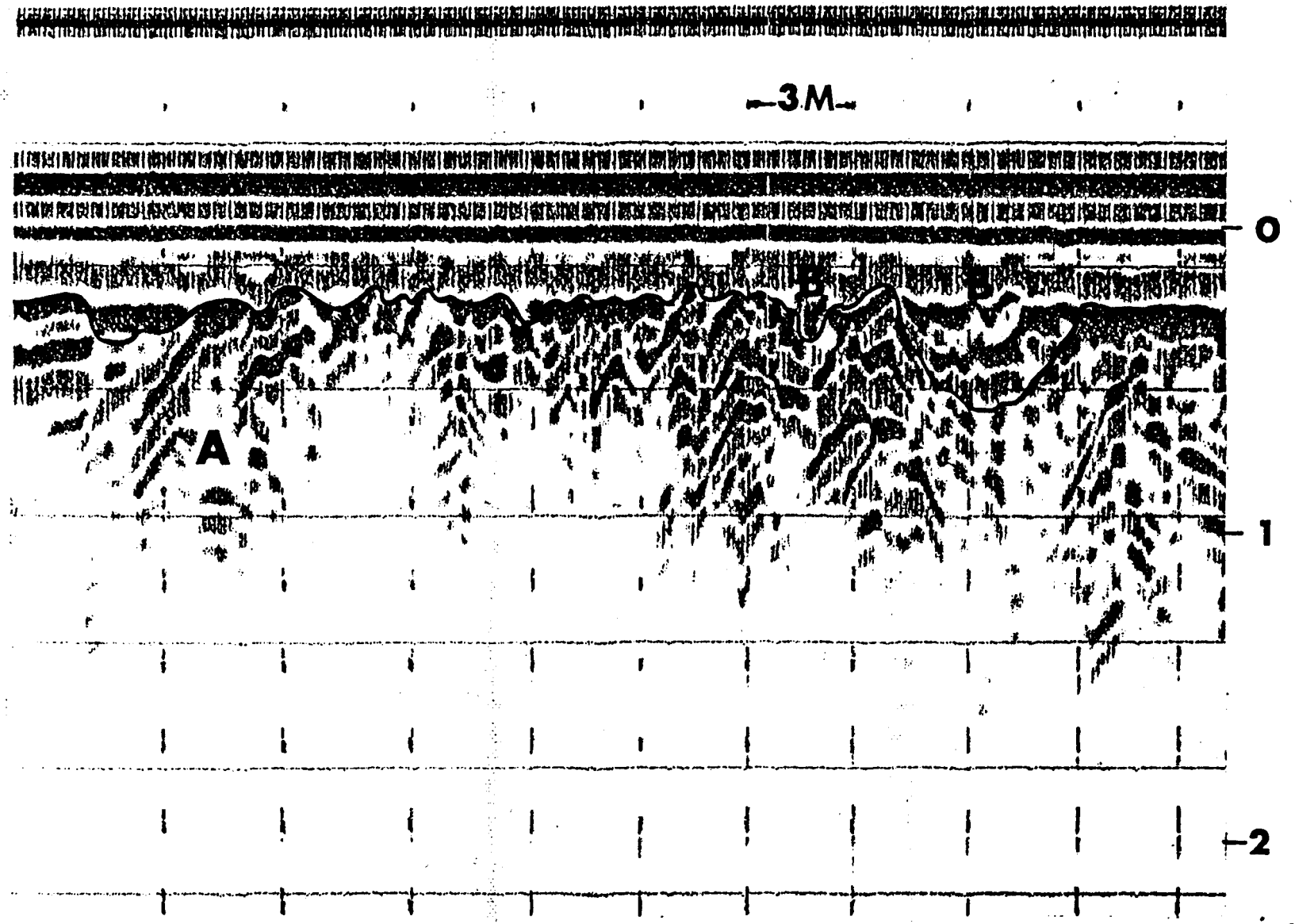


FIG. 1

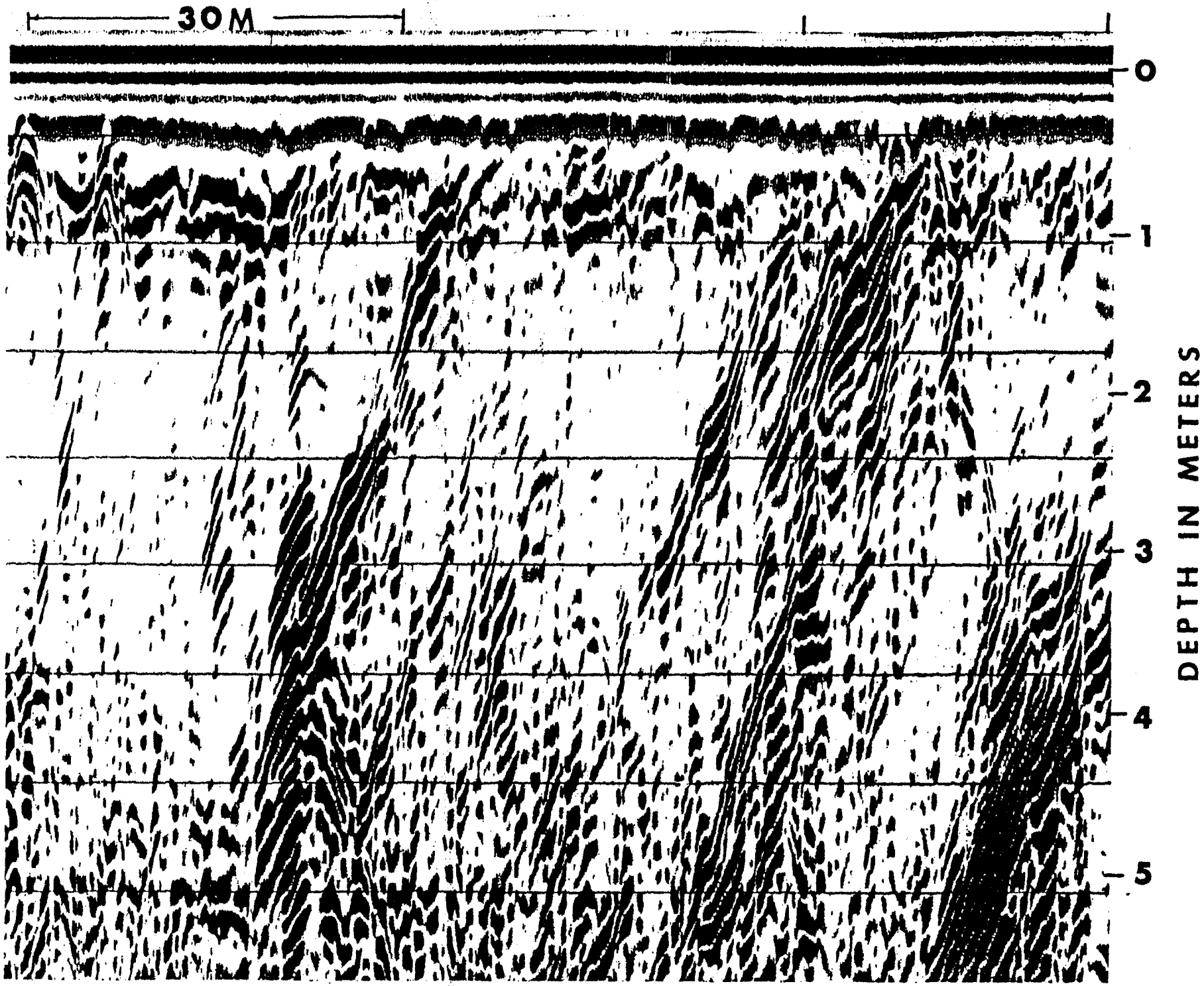
A GRAPHIC PROFILE

FIG 2



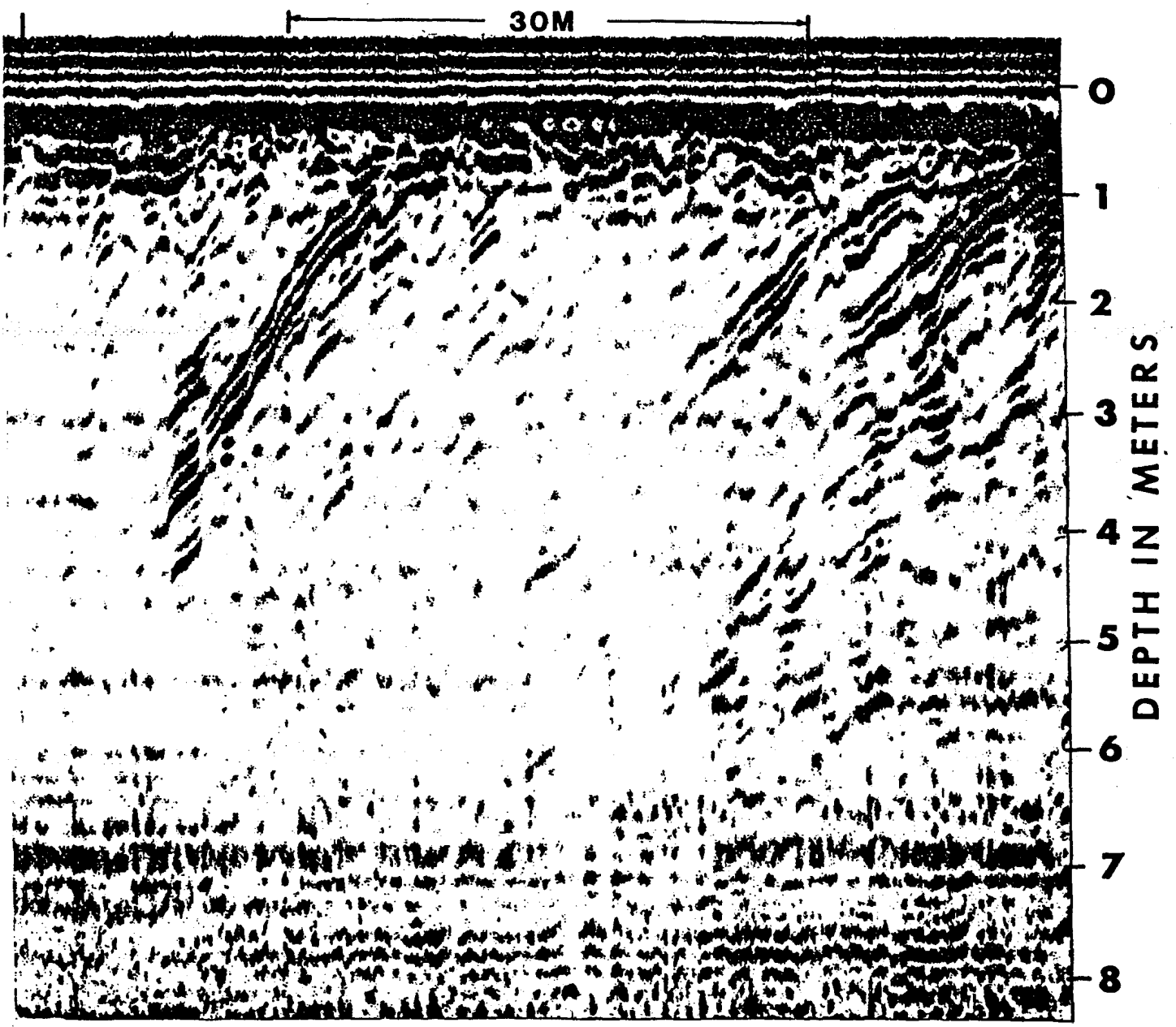
DEPTH TO BEDROCK
AREA OF WALLEN SOILS

FIG. 3



MASSANUTTEN SANDSTONE

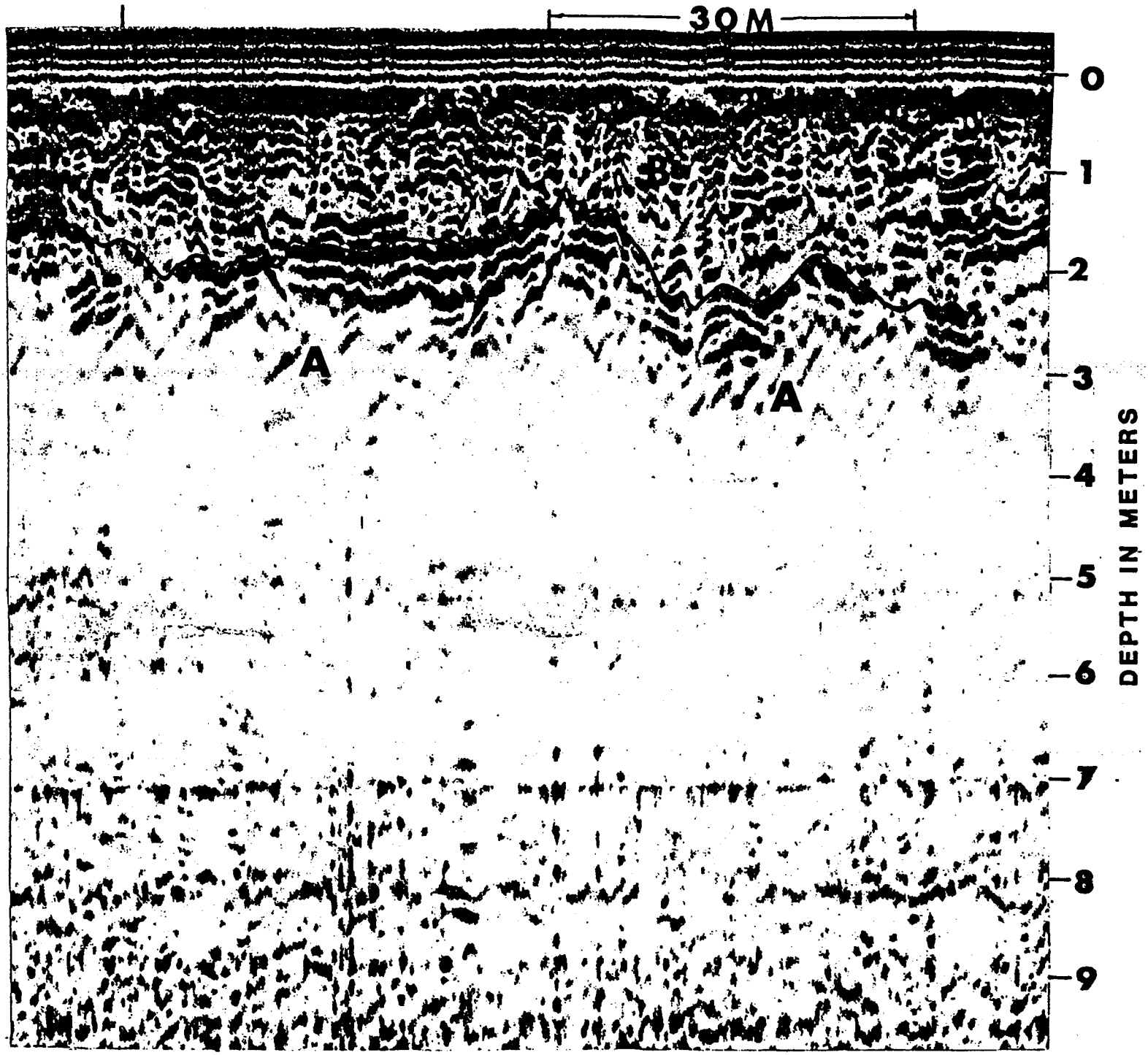
FIG. 4



BEDDING PLANES

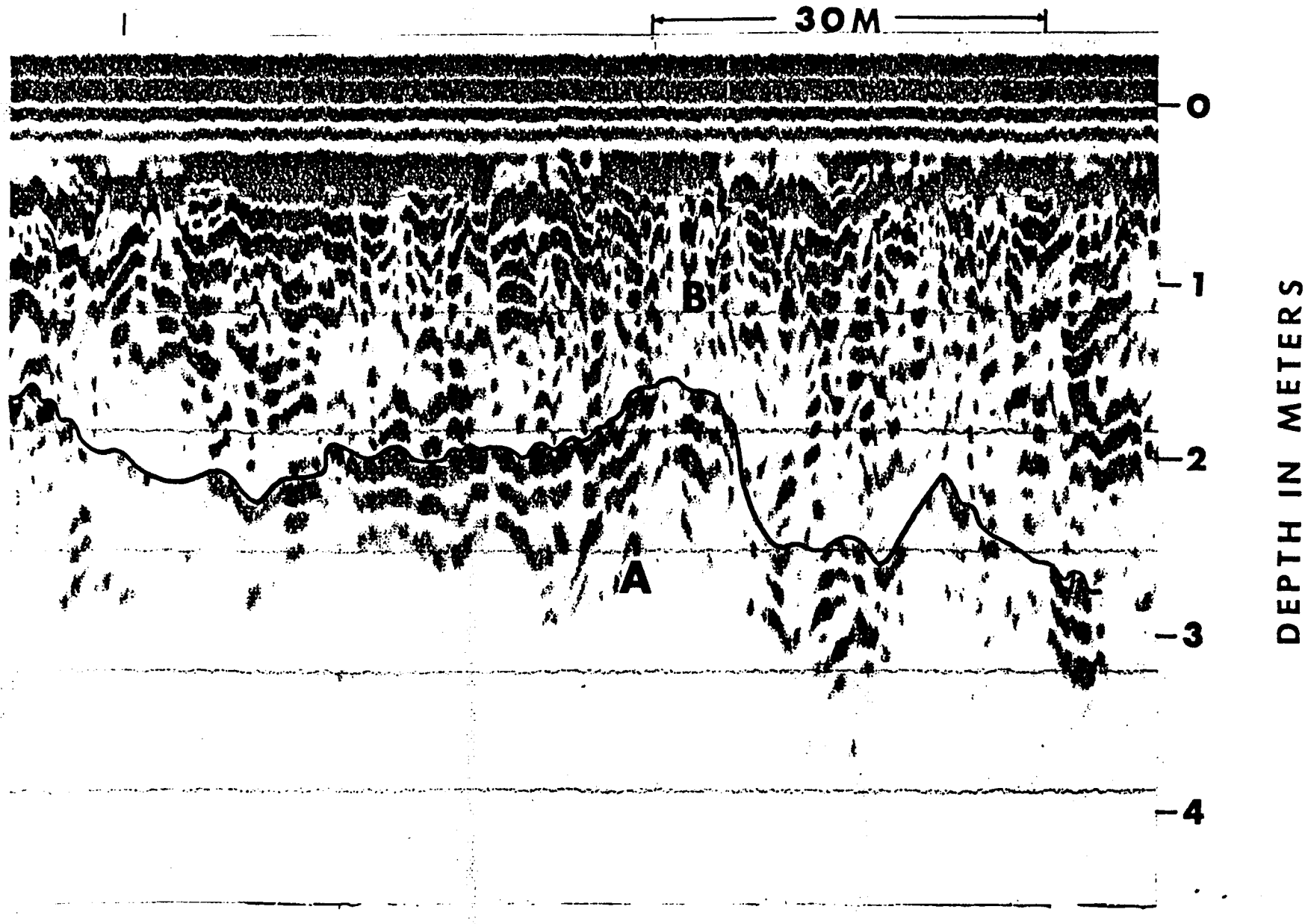
MASSANUTTEN SANDSTONE

FIG. 5

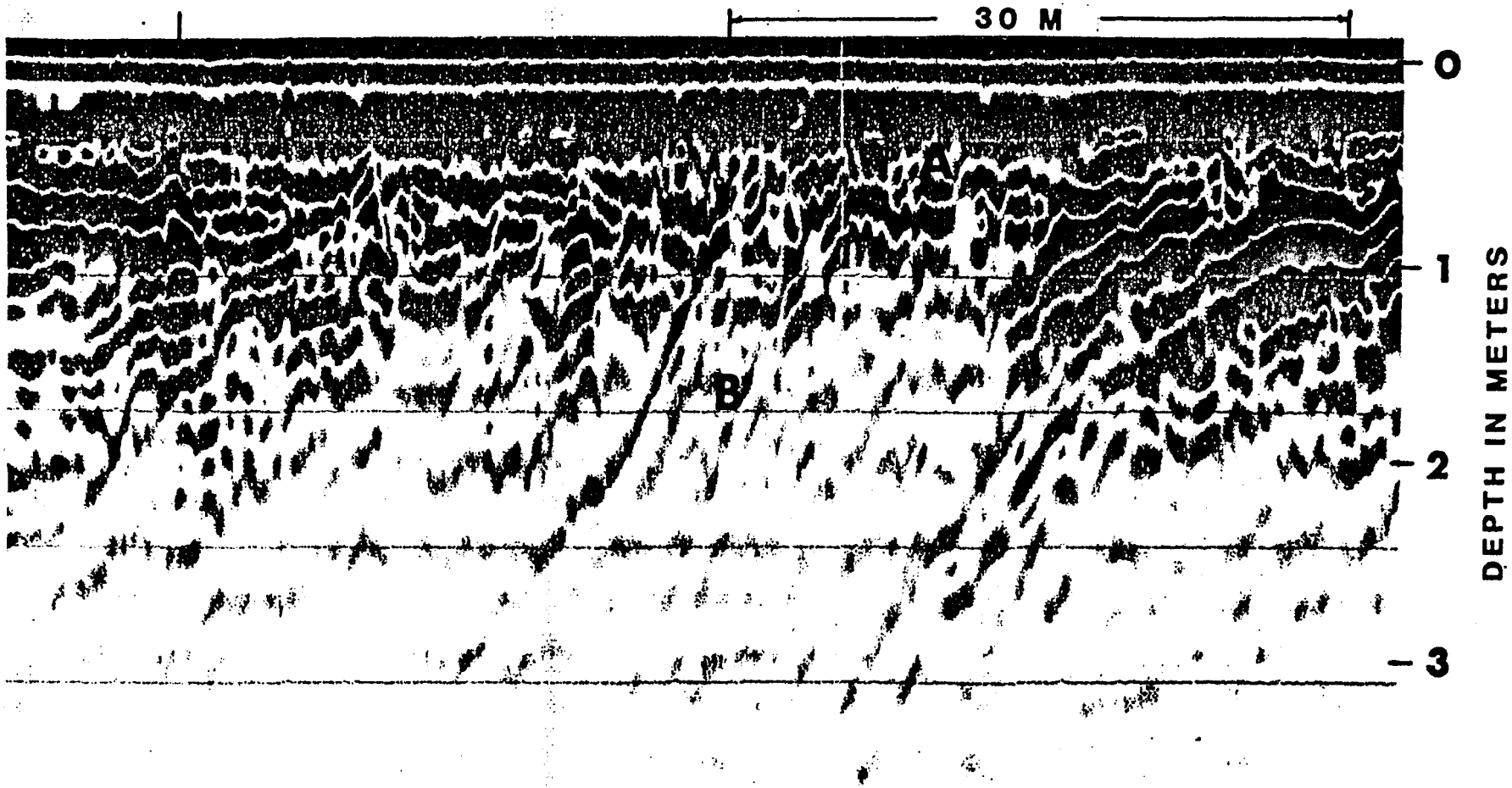


DEPTH TO BEDROCK

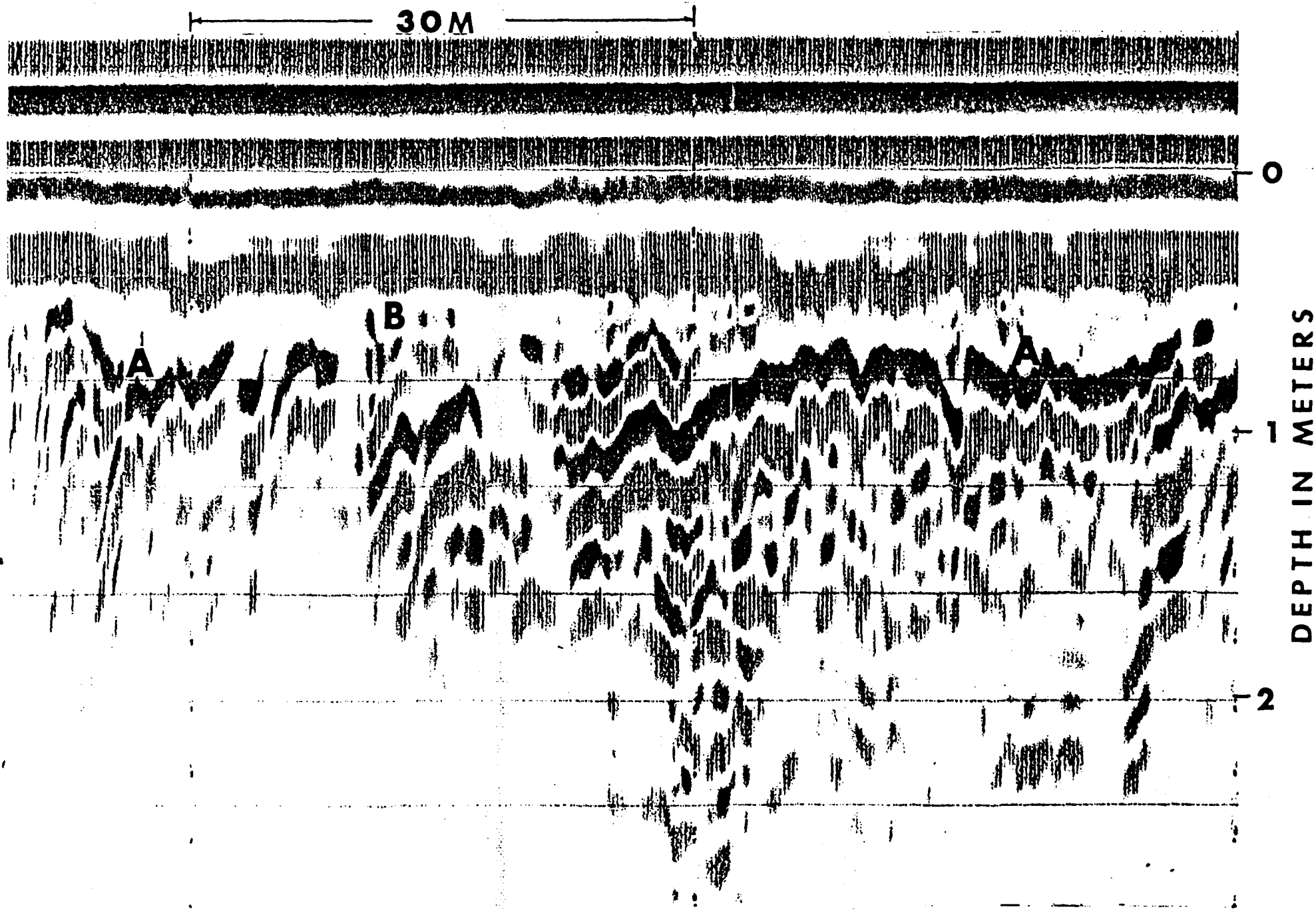
MASSANUTTEN SANDSTONE



COLLUVIUM OVERLYING SANDSTONE BEDROCK



GPR PROFILE FROM AN AREA OF SEQUOIA SOILS



GPR PROFILE OF TYPIC FRAGIUDULTS
LAIDIG SERIES