United States Department of Agriculture

Soil Conservation Service

401 SE 1st Avenue, Room 248
Gainesville, Florida
32601

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

Date: October 11, 1983

To: Donald C. Bivens
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During the period of August 29, 1983 through September 2, 1983, the ground-penetrating radar (GPR) was field tested in Tennessee. The objectives of this trip were to familiarize staff and field personnel with the GPR system, and to examine the applicability of this investigative tool in Tennessee.

Time was apportioned as follows: August 29, 1983 and September 2, 1983, in travel status; August 30, 1983, with Ronald Graner, Geologist, examining bedrock and collapse features near Clarksville, and structural foundations along Hurricane Creek in Humphreys County; August 31, 1983, with Bobby Birdwell, State Soil Scientist, and David Lewis, Jr., and Raymond Sims of the state soils staff, examining fragipans in the vicinity of Jackson; and September 1, 1983, in attendance at the annual Soil Survey Work Planning Conference in Jackson.

The equipment utilized during this field trip was the SIR System-8 with an EPC Laboratories, Incorporated, Model 2208S graphic recorder and a Hewlett-Packard Model 3964A tape recorder. An expanded complement of antennas (80 MHz, 120 MHz, 300 MHz, and 500 MHz) were used together for the first time. The equipment operated well and there were no mechanical problems.

In general, the effectiveness of the radar unit in the areas examined ranged from good to poor. The results from this field trip are too sketchy and inconclusive to warrant an appraisal of the systems potential in Tennessee.

Depth of penetration ranged from less than 2 feet to as much as 12 meters (based on "tabled" values of wave propagation in the absence of ground truth data), and varied inversely with the clay content. The system appears to differentiate differences in soil density which are associated with fragipans. All antennas were successfully used at some sites in Tennessee. Generally, the 500 MHz and 300 MHz antennas worked well in coarse-textured deposits, but the 120 MHz antenna appears to be the most versatile for use in Tennessee. More time needs to be spent categorizing the areas in Tennessee in which the system will and will not perform well and developing interpretive expertise.

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

James A. Doolittle

JAMES A. DOOLITTLE
Soil Specialist (GPR)

Attachments

cc:
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GEOLOGIC INVESTIGATIONS

The classic approach to subsurface site investigations consists of drilling a number of bore holes and examining the core samples. The number of cores sampled is often limited by considerations of time and money. Information extracted from core samples is extended across areas that have not been investigated. In some "high risk" areas this procedure is hazardous.

A relatively new technique, the ground-penetrating radar (GPR), is being field tested as an expedient reconnaissance and investigative tool for gathering continuous subsurface information. The system appears to be best suited for shallow (generally less than 30 feet) investigations. Unfortunately, the GPR does not perform well on sites where appreciable amounts of clays (especially the 2:1 expanding lattice clay) are present. It is anticipated that in many areas of the country, the GPR will provide significantly greater levels of confidence in site assessments than conventional methods with an equally significant economy of time and money.

The sites investigated in the Nashville basin were in areas of known subsurface fracturing or cavities caused by solution. These features are not easily identified by existing techniques and often occur in structural foundations. The desire to locate and size zones of weakness during the early stages of structural site assessments prompted the Soil Conservation Service to explore the effectiveness of GPR technology in providing meaningful subsurface information.

The first site selected for study was an active sink in an area adjoining the Clarksville Hospital. The sink is located in an area of Baxter (fine, mixed, mesic Typic Paleudalfs) soil. The high clay content of the Baxter soil prompted the use of the 80 MHz antenna, the lowest frequency antenna available. The 80 MHz antenna, having higher average and peak powers of radiations, was designed to provide maximum penetration. Two separate transects were conducted across the sink and its surrounding slopes with the 80 MHz antenna.

Figure 1 is a copy of a portion of one of these transects. Even with the 80 MHz antenna the depth of penetration was limited to less than two feet. Generally, earthen materials having high conductivities rapidly dissipate the transmitted electromagnetic energy and restrict the effective probing depth of the GPR. The conductivity of earthen materials increases with moisture content, the concentration of salts in solution, and the amount and type of clays in the matrix. The high clay content and saturated soil condition of this area were principal factors restricting the depth of penetration.

A zone of no signal return, referred to as a "white-out area," blankets the middle and lower portions of the graphic printout. A white-out area is produced by either a lack of interfaces or the rapid and complete dissipation of the radar signal. In this example, the absence of radar response is attributed to the high concentration of saturated clays in the earthen material.

The reflection from a paved road with underlying fill (area delineated between "a" and "b") and a buried culvert (peaked reflections at "c") are apparent in the upper portion of this figure. It was surprising to see such a high degree of near surface resolution with the 80 MHz antenna. This was unexpected. Most operational quidelines specify that the lowest frequency antenna (80 MHz) achieves the greatest effective depth of penetration, but

provides the poorest resolution of features. Evidently, as the apparent dielectric constant of a medium increases, the propagating wave forms of the lower frequency antenna becomes electrically shorter and the resolution improves.

Figure 2 is from a transect that was conducted in a park near Clarksville, Tennessee. The area was wooded and sloped into a stream channel where alluvial deposits were evident along a cutbank. The area was underlain by bedrock at variable depths. Transects were conducted with the 80 MHz, 120 MHz, and the 300 MHz antennas. The 300 MHz antenna experienced high levels of noise which confused or masked the interface signals. Most subsurface features were too poorly resolved for proper interpretations with the 80 MHz antenna. The signal from the 120 MHz antenna was remarkably clear and provided adequate penetration depth.

Figure 2 is a copy of a portion of the transect taken with the 120 MHz antenna. The depth scales used in each of the geologic study sites were based on approximations of the relative dielectric constants of the earthen material. Admittedly, it is difficult to accurately approximate the depth scales in transects without ground truth boring data. Most earthen materials are ansiotropic and each layer has different electromagnetic properties which effect the rate of signal propagation. The approximated relative dielectric constant of the profile is used to calculate the depth scale according to the formula:

$$T_{(ns)} = d_{(m)} \times \sqrt{\frac{Er}{0.15}}$$

where $T_{(ns)}$ = scanning time in nanoseconds
$d_{(m)}$ = distance in meters
Er = relative dielectric constant

In Figure 2, a scanning depth of 8.06 meters was scaled on the graphic profile based upon an assumed dielectric constant of 10.

The radar has clearly recorded the contact between the overlying sediments and the limestone bedrock (see "a"). The bedrock appears to dip steeply away from the upper center portion of this figure. This transect was conducted across an irregular and sloping surface. The surface is always printed as being horizontal on the graphic printout regardless of the variation in slope angle along the transect. The apparent inclination of the upper contact of the bedrock must be reconstructed into its true inclination after adjustments have been made for slope angle.

The antenna was briefly towed across a terrace. Strata of gravelly alluvium are believed to be evident at and above "b."

The third site visited by the GPR was along a road that was built on a pond embankment. The embankment was constructed of compacted clays. Transects were conducted with both the 80 MHz and the 120 MHz antennas. Results were again discouraging as a result of high clay content.

The last stop on the geologic investigation was along the center line of a proposed dam site on Hurricane Creek in Humphreys County. Transects were conducted with both the 120 MHz (Figure 3) and the 80 MHz (Figure 4) antennas. The results were discouraging in terms of the desired depth of penetration. The maximum assumed effective depth of penetration was approximately 6 meters with the 120 MHz antenna and 8 meters with the 80 MHz antenna. Although the sediments were generally described as being "coarse-textured," and extremely cherty layer near the surface may have caused a significant amount of signal reflection which decreased the energy available for deeper penetration. In both figures, note the abundance of near surface (less than 3 meters) interfaces.

The 120 MH_Z antenna (Figure 3) offers superior resolution of features to depths of 6 meters. A double return echo, a form of unwanted noise, is evident at a depth of 9 meters across Figure 3.

The 80 MH_Z antenna (Figure 4), though having greater powers of penetration, produced poorer resolution of features. In order to discriminate between two closely spaced interfaces, the 80 MH_Z antenna, with its wider band width, requires a greater spacing between interfaces than does the 120 MH_Z antenna. Some less prominent interfaces appear to have been omitted by the 80 MH_Z antenna, while many closely adjoining interfaces appear to have been averaged together. The 80 MH_Z antenna is most suitable for investigations in relatively homogeneous materials having few interfaces where depth of penetration is a principal consideration.

SOIL INVESTIGATIONS

The morning of August 31, 1983, was spent familiarizing the soil scientists of Tennessee with the operation of the GPR on a dissected alluvial terrace at the Jackson Agricultural Center. Transects were conducted across a sideslope on coarse-textured sediments. The soils are underlain by thin, discontinuous, sandy loam or sandy clay loam strata. During the exercise the 120 MH_Z, 300 MH_Z, and 500 MH_Z antennas were successfully utilized. The best resolution of the subsurface strata was achieved with the 300 MH_Z and 500 MH_Z antennas. The maximum depth of penetration of the 500 MH_Z antenna was calculated to be 9 feet. David Lewis, Jr., conducted a detailed investigation comparing the scaled depths on the graphic profile with ground truth auger data. The agreement between the scaled graphic depths and the ground truth auger borings was good.

A second site was selected on a level to gently undulating segment of the same terrace. The dominant soils were Dexter (fine-silty, mixed, thermic Ultic Hapludalfs) and Freeland (fine-silty, mixed, thermic Glossic Fragiudalfs). A preliminary transect was conducted with the 300 MH_Z antenna. The quality of the graphic profile was poor. Specifically, the profile was cluttered with excessive bands of induced natural resonance which masked the desired signals. A second transect was conducted across the length of the field with the 120 MH_Z antenna. The results (Figure 5) of this transect point to the applicability of the GPR to detect density differences and possibly to discern fragipans within the upper meter of soils in some areas of western Tennessee.

In Figure 5, copies of the original transect were reproduced, reduced, and placed together with a one-half inch overlap. Dexter soils occupy the entirety of the first segment and all of the second segment to one mark to the right of "c." At this point a weakly expressed fragipan begins to develop at a depth of about 85 centimeters and the soil is Freeland. The pan deepens at "d" where an intervening and segment interface appears to develop at approximately 75 centimeters. This interface was not examined in the field to clarify its identity. The pan abruptly deepens and the intervening layer ceases between "e" and "f." The soil is again Dexter to the right of "f." Also evident in this transect are assumed discontinuous, subsurface sand lenses around points "a" and "g," and an artificial drainage line at "b."

The graphic profile in Figure 5 is quite clear and descriptive. With more field work and the development of more subtle interpretive skills in this area, it may become possible to use the GPR to consistently and reliably differentiate areas having varying degrees of fragipan development. The 120 MHz antenna seems to be the best off-the-shelf transducer commercially available for soils investigations in Tennessee.

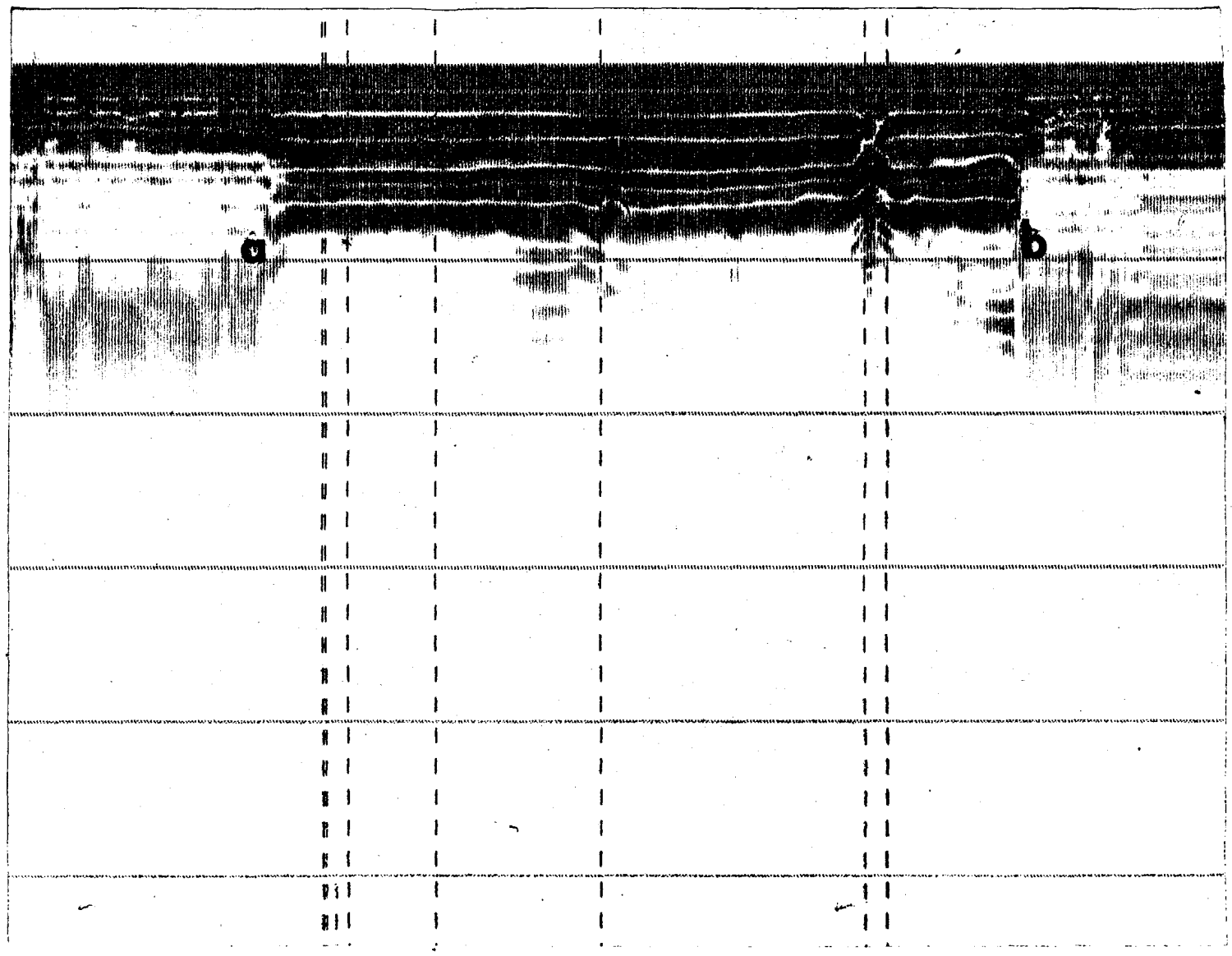

FIG. 1 AREA OF SATURATED CLAYEY SOILS

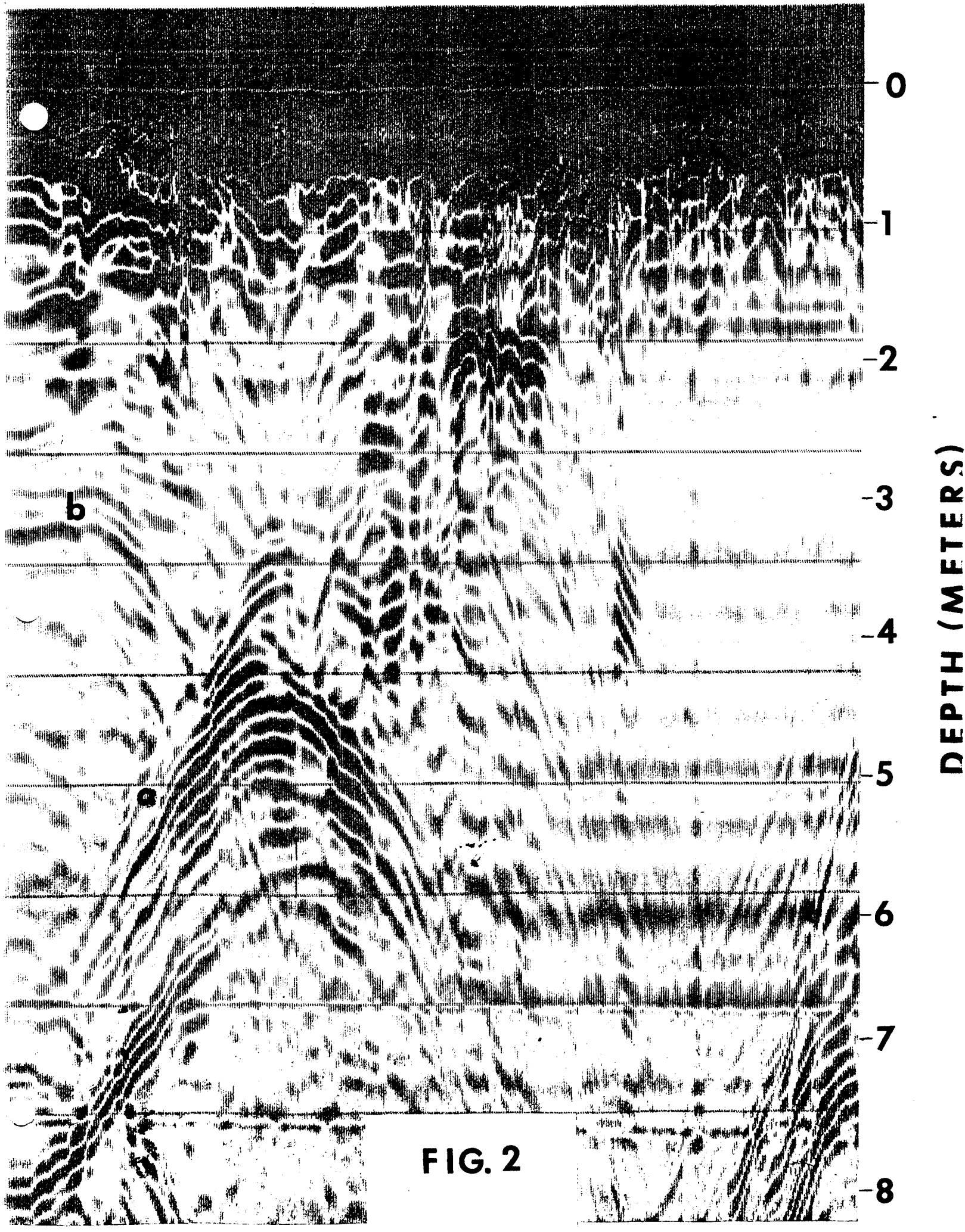

FIG. 2

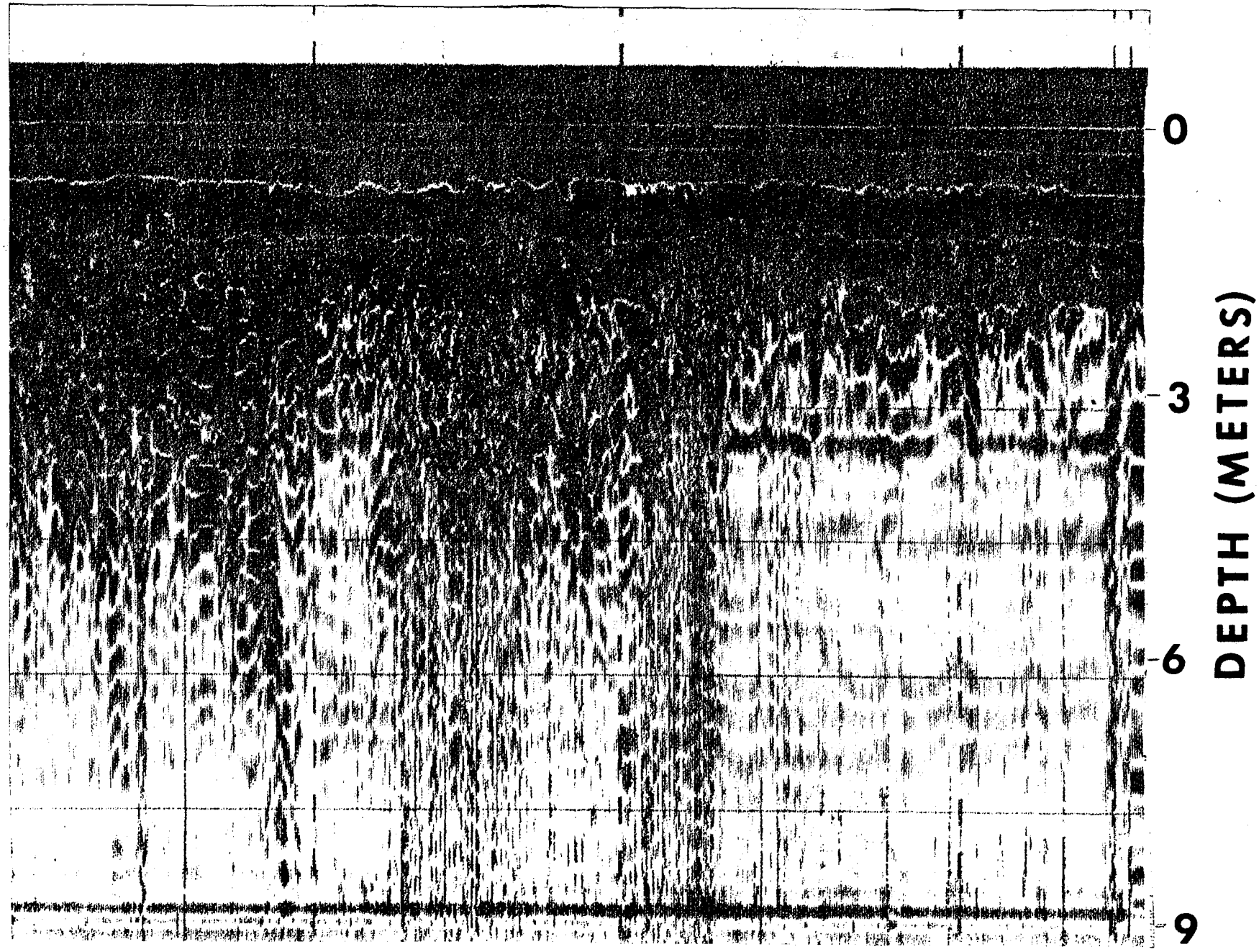

FIG. 3 TRANSECT ACROSS CHERTY ALLUVIUM

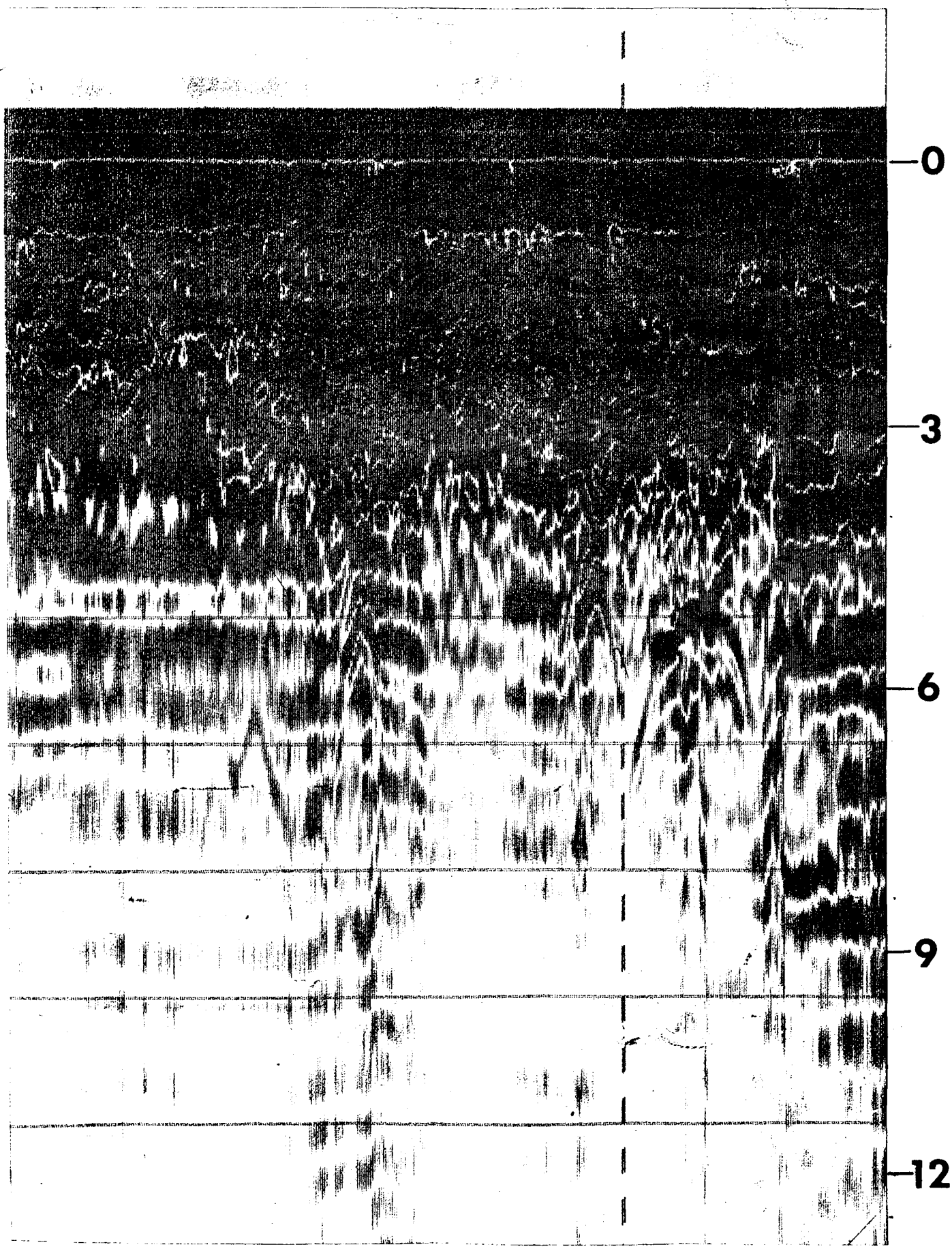

FIG. 4 TRANSECT ACROSS CHERTY ALLUVIUM

TRANSECT ACROSS A WEST TENNESSEE LANDSCAPE

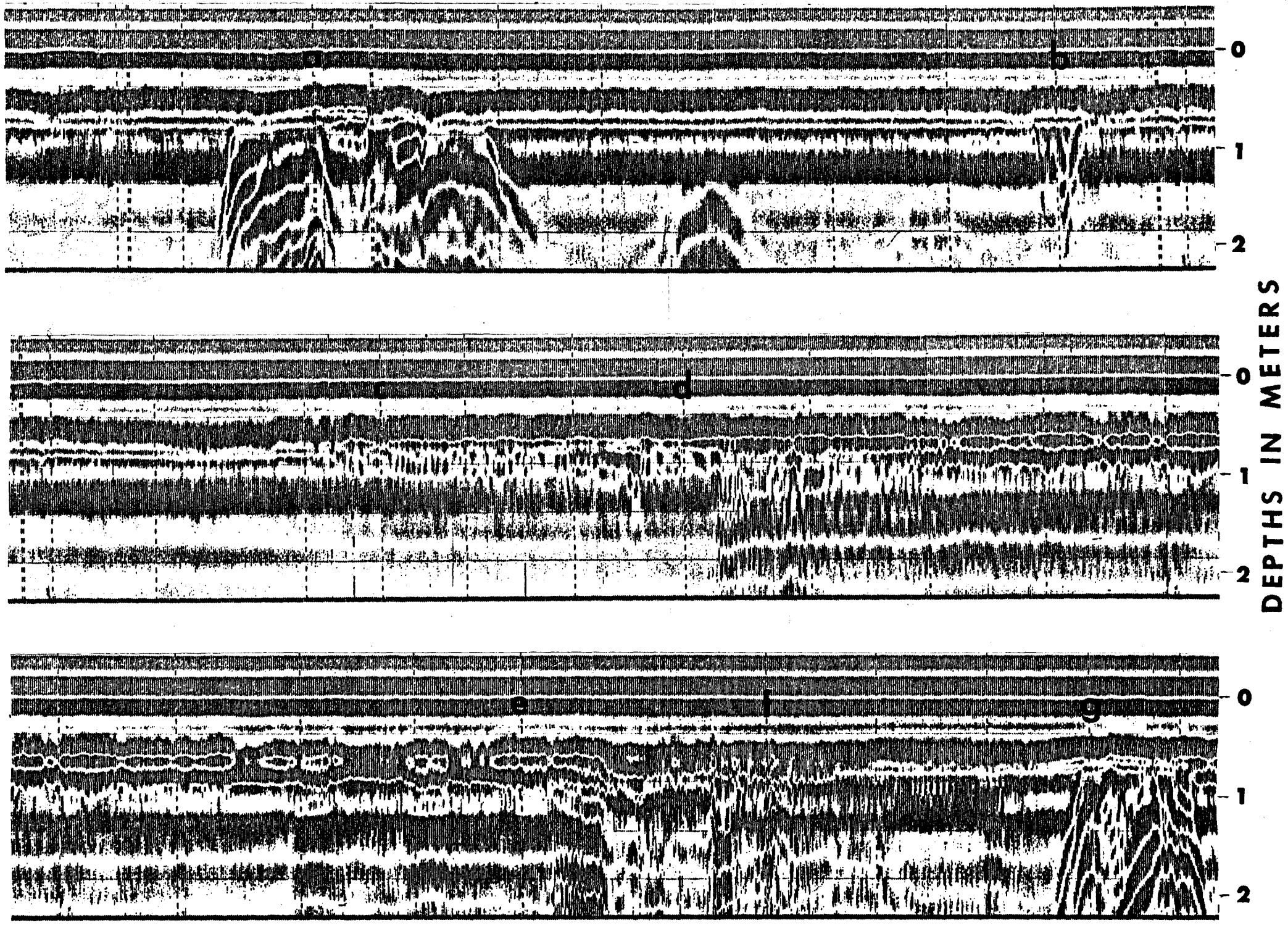
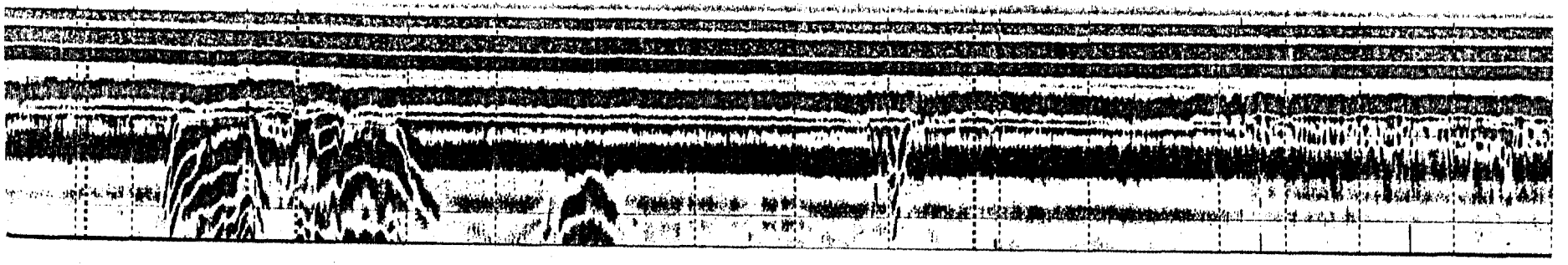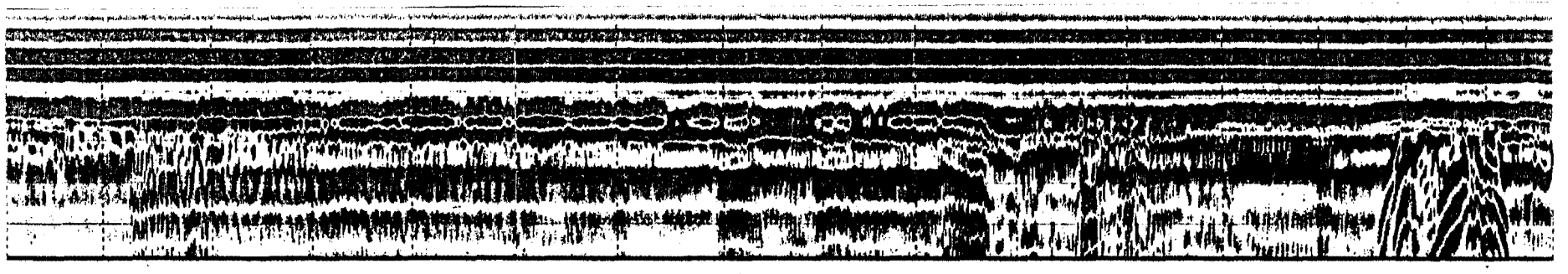
FIG. 5