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 - Alabama

Date: December 1, 1983

To: Ernest V. Todd
State Conservationist
SCS, Auburn, Alabama

File Code: 430-5

During the periods of October 24 through 28, and November 7 through 9, 1983, the ground-penetrating radar (GPR) system was field tested in Alabama. The objectives of the first weeks activities were to investigate: the depth to chalk and the development of traffic pans within the Blackland Prairie; the composition of map units and the development of traffic pans on the Gulf Coastal Plain; and the depth and variability of sediments along Choccolocco Creek near Anniston. Personnel assisting with the field work included: Wade Hurt, Assistant State Soil Scientist; Bob Crisler, Geologist; Joe Spooner, Assistant State Conservation Engineer and Recreational Specialist; Robert Berry, Area Conservationist; Charles Montgomery, Cleo Stubbs, and Herbert Ross, Soil Scientists; and Doug Gresham, Jim Lewis, and Louie McDonald, District Conservationists.

The objectives of the second weeks field work were to determine the location of buried subsurface structures and artifacts associated with the extinct town of Cahaba, the first permanent capitol of Alabama. Personnel assisting with the field work at Cahaba included: Diana Gelburd, National Cultural Resource Specialist; C. Reese Berdanier, Soil Survey Investigation Specialist; Mason Dollar, Watershed Planning Staff Leader; Joe Spooner, Assistant State Conservation Engineer and Recreation Specialist; and Doug Gresham, District Conservationist.

On November 9, 1983, a field demonstration was held at Auburn University's experiment farm near Shorter, Alabama. The purpose of this demonstration was to familiarize staff and faculty with the GPR system and to foster discussion on the applicability of this investigative tool in Alabama.

The equipment utilized during this field trip was the SIR System-8 with microprocessor and the ADTEK SR-8004H Graphic Recorder. The complete complement of antennas (80, 120, 300, and 500 MHz) were utilized. Generally, the equipment operated well. The automatic signal positioning switch on the control unit was inoperative during the first week and the signal had to be positioned manually. A backup control unit was utilized the second week after the principal control unit failed to distribute HV power to the oscilloscope and became inoperative during field work in Louisiana.

The GPR performed well in most areas of the state in which it was tested. The present system is generally unsuitable for use in the Blackland Prairie where the high content of smectite clays rapidly dissipates the radars signal and severely limits the effective depth of penetration.

Let it be known that your state led the way in the use of GPR technology to investigate the extent and expression of traffic pans and eroded areas in soils. This unique and, to my knowledge, hitherto untried application of GPR technology appears to have significant potential throughout many areas of the coastal plain and perhaps the nation. The potential of the present GPR system, with the 120 and 80 MHz antennas, to define the occurrence, strength, depth, and extent of argillic horizons, traffic pans, and eroded areas in many coastal plain soils has been established in Alabama. The potential use and quantification of this data must await further use, research, and development.

The GPR system provided a wealth of subbottom information along Choccolocco Creek, but the usefulness of this information was limited by the quality and quantity of ground truth data. As an experiment, our work on Choccolocco Creek established field procedures for sediment surveys along streams and rivers, and demonstrated the potential for future applications of GPR technology in this area.

At Cahaba the GPR provided subsurface "radar maps" of several proposed building sites. While these "maps" did not identify specific buried artifacts or provide functional interpretations of disturbed areas, it did provide information concerning the distribution and nature of the buried artifacts. This information should provide invaluable assistance in selecting sites for the proposed recreational and interpretive history park. All pertinent "radar maps" of Cahaba have been returned to Joe Spooner under a separate letter.

I wish to pass along my personal thanks for the cooperation and enthusiasm that all members of your staff extended to me. My special regards are passed along to Wade Hurt and Bob Crisler for their persistent and determined efforts in the field.

James A. Doolittle
Soil Specialist (GPR)

Attachment

cc: w/attachment
Richard W. Arnold, Director, Soils, SCS, Washington, D.C.
Billy M. Johnson, Director, SNTC, SCS, Fort Worth, TX
James W. Mitchell, State Conservationist, SCS, Gainesville, FL
Diana Gelburd, National Cultural Resource Specialist, SCS, Washington, D.C.

SOILS

The Blackland Prairie of Dallas County, Alabama, provided the setting for the first portion of the ground-penetrating radar's (GPR) investigation. Many soils of the Blackland Prairie formed in beds of acid clays overlying chalk at variable depths. Prior to field work, the probability that the GPR system would be unable to penetrate deeply into these high clay content soils was discussed. High contents of smectite clays rapidly dissipate the radar's signal and limit the systems effective depth of penetration. After considering these limitations, it was decided to continue the proposed investigation of shallow traffic pans and determine the maximum depth of penetration of the systems antennas in the Blackland Prairie.

An area of Vaiden (very-fine, montmorillonitic, thermic Vertic Hapludalfs) in western Dallas County was selected for field investigation. Though weakly expressed, a traffic pan was observed and varied in depth from 5 to 13 centimeters.

All available antennas (80, 120, 300, and 500 MHz) were utilized in this study. The system's antennas were unable to produce or discern reflections from the traffic pan. In defense of the GPR, it should be noted that the traffic pan was weakly expressed and the electromagnetic gradient across this interface was undoubtedly weak.

The rapid dissipation of the radar signal in Vaiden soils produced a "white-out" area immediately below the surface reflection on the graphic printouts. A "white-out" area is a zone of no signal return. It results from the rapid and complete dissipation of the radar signal, the absence of subsurface interfaces, or both. Due to the presence of a "white-out" area, the radar's effective depth of penetration was uncertain.

The maximum depth at which an interface can be detected is inversely related to the rate of signal attenuation in the medium. The attenuation coefficient for saturated clays is approximately 20 decibels per meter ($db.m^{-1}$). This value is relatively high when compared with similar values for saturated sands (2.3 $db.m^{-1}$) or dry sands (0.14 $db.m^{-1}$). It was assumed that none of the system's antennas could penetrate the Vaiden soil deeply. But some would argue that the antennas were penetrating deeper than expected, and the lack of subsurface reflections resulted from an absence of subsurface interfaces. To resolve this question, a study was conducted to determine the maximum depth at which a three-quarter inch metal pipe could be detected in Vaiden soils with the system's antennas. The pipe was approximately 60 centimeters long. It was driven horizontally into the soil from a wall in a freshly excavated, shallow trench. The pipe was driven into the soil at measured depths of 8, 15, and 30 centimeters.

The maximum detectable depths were: 15 centimeters with the 80 MHz antenna; 8 centimeters with the 120 MHz antenna (Figure 1); and only upon exposure with the 300 and 500 MHz antennas. At a depth of 8 centimeters below the surface, the reflection from the pipe and the surface were indistinguishable with the 80 MHz antenna. In Figure 1, a clear reflection of the pipe (A) was produced when the 120 MHz antenna was hand-towed at right angles across it.

Further investigations of near surface conditions were conducted in the Blackland Prairie with equally discouraging results. Additional transects were conducted in areas of Sumter (fine-silty, carbonatic, thermic Rendollic Eutrochrepts) and Demopolis (loamy-skeletal, carbonatic, thermic, shallow Typic Udorthents) soils. Multiple transects were conducted in areas of each soil with both the 80 and 120 MHz antennas. The control unit was adjusted and transects were conducted at various range, gain, and filtration settings. A microprocessor with a running average algorithm was utilized to remove unwanted reverberations in some transects.

Generally, the graphic printouts from the Blackland Prairie were of poor quality, and the identification of distinct interfaces was problematic due to low signal to noise ratios. The majority of the graphic printouts were cluttered with broad bands of induced natural resonances.

Figure 2 is from a transect that was conducted in an areas of Sumter soil in the Blackland Prairie. Although the Sumter soil is fine-silty, the total clay content (including carbonatic clays) ranges from 35 to 50 percent and is dominated by smectites. As in other transects, the imagery in Figure 2 is poor. The profile is cluttered with multiple bands of induced natural resonances which mask the desired signal of the underlying soil/chalk interface. This interface was ground-truthed by augering at each observation site. The interface ranged in depth from 36 to 81 centimeters (provided random cobbles were not contacted). Comparing the ground-truth data with the radar imagery, it is unclear whether the radar was processing reflections from the soil/chalk interface or from some other unidentified, intermediate horizon or layer.

The present GPR system appears to be unable to accurately define most subsurface interfaces in the Blackland Prairie. The experience and knowledge that was gained later in the week, concerning the identification and differentiation of traffic pans and eroded areas, may warrant a reevaluation in the future of the GPR potential in the Blackland Prairie.

After confirming the GPR's poor response in the Blackland Prairie, the system was tried on soils of the Gulf Coastal Plain. Generally, these soils have lower clay contents and are dominated by kaolinitic rather than by smectite clays. The difference was immediately noticeable and the results proved to be most promising for future GPR development and research.

The 120 MHz antenna, based on field testing, provides the best balance of resolution and penetrating depth, and is the most suitable antenna for soil investigations on the coastal plain of Alabama. Images from the 300 MHZ antenna were severely depth restricted and were obscured by multiple bands of induced resonance. 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.

The site of the coastal plain investigation was in Lowndes County, near Lowndesboro. The first soil investigated in this area was Savannah (fine-loamy, siliceous, thermic Typic Fragiudults). Figure 3 is a portion of a transect that was conducted in this area. In this figure, the polarity control on the graphic recorder was set so that all positive pulse would be printed full black, while all negative pulse would only be highlighted. This procedure facilitates the identification of subsurface interfaces. The upper set (positive and negative pulses) of lines are inherent characteristics of the antenna. The first interface is the soil surface; the second interface is the fragipan (A) or a contrasting layer of alluvium (B). The reflection from the fragipan (A) is distinct and maintains a near constant depth below the surface reflection from observation site 1 through 4. To the left of observation site 5, the reflection from the fragipan abruptly plunges and terminates. Near observation site 5, the antenna was towed across a lower lying, wetter drainage area. Wetter soil conditions can be inferred by the increase in subsurface reverberations (D) to the right of observation site 4. Observation sites 5 and 6 are in an area of Mantachie (fine-loamy, siliceous, acid, thermic Aeric Fluvaquents) and Mooreville (fine-loamy, siliceous, thermic Fluvaquentic Dystrochrepts) soils. The alternating layers (B and C) of alluvial deposits are easily defined and traced across the drainage area.

As the water table was encountered at a relatively shallow depth (58 centimeters) within the drainageway, the depth scale along the right margin needs to be adjusted to reflect the slower rate of signal propagation through the more saturated conditions. The delay time of the echo from the fragipan near site 5 may have also been affected by changes in soil moisture. If so, this would explain the downward slope of the fragipan near this site. The delay time of a reflection from an interface is governed by both the rate of signal propagation and the distance below the surface. A horizontal gradient in moisture, resulting from wetter soil conditions in the drainageway, would cause the reflection from the fragipan to be delayed and the image to slope downward due to the reduction in the velocity of propagation. None-the-less, the correlation between ground-truth auger borings and the scaled radar images was within 5 centimeters at all sites underlain by the fragipan.

A second study area was selected near Lowndesboro to determine whether the GPR could distinguish Hapludults from Paleudults. The taxonomic criterion considered in this investigation was the clay distribution. It was of interest whether the GPR system could detect a decrease in clay content by 20 percent or more of the maximum within 1.5 meters of the soil surface. The major soil in this study area was Cahaba (fine-loamy, siliceous, thermic Typic Hapludults).

The scanning time on the control unit was initially set at 64 nanoseconds (ns) which corresponded to a probing depth of approximately 2.4 meters (assuming a propagation velocity of 8 $ns.ft^{-1}$, based on tabled values for loamy material). Little subsurface information, other than meaningless subsurface reverberations, were obtained below a depth of about 50 centimeters at this setting. The decrease in clay content with increasing soil depth could not be verified with the GPR, and either did not occur or was too gradual a transition for the GPR to discern. As similar results have been obtained in areas of Paleudults and Hapludults in Florida, it appears improbable that the present GPR system can be effectively utilized for such studies.

Since all of the discernable information obtained by the GPR was in the upper 50 centimeters of the soil profile, a second transect was conducted in the study area with a reduced scanning time of 32 ns. As a procedure, reducing the scanning time increases the available printing space on the graphic recorder per unit depth scanned. This enlargement process increases the detail and the accuracy of shallow depth measurements. The adjusted scanning time provided sufficient time to probe to a depth of approximately 1 meter. Based on ground-truth data, the calculated rate of signal propagation in Cahaba soil is approximately 9.8 $ns.ft^{-1}$.

Figure 4 is a segment of the graphic printout from this transect. The roughness of the surface and the depth to and the lateral extent of the argillic horizon (A) are evident in this figure.

Lateral changes in electromagnetic properties along the argillic horizon can be inferred from the changes in the widths of the light and dark bands on the graphic printout. As a general rule: the more abrupt or contrasting an interface, the stronger the amplitude of the reflected signal, the blacker and wider the dark bands, and the narrower the width of the white bands. An abrupt change in textures across the eluvial/illuvial interface should produce wide dark bands and narrow white bands. If the soil is eroded and the upper part of the argillic horizon has been mixed with the plowed layer, the contrast between the eluvial and illuvial horizons is diminished and the width of the white bands of the argillic horizon should increase. Theoretically, in some 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 4, the image of confirmed area of eroded soil is apparent at C. In this area, the upper part of the argillic horizon had been plowed into the surface layer. Consequently, no subsurface image for the argillic horizon is apparent at C; the argillic horizon is at the surface! Note the weakening and upward inclination of the dark bands representing the argillic horizon to the right of C. A shallow field drain in which the argillic horizon was at the surface was referenced with a dashed vertical line on the graphic printout (B) as the antenna was towed across it. Note the absence of an image for a "subsurface" argillic at B.

To confirm these inferences, a shallow, rectangular pit was excavated down to the argillic horizon and the 120 MHz antenna was towed across it. As evident in Figure 5, the dark bands of the argillic horizon abruptly terminate on either side of the excavated pit which has been delineated by dashed vertical lines. The insular dark band in the interior of the pit (A) is believed to have been caused by surface materials that were pushed into the pit by the antenna. The results are considered remarkable!

Figure 6 is from a transect that was conducted across a complex soilscape in Lowndes County. Wide variations in soil type and in subsurface conditions were observed along the transect route. The depth to the argillic horizon (A) varied from at the surface to greater than 50 centimeters. The variation between ground-truth auger boring depths and scaled radar depths to the argillic horizon was less than 3 centimeters for all observation sites having the argillic horizon deeper than 18 centimeters. Wider variations between auger boring and scaled data occurred at observation sites where the upper part of the argillic horizon had been plowed into the surface layer as a result of erosion (C). The wider variation can be attributed to the lack of sufficient contrast between the plowed layer and the argillic horizon in areas where the argillic horizon is within 18 centimeters of the surface.

The intermediate gray reflections (B) beneath observation site 5, and similar reflections beneath sites 6, 7, and 8, were correlated with the recurrence of a traffic pan across the soilscape. In this transect the image of the traffic pan is immediately below the surface reflection and is identifiable by its duller and less intense shade of black.

With the GPR, a natural tendency is to "squeak-up" the gain on the control unit in order to amplify deeper and weaker subsurface reflections. Unfortunately, this process also amplifies unwanted noise. Noise, in the form of induced natural resonances and double return echoes, makes interpretations difficult. Though the direction of travel is different, Figures 7 and 8 are from the same transect line. The lower gain settings of Figure 8 has reduced the magnitude of unwanted noise and has clarified the image of the argillic horizon. Although polarity highlighting was used in Figure 7, the overlapping of several reverberated signals makes proper identification and interpretation difficult.

SEDIMENT SURVEY

The GPR system was utilized to profile bottom sediments along Choccolocco Creek near Anniston in northeastern Alabama. This was the first investigation of a stream channel with a system operated by SCS. It was quickly learned that operating the radar system in the turbulent flow of a stream was quite different from operating the system on a tranquil lake. Not only did the waters of Choccolocco Creek vary in speeds and in depths, but the channel was often choked with snags from below and tree limbs from above.

The control unit and graphic recorder were placed in an aluminum boat. The 120 MHz antenna was placed in a rubber raft. Unfortunately, the raft was not securely tied to the boat and wandered freely across the channel. Consequently, the graphic printout did not accurately portray the center line of the stream.

In future operations, the raft should be securely tied to the front of the control boat. The control boat should be powered by motor, or if shallow waters restrict the use of power, should be tended by two line handlers from opposite sides of the channel. If possible, a trial run should be conducted without the GPR system to ascertain and perhaps remedy potential problems from snags, shallows, and currents.

As evident in Figure 9, the GPR system can provide a wealth of information concerning subbottom deposits. The graphic printout is believed to have recorded: a rock ledge at A; a midchannel sand bar at B; and the first continuous subbottom deposit (D) that predates the present erosional cycle. The limbs from overhanging trees produced false echoes at C due to the unshielded design of the 120 MHz antenna. Ripples that were induced by dragging the transmission cable in the water are apparent at E.

Ground-truth data is essential in all investigations in order to identify the images and to scale the depths. In Figure 9, the numerous layers which reflected the radar signal created an interpretive dilemma. The usefulness of the GPR system along Choccolocco Creek was limited by the quantity and quality of ground-truth data rather than by medium or by the radar. Unquestionably, the GPR system is capable of providing detailed information concerning the sediments along Choccolocco Creek and similar stream beds in Alabama. But without adequate ground-truth data and interpretive skills only the gross morphology of stream channels can be described.

ARCHAEOLOGICAL INVESTIGATION

Cahaba, the first permanent capitol, was an early trade and cultural center of Alabama. Today, few vestiges remain to recount the cities and the areas historic eminence. The Soil Conservation Service is providing funds and technical guidance to develop a water based recreational and interpretive history park. The plans include the construction of a visitors center, pavillions, docks, and comfort stations. Prior to the potentially destructive construction of these proposed structures, an archaeological survey of the sites was mandated. The ground-penetrating radar (GPR) was selected as a reconnaissance tool to pinpoint the precise location of buried structural remains, if any, within the proposed areas of construction.

Four sites were selected for GPR investigations. A grid system was laid out over each of these survey areas. The grid system facilitated locating subsurface objects in relationship to fixed reference points on the surface. The grid system consists of a series of equidistant parallel lines which are generally laid out in north-south and east-west directions. Along each line, flags are pushed into the ground at fixed intervals and served as reference points. The shape of the completed grid depends on the number of north-south and east-west grid lines that are required to cover the survey area. The completed grid patterns for the proposed comfort station, pavillion, and septic tank field sites are shown respectively in charts 1, 2, and 3. As depicted in these charts, the grid lines were identified by consecutive numbers or letters. All grid line intersections were identified by a letter-number combination.

The GPR was calibrated and interpretive skills developed while conducting several trial runs near the site of the Perine Well. At this location a buried sidewalk, conduit, and brick clusters were repeatedly crossed with the antennas and the images on the graphic printout were verified by conventional "shovel testing" methods. Based upon these trials, the 120 MHz antenna was determined to provide the best balance of resolution and penetrating depth in the Cahaba area.

Figure 10 is representative of the transects that were taken in the Cahaba area (grid line D in chart 2). The numbers at the top of the graphic profile corresponds to "flagged" reference points (intersection of grid lines). The distance between each reference point was ten feet. The unequal spacing of the reference points is explained by variations in the speed of advance of the antenna. It is exceedingly difficult to maintain a uniform towing speed while towing the antenna along a grid line. The graphic profile is vertically exaggerated. In this presentation, the vertical scale is approximately 1 meter while the horizontal scale is over 30 meters.

The presentation in Figure 10 consists of reflections from three basic components: the transmitted pulse, the surface, and major subsurface interfaces. The first images recorded on the graphic profile are caused by direct feed through from the transmitted pulse. These images result from the direct coupling of the transmit and receive antennas. Though a source of unwanted clutter, these images are useful to reference the time of pulse radiation. In Figure 10, the transmitted reflections are the upper two solid black lines (A).

The image from the strong surface reflection is represented by the two broader and grayer horizontal lines (B). The first zero crossing (narrow white band between black lines) is usually selected, as a matter of its repeatability and convenience, as the soil surface for depth calibrations and measurements.

In Figure 10, the natural rhythm of subsurface layers or horizons is evident between reference sites 5 through 10. These images were not identified in the field but may correspond to reflections from a denser traffic pan or the clay enriched argillic horizon. The natural rhythm of these underlying layers or horizons has been disrupted between reference points 2 and 4, and to the right of reference point 1. Within the larger disturbed area, three point objects can be identified by their hyperbolic patterns. These point objects are presumably buried bricks or the remnants of brick pillars.

The GPR was able to readily pinpoint the location of buried artifacts, if any, at each proposed building site. Based on interpretations, several areas within the proposed building sites were excavated to ascertain the reliability and the accuracy of the GPR system. At each of the excavated sites, buried bricks were encountered at relatively shallow depths.

The GPR system provided detailed and accurate subsurface documentation of the areas investigated at Old Cahaba. The grid lines were spaced at intervals of 10 to 50 feet. At some sites a reconnaissance survey was conducted without the aid of grid lines. The level of confidence that should be assigned to each site investigated is directly related to the intensity of sampling and inversely related to the grid interval.

With the exception of the pavillion site, the areas investigated appear to be free of buried structural remains. All point objects identified during these investigations were principally small clusters of bricks. Within the larger area of the proposed pavillion site (chart 2), the GPR had located focal points for future excavations. This information will (1) afford future economy of time and resources if the area is excavated with conventional archaeological methods; and (2), will allow questionable areas to be avoided.

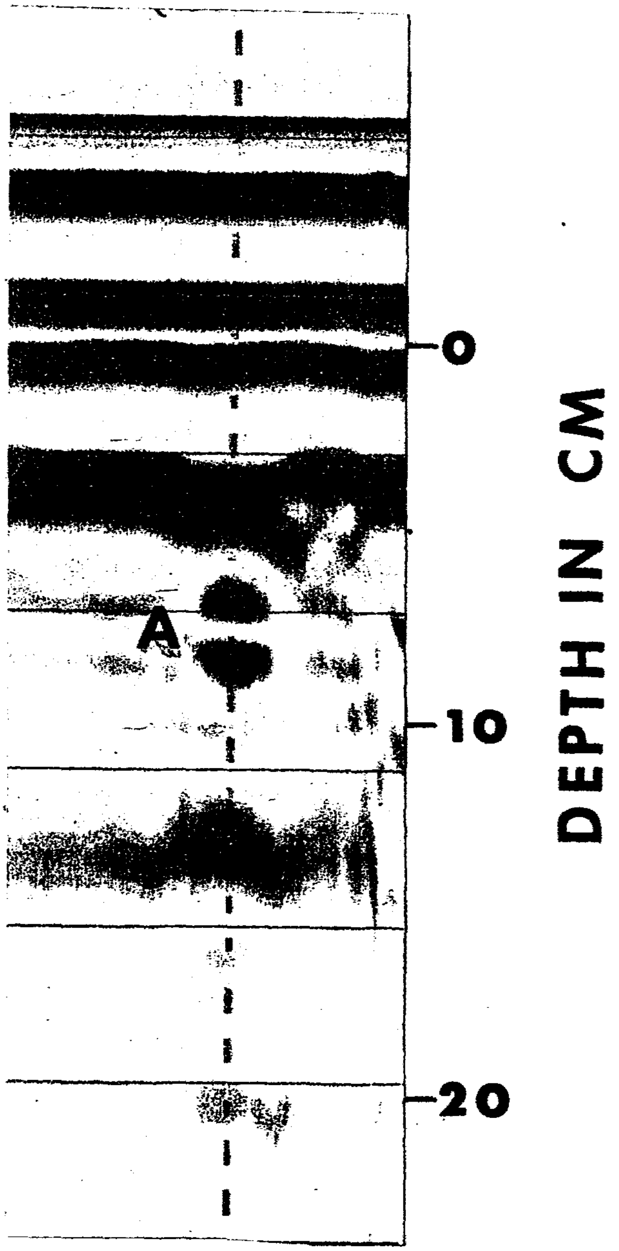


FIG. 1 BURIED PIPE

AREA OF VAIDEN SOIL

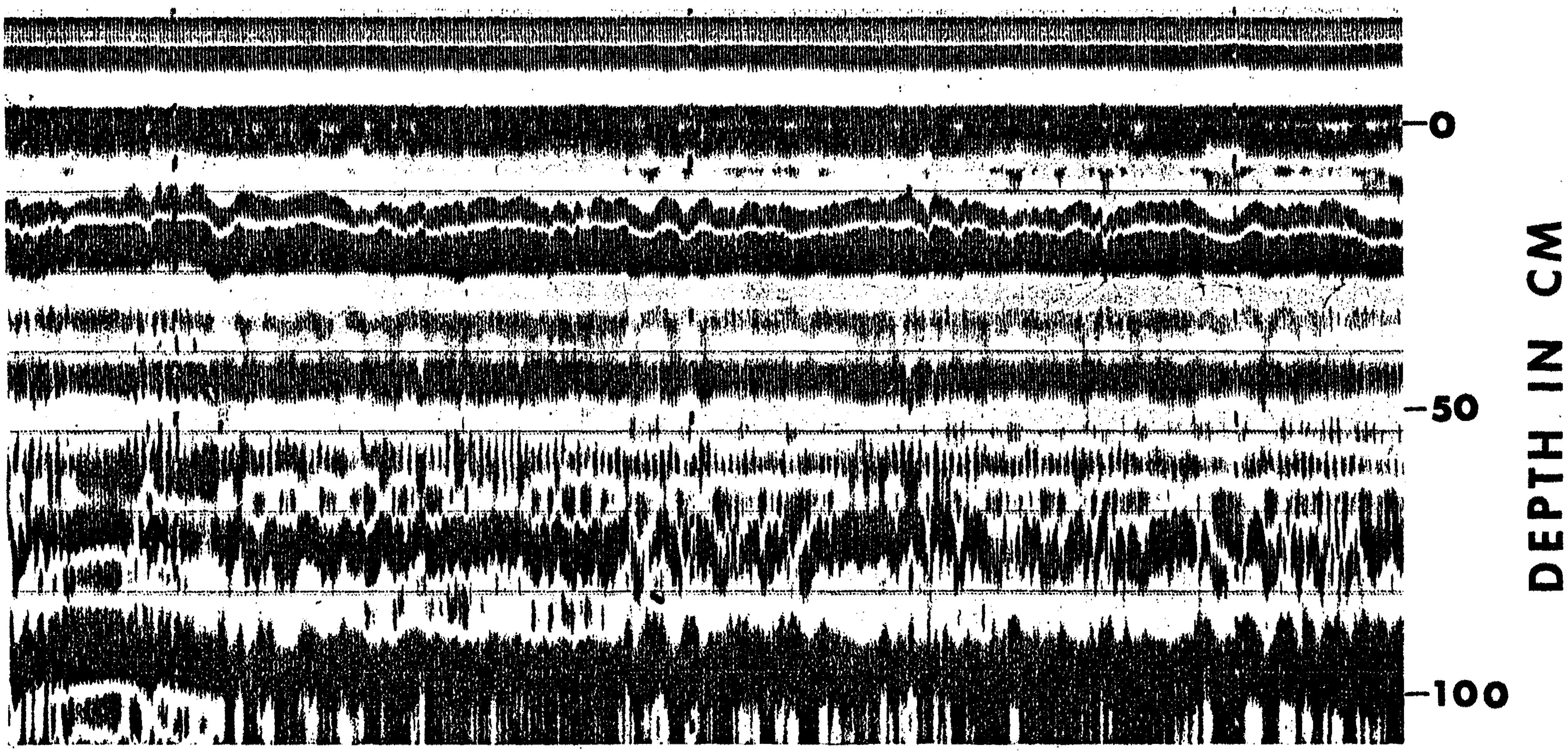


FIG. 2 TRANSECT IN AREA OF SUMTER SOIL

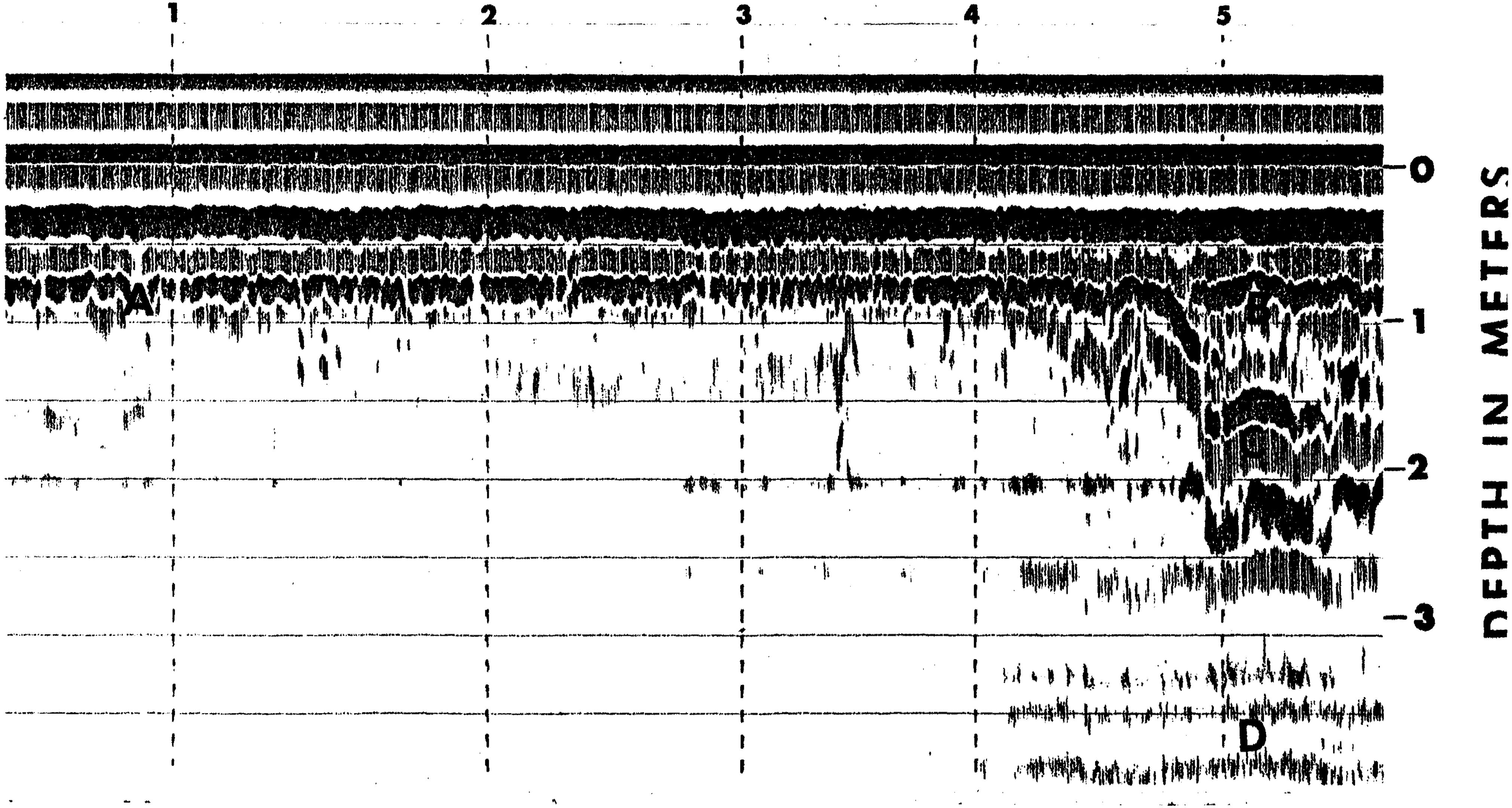


FIG. 3 TRANSECT IN AN AREA OF SAVANNAH SOILS

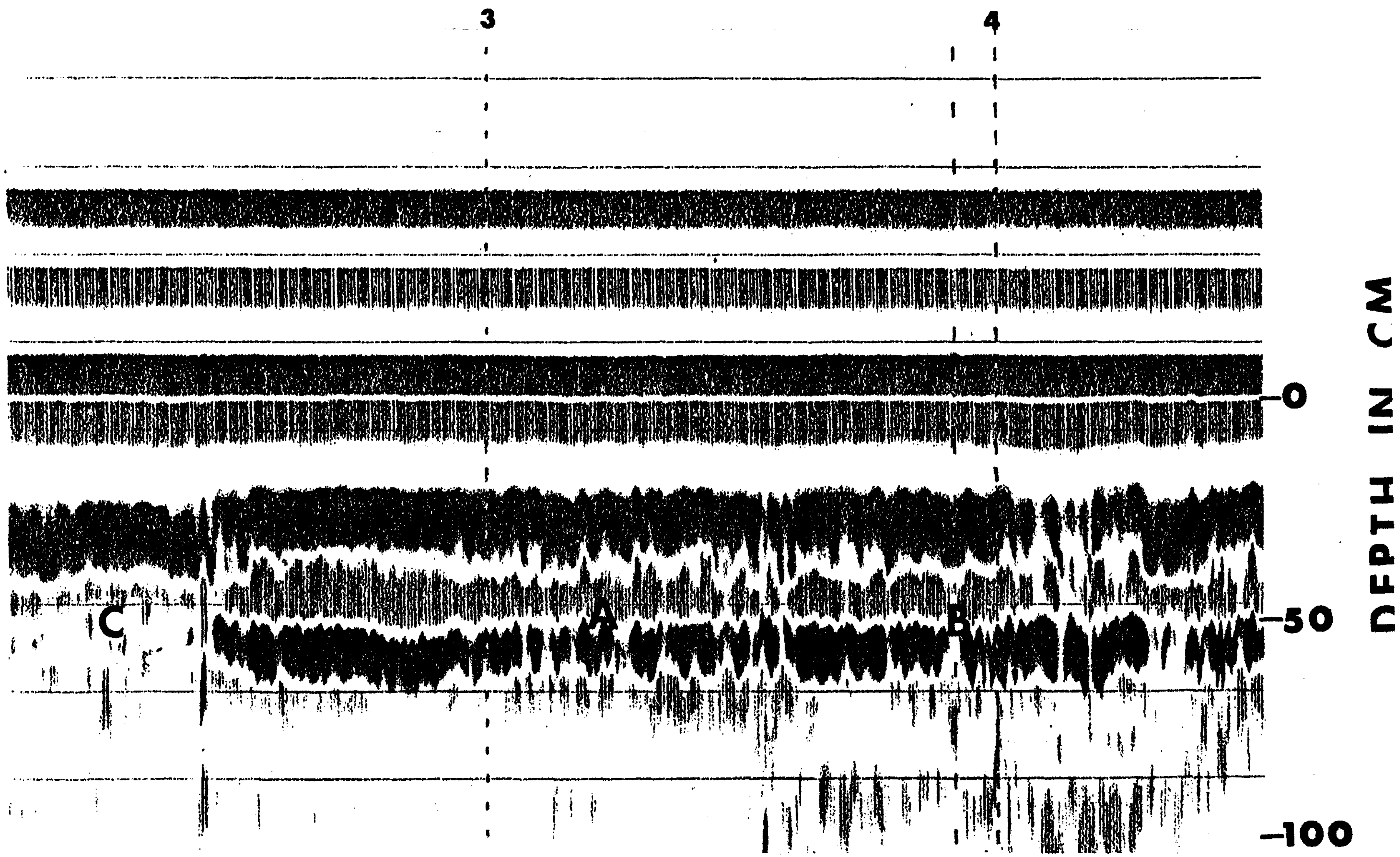


FIG. 4 TRANSECT IN AN AREA OF CAHABA SOILS

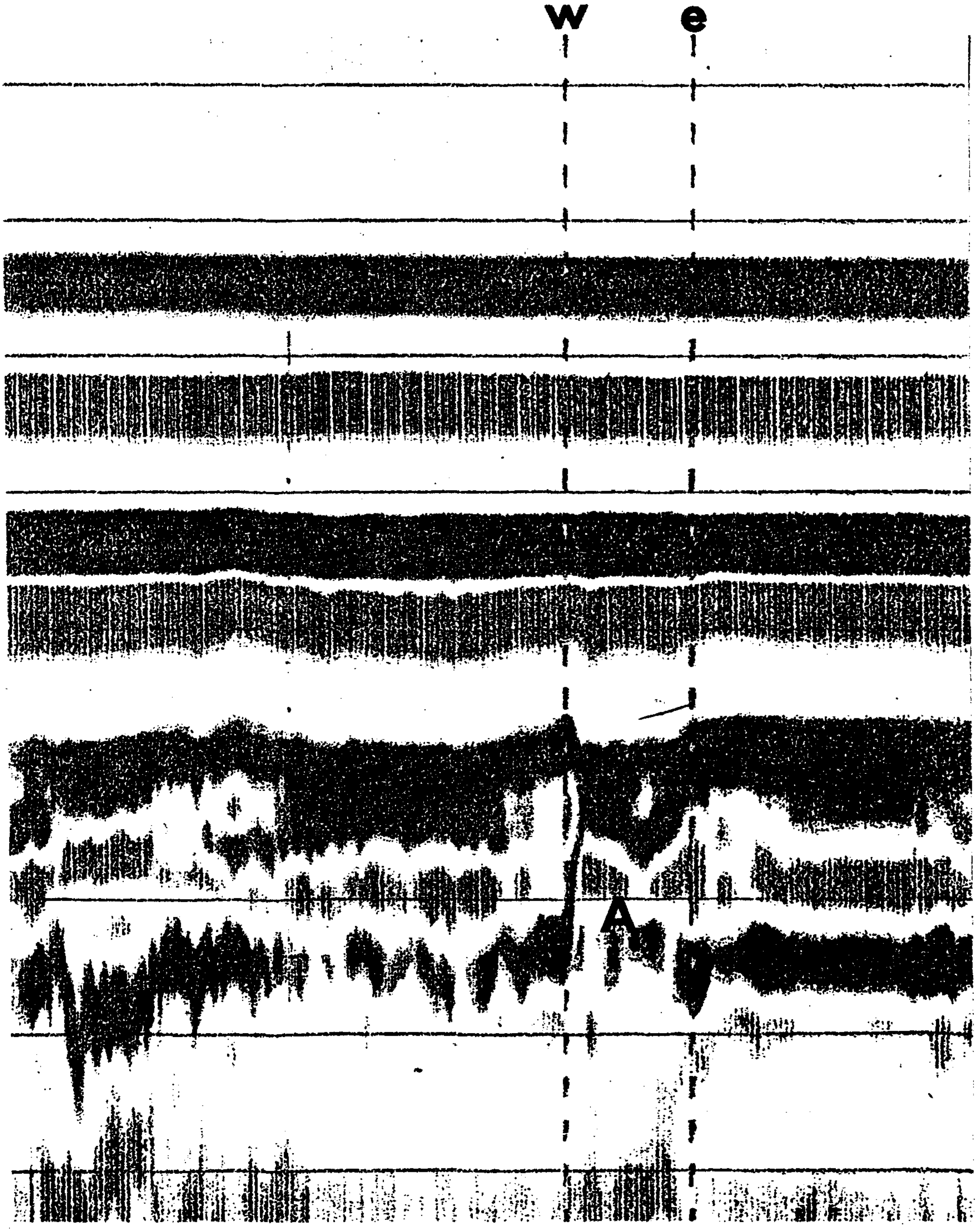
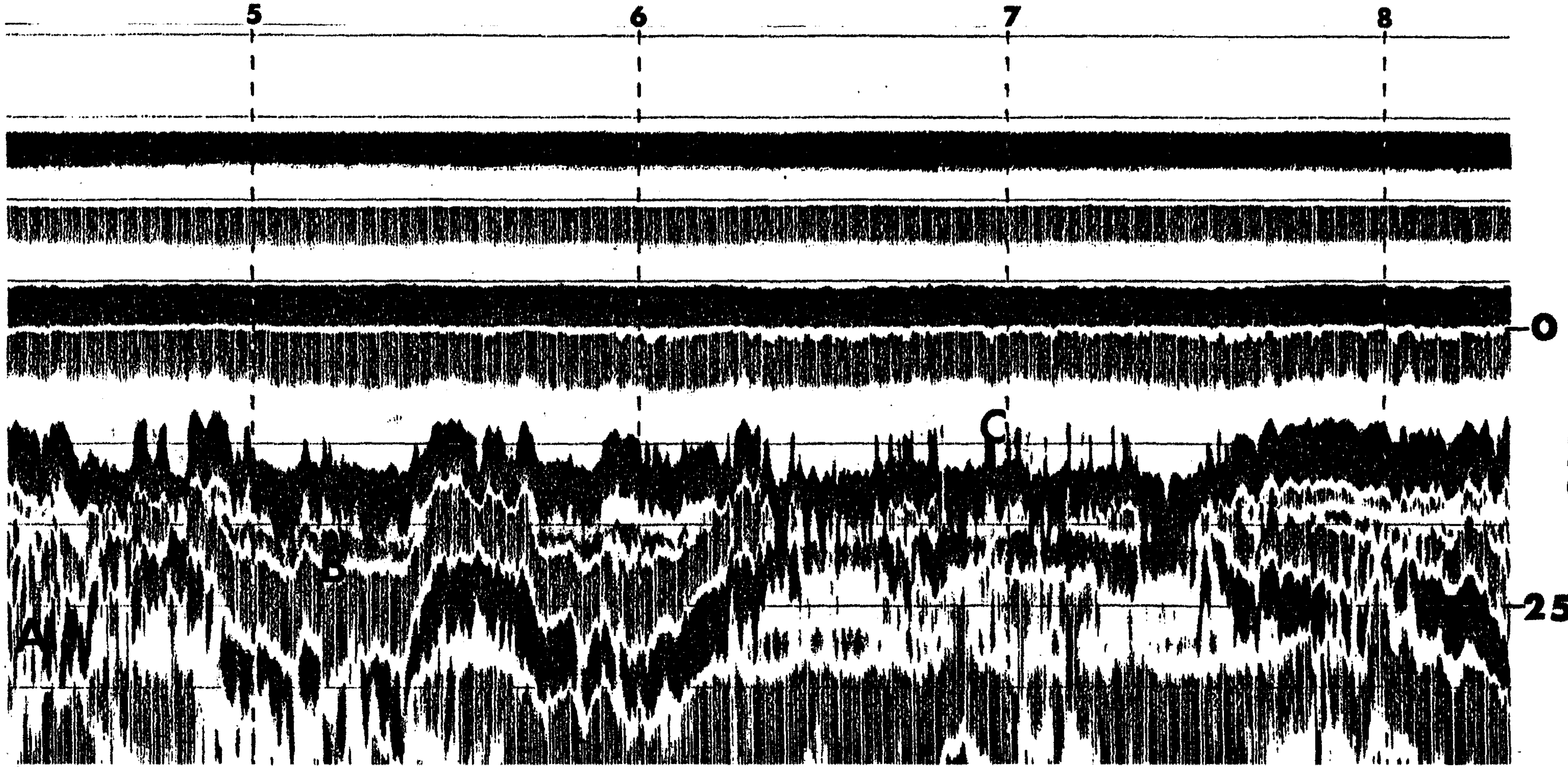


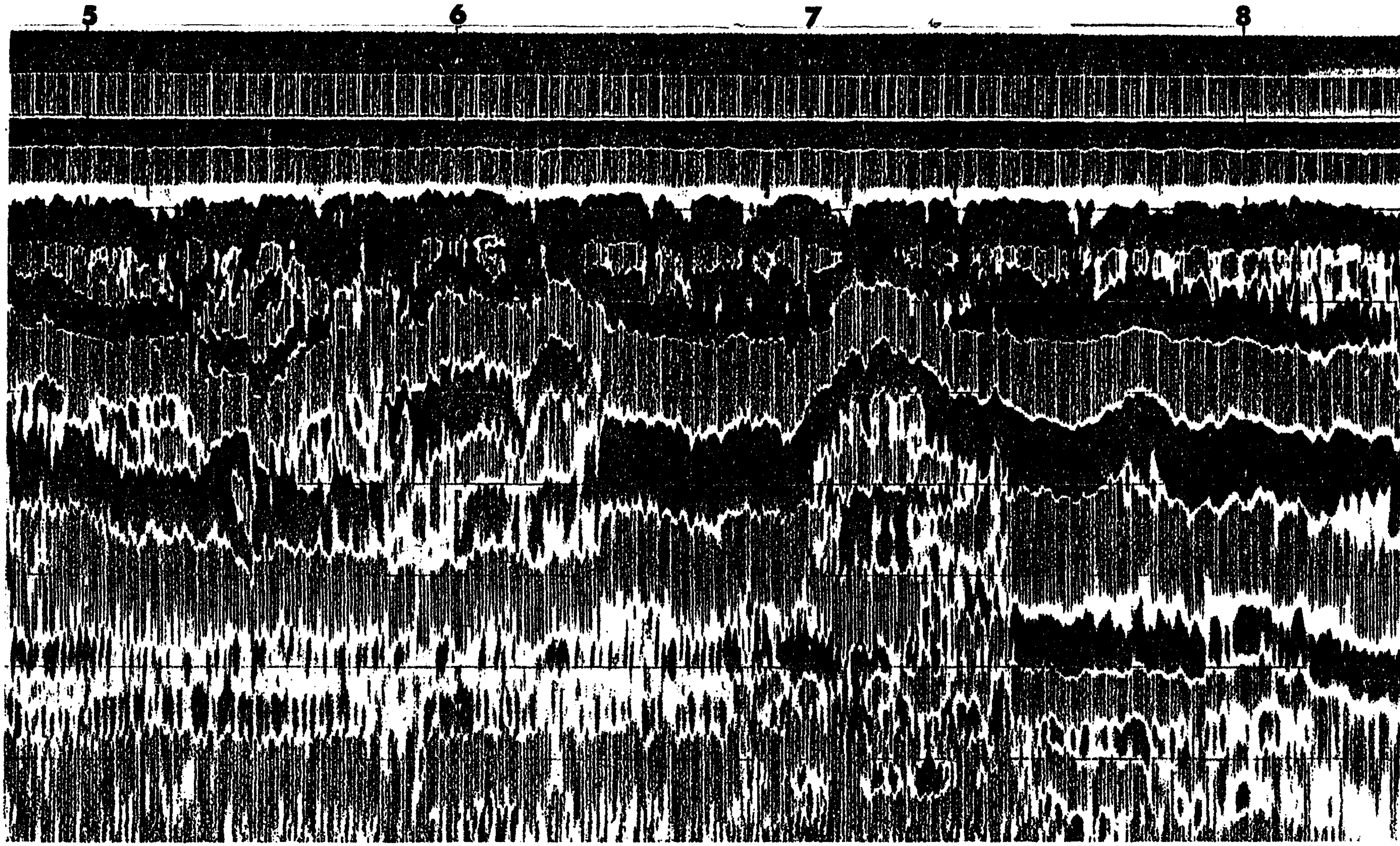
FIG. 5 EROSION TEST SITE

FIG. 6



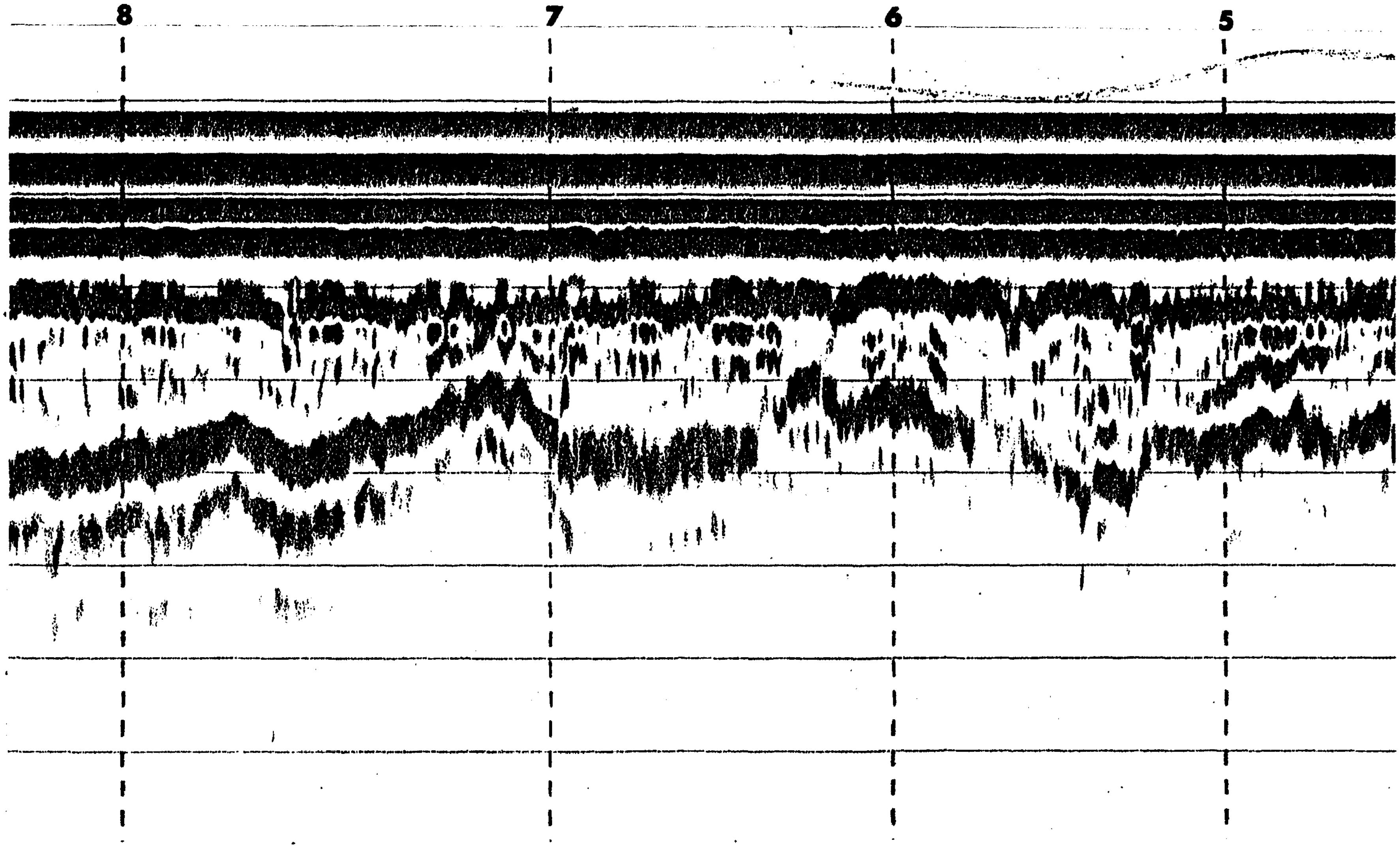
GPR PROFILE OF
TRAFFIC PANS AND SEVERELY ERODED AREAS
IN A LOWER COASTAL PLAIN SOILSCAPE

FIG. 7



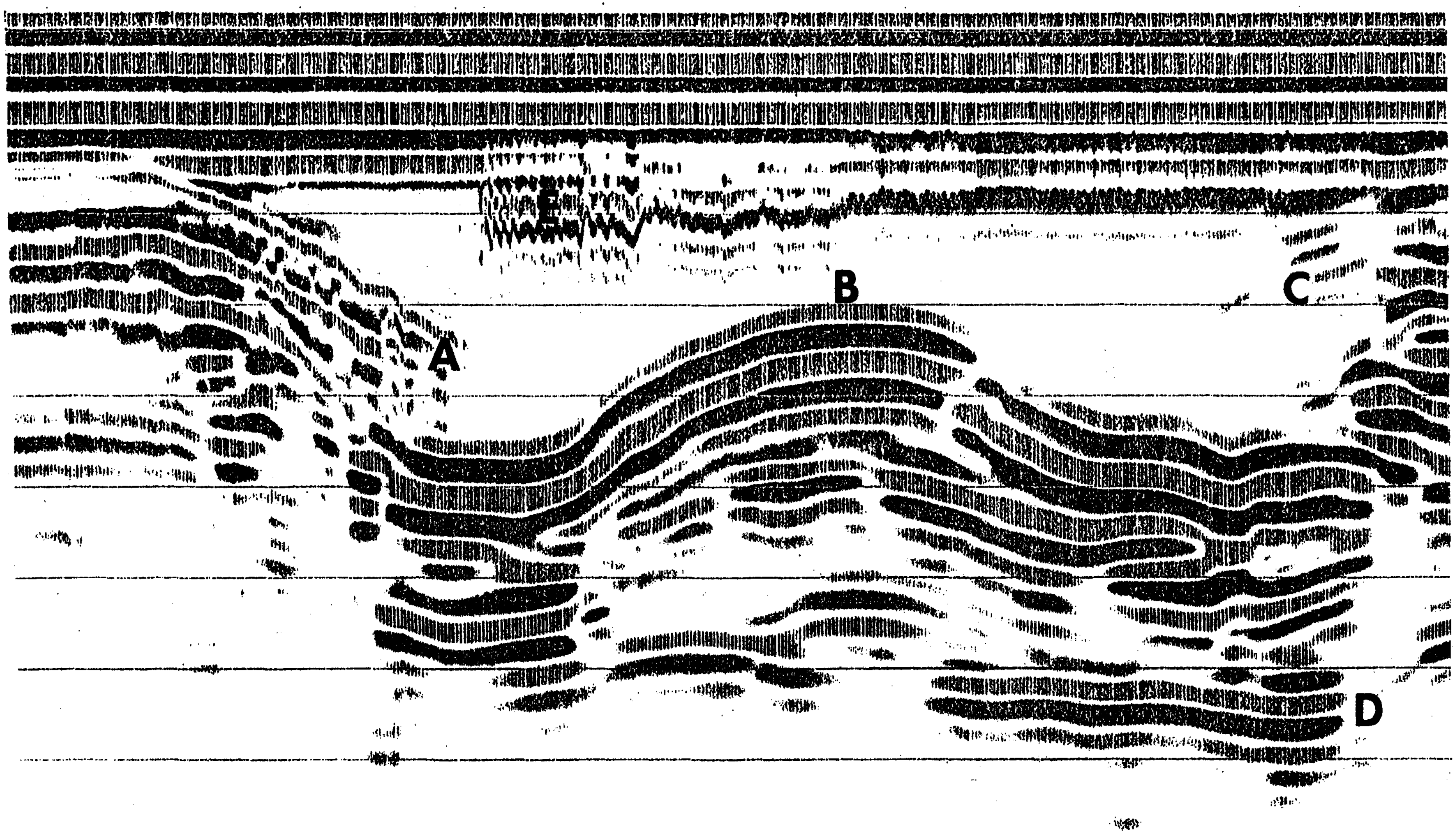
ARGILLIC HORIZON : HIGH GAIN

FIG. 8



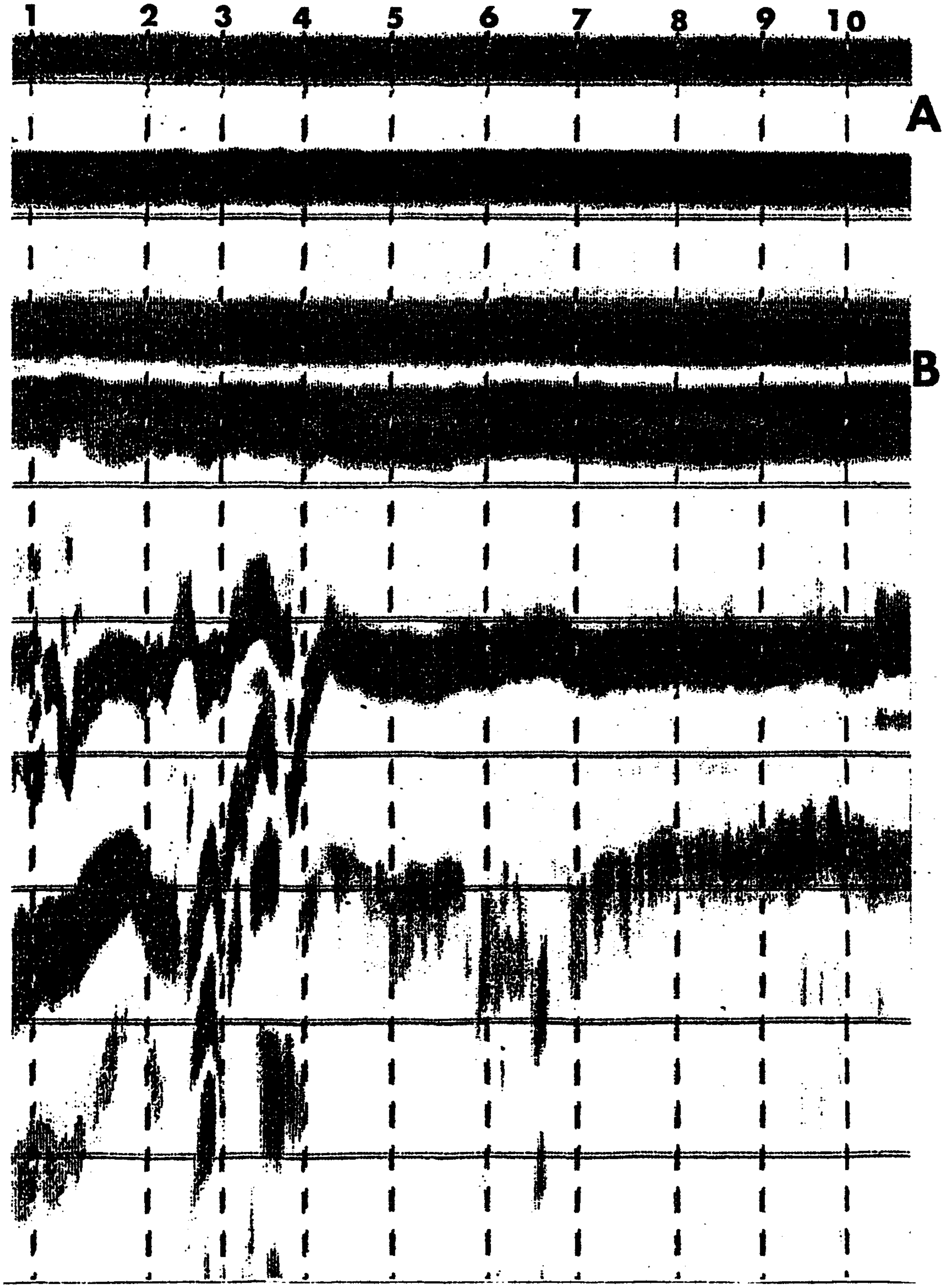
ARGILLIC HORIZON : LOW GAIN

FIG. 9



CROSS CHANNEL PROFILE
CHOCCOLOCCO CREEK

FIG. 10



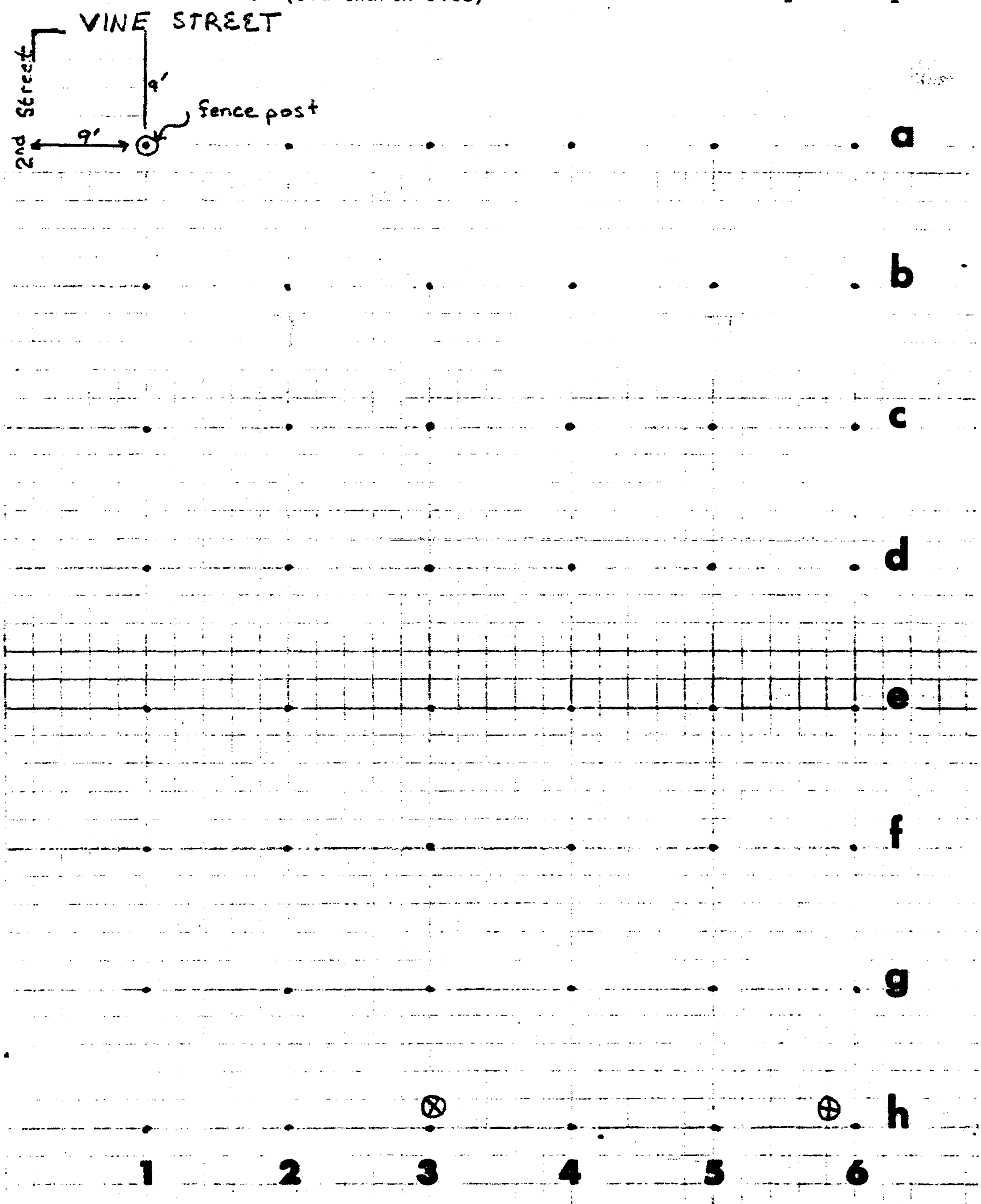
' BRICK PILLARS ' FROM OLD CAHABA

COMPUTATION SHEET
SCS-ENG-523 Rev. 8-69

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

CHART 1

STATE: Alabama		PROJECT: Old Cahaba		
BY: GPR	DATE: 7 Nov. 83	CHECKED BY	DATE	JOB NO.
SUBJECT: Comfort Station Site (old church site)				SHEET 1 OF 1



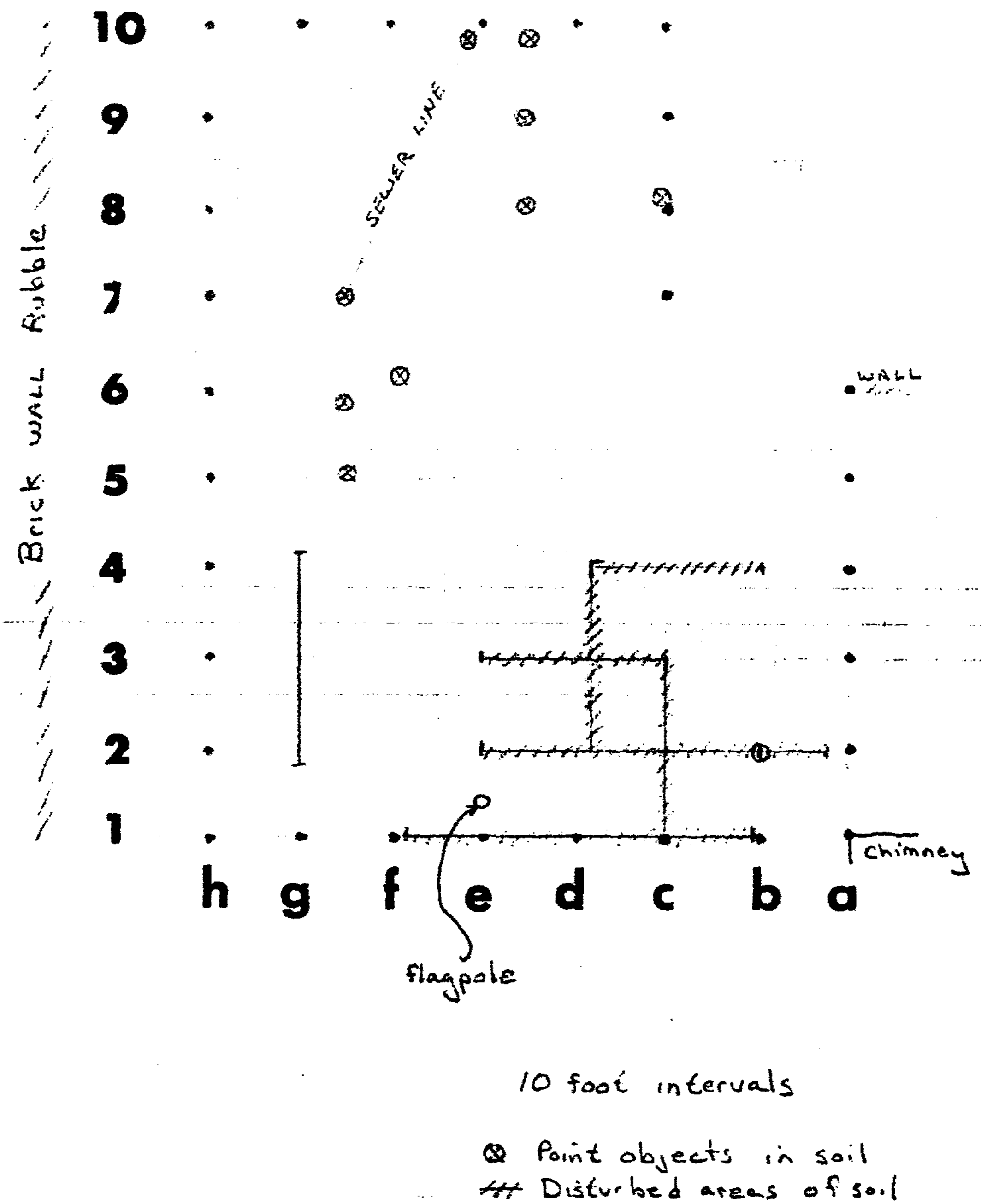
⊗ Point objects in soil

CHART 2

ALABAMA Old Cahaba

GPR 8 Nov. 1983

Old Warehouse Pavillion Site 1 1



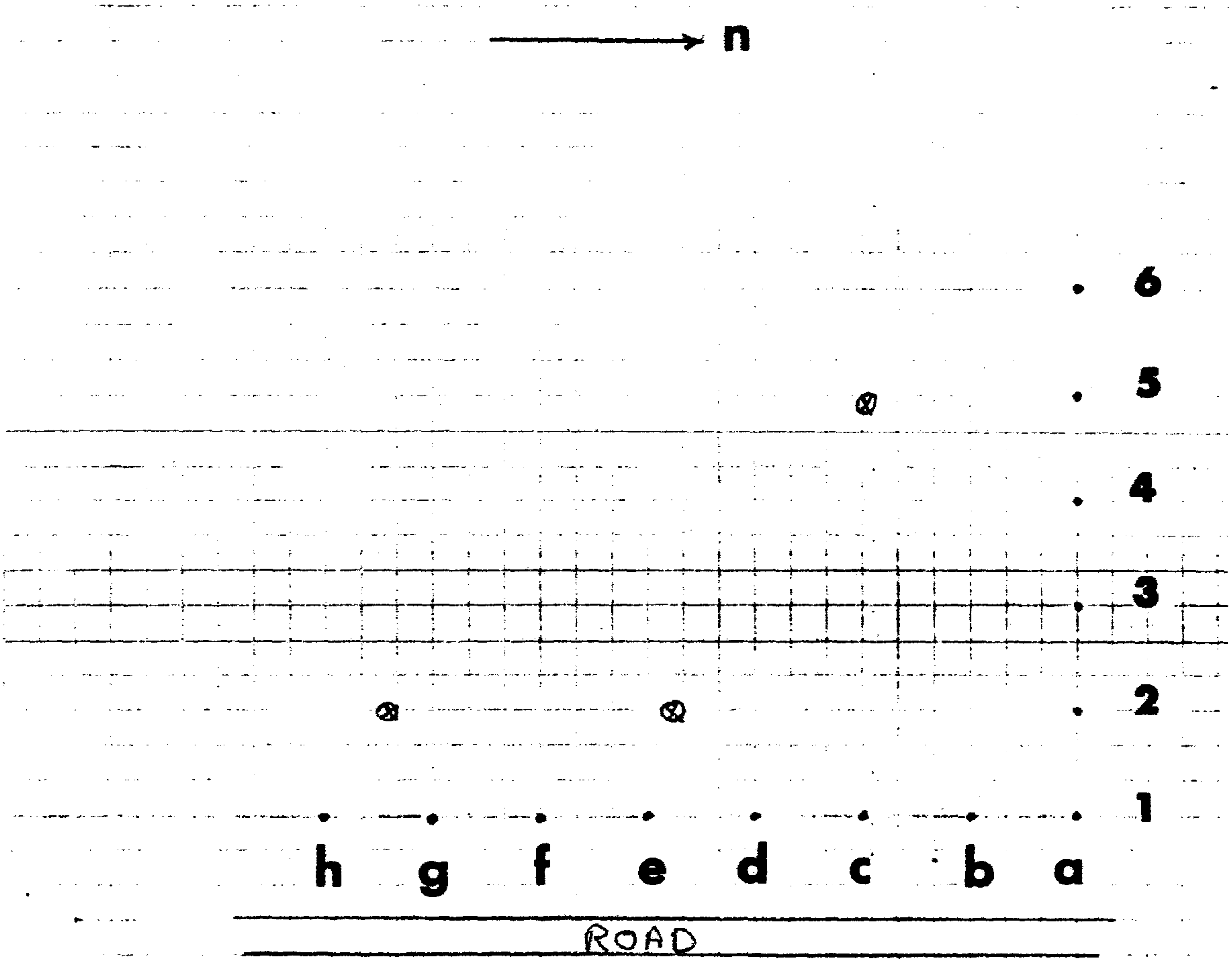
COMPUTATION SHEET | **U. S. DEPARTMENT OF AGRICULTURE**

SCS-ENG-523 Rev. 8-69 | **SOIL CONSERVATION SERVICE**

GPO:1969-O-357-545

CHART 3

STATE ALABAMA		PROJECT Old Cahaba		
BY GPR	DATE 8 Nov 83	CHECKED BY	DATE	JOB NO.
SUBJECT Proposed Septic Field Site				SHEET 1 OF 1



50 foot interval

Site A1 is in NE corner of field
50 feet south of pecan tree

⊗ point objects in soil