



Eugene Goss
COMMISSIONER OF HIGHWAYS

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT, KENTUCKY 40601
February 20, 1970

H - 2 - 16

MEMORANDUM TO: A. O. NEISER, State Highway Engineer
Chairman, Research Committee

SUBJECT: RESEARCH REPORT, "DEVELOPMENT OF A PRACTICAL
METHOD OF LOCATING AND TRACING SEEPAGE WATER
IN UNSTABLE SLOPES"; KYHPR -63 - 16; HPR-1(5), Part II.

The above-titled study originated in 1963 in connection with the large embankment failure on I 75 (Covington hill). Extensive exploration and reconstruction followed. As a matter of record, the reconstruction plans were programmed in two stages; the second stage has not been activated and may not be needed. Some slow subsidence continues along the upper fill (opposite Dickman Lake). Our most recent status report on that work was issued in September 1968 (H.F. Southgate).

There are two contradistinctive hypotheses involved in the stability design of earth structures: one relies on the control of seepage waters to more or less "normalize" the strength of the soil, the other relies on counterpoises and other balances to obtain stability -- in spite of natural seepage. We rather preferred to control seepage waters insofar as possible and thereby confronted the inevitable problem of exploring subsurface water conditions attendant to existing slides.

In retrospect, we were aware of the possibility that dry weather springs might have been buried in side-hill fill situations and of the possibility that surface-water sinks might have been created in rock fills. Seeps at the toe or at higher levels on the embankment slopes were regarded as tell-tale signs. Dye-tracers, electrical resistivity, and even water-witching were thought worthy of consideration.

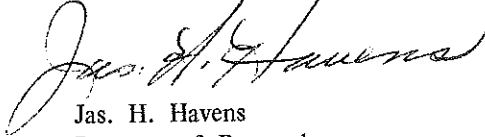
In the interim, several failing, side-hill embankments have been excavated and reconstructed; in some cases, no discrete spring or aquifer was found; in fact, upon exposing some of the original cut-and-benched faces where the fill material was very wet, mere trickles of water were found seeping from some strata -- and even these sometimes dried up. Nevertheless, this insidious type of seepage, together with damming-effects within the fill, permitted sufficient water to accumulate to cause failure. The idea of tracing these migrating waters was abandoned. It became more evident that static-head and water-table elevations were more significant. Piezometric surfaces may be determined from bore-hole wells -- with or without implanted gauges.

Dye-tracers tend to be absorbed by clayey soils unless discrete veins of water exist. Electrical resistivity is affected by extraneous influences, such as guardrails, pipe lines, power lines, etc. Also, resistivity is not necessarily proportional to the amount of groundwater present. The bored wells seem far more reliable.

During the term of this study, various side benefits have accrued. A computer method of making embankment stability analyses emerged and is being used as a design criterion. Several case studies have been reported, and two additional research projects have splintered off. KYHPR-65-38 pertains to the measurement of basic strength parameters of soils, and KYHPR-68-48 is a more general continuation study of landslides.

This is the final report on this particular study.

Respectfully submitted,



Jas. H. Havens
Director of Research

JHH:cel

Attachment

cc's: Research Committee

Assistant State Highway Engineer, Research and Development
Assistant State Highway Engineer, Planning and Programming
Assistant State Highway Engineer, Pre-Construction
Assistant State Highway Engineer, Construction
Assistant State Highway Engineer, Operations
Assistant State Highway Engineer, Staff Services
Assistant Operations Engineer
Executive Director, Office of Computer Services
Executive Director, Office of Equipment and Properties
Director, Division of Bridges
Director, Division of Construction
Director, Division of Design
Director, Division of Maintenance
Director, Division of Materials
Director, Division of Photogrammetry
Director, Division of Planning
Director, Division of Right of Way
Director, Division of Roadside Development
Director, Division of Rural Roads
Director, Division of Traffic
Division Engineer, Bureau of Public Roads
Chairman, Department of Civil Engineering, University of Kentucky
Associate Dean for Continuing Education, College of Engineering, University of Kentucky
All District Engineers

Research Report

**LOCATING AND TRACING SEEPAGE
WATER IN UNSTABLE SLOPES**

**FINAL REPORT
KYHPR-63-16; HPR-1(5), Part II**

by
Yasin A. Alkhoja
Research Engineer Associate

and

Gordon D. Scott
Research Engineer Principal

**Division of Research
DEPARTMENT OF HIGHWAYS
Commonwealth of Kentucky**

In cooperation with the
U. S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

The opinions, findings, and conclusions
in this report are not necessarily those of
the Department of Highways or the Bureau of
Public Roads

February 1970

INTRODUCTION

With the increase in modern highway construction, the occurrence of landslides has been growing proportionally due to the use of deeper cuts and higher fills. It has been observed that landslides on highways often occur in fills on hillsides. Accumulation of water in the embankment, usually seeping from a nearby hill, may reduce the shear strength of the embankment soil and result in failure at a later time. Many landslides on Kentucky highways have occurred a few years after construction and obviously have been caused by the gradual weakening of the embankment due to a damming and accumulation of water. Thus, locating and tracing seepage water in unstable slopes or in potential landslide areas become a significant tool in designing systems to remove or cut off the water so that the stability of the slope is maintained or increased.

Locating and tracing ground water have been done by two old and effective but rather expensive and time-consuming methods - borings and excavation. In recent years, efforts have been made to develop methods which are as effective as borings and excavation but require less time and can be accomplished at lower costs. The study reported herein is part of this effort to improve techniques. Interesting information and additional data have been added to the state of knowledge. In this investigation, several methods, such as the use of tracers, water table observation, and electrical resistivity, were considered and studied.

In a recent study, Jones and Peebles (1) placed special emphasis on the method of using tracers composed of either chemical dyes or radioactive tritium. They did extensive research, both in the field and in the laboratory, on the chemical dye tracers method. Sensitive electronic equipment, Model 110 Turner Fluorometer for monitoring fluorescent dyes and Model AC Fisher Electrophotometer for monitoring non-fluorescent dyes, was used to monitor dye concentrations. Although they achieved some promising results, they did not develop an accurate and dependable method.

Corey (2) illustrated the suitability of various types of dyes for tracing flow paths in acid soils. He proposed an empirical criterion for choosing potentially suitable dyes for water movement studies.

Three possibilities for use in geophysical location of water include: 1) direct location, in which water occurring in the form of thermal, saline, or radioactive springs may be located by temperature, electrical, or radioactivity measurements, or by the noise it makes in escaping from pipe leaks; 2) structural water location, which involves the attempt to find locations geologically favorable as sources of water; and 3) stratigraphic water location, which attempts to determine the condition and depth of the aquifer itself. Electrical methods are most applicable and are inexpensive for stratigraphic water location. Water in the pores of soil alters the conductivity of the soil-void system to such an extent that conductivity measurements can be used to assess the hydrological condition of the subsurface. It is impossible to recognize the presence of water by a specific value of earth conductivity. However, where the presence of an aquifer has been established by bore holes or wells, it is possible to correlate conductivities with water-bearing formations.

Buhle and Brueckmann (3) reported that electrical earth resistivity surveys have been conducted by the Illinois State Geological Survey since 1935, mainly in search of water-yielding sand and gravel deposits. The extensive field experience has guided the development of instruments and equipment that are versatile and reliable. The effective use of the equipment depends on an understanding of the local geological setting. Non-geologic factors that can distort the apparent resistivity must be recognized and then minimized or avoided.

Abdun-Nur and Wantland (4) used the electrical resistivity method in investigating deposits of rock and gravel in the plains area. They recognized its usefulness in supplementing and guiding drilling in the exploration of such deposits and gave examples of actual investigations. It was concluded that, in case of deposits of similar materials, the electrical resistivity method provided an effective, quick, and economical means of determining depths, delineating the extent, and estimating the quantities of material involved.

When the earth-resistivity method is used to make subsurface explorations, good geological information should be available about the chosen site (5). It is also advisable to make calibration tests with the resistivity apparatus over exposures of formations believed to be typical of those in the area of immediate interest.

Moore (6) briefly described the use of the resistivity method in landslide investigations. The resistivity technique can be used in such situations because of the effect of higher water contents at the slip surface or shear zone upon the measured resistivity values. Fifteen states have used this method in brief demonstration tests on landslide problems, though only in a few instances has a complete and thorough survey of a particular landslide been made.

Goodwin (7) used the resistivity method in a study of bridge foundations. Although the study was a preliminary one, it indicated the advantage and apparent usefulness of the electrical resistivity method in subsurface exploration. Goodwin described thoroughly the apparatus and procedure with good illustrative pictures and diagrams.

In previous studies, it has been suggested that there is still much to be done to develop the electrical resistivity method as well as the use of tracers to locate seepage waters. Since the interpretation of the readings obtained by the resistivity method is very important, it follows that it must be done with extra care by experienced and well-trained personnel.

METHODS OF INVESTIGATION

TRACERS

By injecting a tracer into ground water through drill holes in suspected sources, movement of the tagged ground water can be traced by bailing water samples from other drill holes and measuring the concentration of the tracer material from each sampling point. Knowing the distance of the sampling holes from the injection hole and the time for the marked water to travel that distance, the velocity of the ground water movement can be calculated. Thus, speed, direction, and location of the ground water can be detected.

There are many types of tracer materials, each yielding good results under certain conditions. Some classes of materials that have been used include dyes, chemicals, suspended particles, dissolved gases, bacteria, and radioactive isotopes (1).

Satisfactory results are more likely in relatively homogeneous soils having medium hydraulic conductivity. Therefore, poor results will be expected in heterogeneous soils with low hydraulic conductivities. No tracer known at the present time meets all, or most, of the requirements of a good or ideal tracer. An ideal tracer material must be economical, safe, not present in the original water, capable of following the water movement without altering it, non-absorbent or nearly so, capable of being detected in low concentrations, and non-reactive with the porous medium. Important factors that restrict the use of otherwise suitable tracers are absorption, dispersion, filtration, and public acceptance (1).

In this investigation, limited study of the tracer method was undertaken at only a few sites. After charging suspected sources of seepage waters with fluorescent dyes, checks for the presence of the dye were made in known wet zones in the area under study at various times. Observations for the presence of dye in the wet areas was made by black (ultraviolet) light. This method was to verify whether the suspected source was a real one or not. No effort was made to calculate the velocity of ground water flow, and no attempts were made to measure the actual concentration of the dye in the wet areas.

WATER TABLE OBSERVATION

A network of auger holes is drilled in the area under study, and water table measurements are recorded over a considerable period of time. From these measurements, ground water contour maps can be plotted to show the change of the water table over a period of time. This method provides an accurate picture of the ground water level, and the movement of the water is inferred from the space gradients observed on the contour maps.

In landslide investigations, determining the direction of movement, amount of flow, maximum gradient, and velocity of flow is very important. To determine the velocity, the hydraulic conductivity of the soil under investigation must be determined first. Hydraulic conductivity can be measured in situ by several methods (1):

1. Single-hole method for either homogeneous soils or layered soils
2. Two-well method
3. Four-well method
4. Piezometer method
5. Tube method
6. Discharging-well method.

The single auger-hole method is the simplest and can be performed by drilling a hole into the soil below the water. After first determining the water table level by allowing the water surface in the hole to reach equilibrium, the hole is pumped out to a new water level elevation; the rate of rise of water in the hole is then measured. From these measurements, the hydraulic conductivity can be calculated by several different formulas developed by various investigators. After determining the hydraulic conductivity, the amount of flow passing a certain area can be calculated.

ELECTRICAL RESISTIVITY

This method is based on the measurement of earth electrical resistivity in the area under investigation. The application of this method is not simple, however, due to the many different types and conditions of subsurface soils. At times, different soils under different conditions have approximately the same electrical resistivity. This sometimes causes confusion and makes it difficult to differentiate between a wet layer of one type of soil and a dry layer of a soil of a different type. Therefore, knowledge of the geology of the area under investigation is essential when this method is used, and calibration tests with the resistivity apparatus over exposures of formations believed to be typical of those in the area must be performed.

The presence of moisture in soil decreases its resistance to electrical flow, assuming other conditions are the same. The specific resistivity and the electrical resistance are thus inversely proportional to moisture content. The relationship between the electrical and geometric properties of the system is given by

$$\varphi = 2A (E/I)$$

where

φ = specific resistivity in ohm-feet,

A = electrode separation in feet (also depth of measurement),

E = potential difference between the two non-polarizing electrodes expressed in millivolts, and

E/I = electrical resistance of the soil.

Moisture contents of the soil at some sites have been determined from drill hole samples, and attempts were made to correlate these with resistivity results.

The resistivity apparatus includes a case which contains the indicating instruments, batteries for the potentiometer circuit, two non-polarizing electrodes and two current electrodes used to make electrical contact with the earth's surface, and four reels to transport the necessary leads for the electrodes. The area in which the resistivity measurements are to be made is first inspected, and a definite plan is formulated as to the location, direction, and type of resistivity traverse to be used. The basic equipment, which includes the power supply, instrument case, and reels, is located in such a manner as to facilitate the running of several traverses without excessive handling of the equipment. It is necessary to survey the area for pipe lines, transmission lines, etc. which might influence the resistivity readings.

In a field set up, the center of the base traverse is located, and the basic resistivity equipment placed perpendicular to the traverse line and offset a distance sufficient to permit the operator to view the extremities of the traverse at all times. The reels are placed directly in front of the operator at such a distance to keep a taut lead from them to the instrument case. The electrodes are then placed on the traverse line at the desired spacing. The instruments must be calibrated before the leads from the electrodes are placed into their receptacles.

Figure 1 shows the current flow diagram during operation. To make resistivity measurements of the earth, the power supply is adjusted to a convenient scale so as to give a reading on the milliammeter. The potentiometer circuit is closed, and the millivoltmeter is adjusted by the coarse and fine adjustment until the galvanometer shows no deflection. A simultaneous reading of the current and voltage is then made.

Upon completion of each reading, the electrode spacing is changed, keeping equal spacing between the electrodes. This operation is continued until the desired depth of investigation is reached. The resistivity for each depth is calculated and plotted in the field in order to locate any irregularities in the curve. This also provides a convenient check on the field procedure and immediately helps to locate poor connections or broken leads.

RESULTS AND ANALYSIS

TRACERS

Laboratory and field work with tracers were rather limited. Nevertheless, one tracer, a fluorescent dye, was tested in the laboratory and at three different field sites, and a chemical tracer was investigated at a fourth site.

In the laboratory, a large permeameter consisting of a three-inch inside diameter by nine-foot long plexiglas tube was constructed and used to study the ability of fluorescent dyes to resist the filtering and absorbing action of soil.

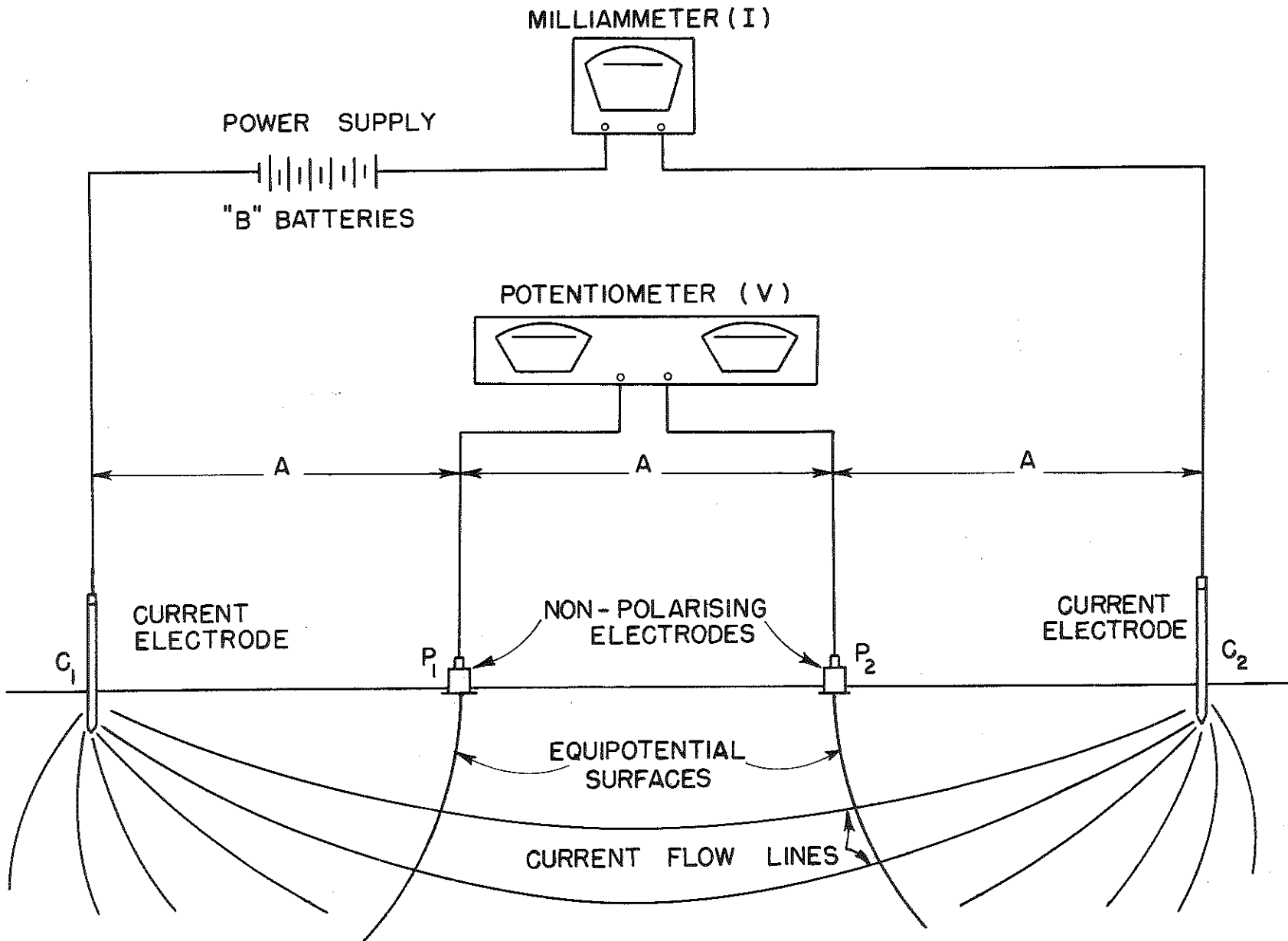


Figure 1. Electrical Resistivity Current Flow Diagram

The permeameter was filled with fine, silty sand and stopped at both ends with porous disks. A solution of fluorescent dye was circulated several times through the sand column. After several passes through the sand filter, the solution appeared as strong as originally injected into the column, and it was concluded that sand will not remove fluorescent dyes from solution for moderate percolation distances. However, this process of re-running the solution through the sand filter was continued for a week, and the dye at the effluent end became somewhat less detectable. When the sand was emptied from the cylinder, it was found that a portion of the dye had been absorbed by the sand material.

Due to a preference to put more emphasis on field work, as well as the decision that was made earlier to concentrate on the electrical resistivity method, it was decided to discontinue the laboratory experiments on tracers.

In the field, tracers were used at four sites -- Caldwell, Lawrence, Kenton, and Clark Counties (see Figure 2); all sites were either actual or potential landslides on highway embankments in Kentucky. At three sites, the same fluorescent dye investigated in the laboratory was used. Four colors (purple, orange, red and blue) of this dye were used. Ultraviolet light was used to detect the presence of fluorescence in the wet areas of the sites after the dye was introduced into the suspected sources of seepage. In total darkness, the dyes fluoresced in distinctly different colors, but in semi-darkness, it was difficult to differentiate between red and orange and between blue and purple. At one site, hydrated lime was used as a tracer.

CALDWELL COUNTY SITE - This slide is on the Western Kentucky Parkway, at Milepost 7, near Princeton. A surface exploration of the landslide and surrounding area indicated several out-croppings of fissured and jointed sandstone. Surface water was observed entering the fissures south of (above) the landslide. From roadway cuts in the vicinity of the slide, it could be observed that the sandstone was on the order of ten feet thick, overlain by approximately five feet of soil, and resting on blue shale. Numerous small faults, the various strata dipping up to approximately 30 degrees, were exposed in the cuts.

The available geological maps indicate that the material is of the Caseyville Formation (lower Pennsylvanian), consisting of sandstone, siltstone, shale, and coal. The sandstone, a fine to coarse-grained deposit, locally forms cliffs as much as 50 feet high. The siltstone, somewhat sandy, is interbedded with thin-bedded sandstone. The shale, generally dark-gray to black and carbonaceous, is usually associated with coal beds, which are thin and lenticular.

After heavy rains in February and early March of 1964, wet weather springs were observed near the toe of the slide area. Fluorescent dye placed in the surface water, just before disappearing underground, was detected at the springs a few hours later. It was concluded, in this case, that the dye did not seep through the soil mass, but instead, traveled through defined channels either under or in the embankment, accounting for its appearance at the springs in such a short time. The tracers verified the suspected sources of the several springs along the toe of the embankment.

LAWRENCE COUNTY SITE - This slide is on US 23, Station 47+00, in the northbound lane, approximately one mile north of Louisa. This area is located in the Eastern Coal Field of Kentucky and involves materials of Pennsylvanian age. The slide area is apparently located near the contact between the river alluvium in the valley and the Breathitt Formation, which forms the valley walls in this area. The Breathitt Formation consists of siltstone, sandstone, and claystone. Minor constituents are coal, clay, ironstone, limestone, and chert. The numerous, thin coal beds throughout the formation are associated with underclays along which seepage water may move. It is suspected that the principal cause of the slide is such seepage water, which has been blocked by the side-hill fill, causing the fill to become saturated, and therefore, to lose strength and slip.

Shortly after construction in 1960, settlement of the northbound lane was observed. At this time no movement of the toe area was noted. Movement continued at a relatively slow rate until late 1963. More rapid movement continued to the middle of 1964. Observations of the slide area indicated that the crown of the slide was located near the center of the northbound lane. The toe of the slide extended into natural ground about ten feet below the bottom of the embankment slope. Possibly, the slide initially existed in the fill and later progressed into the foundation material.

The tracer method was not used extensively at this site, but several attempts were made to trace seepage water after dye was deposited in suspected sources - ponded water in the roadway ditch above the slide. In May 1964, fluorescent dyes were placed in known and suspected sources of seepage water on several days, but no fluorescence of seepage water was detected, using the ultraviolet light, at the toe of the embankment.

KENTON COUNTY SITE - This slide is in Kenton County near Covington, Kentucky. The slide area is located in the northbound lane on a section of I 75 between Kyles Lane, near Station 440+00, and the interchange near Station 523+00.

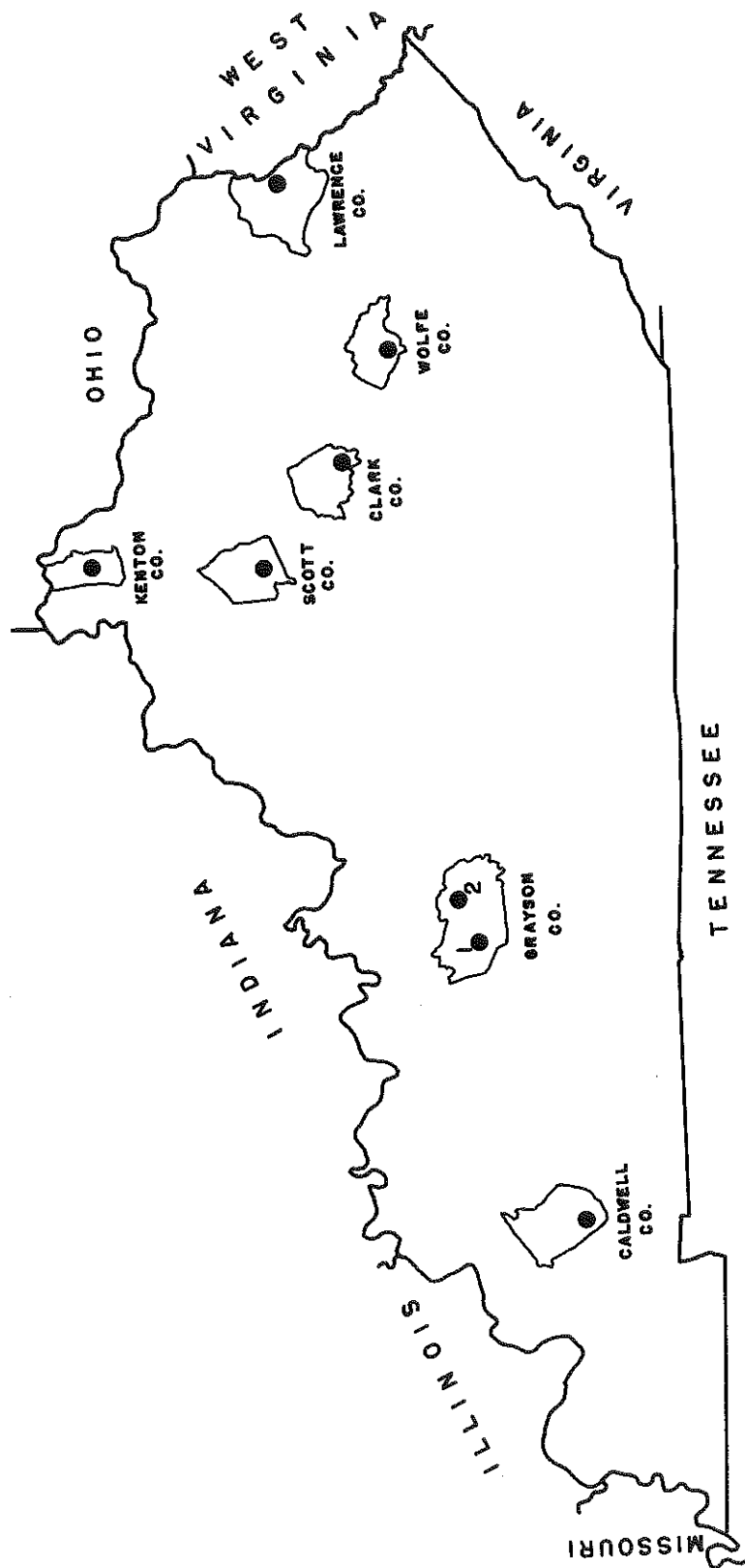


Figure 2. Test Site Locations

Throughout this section of highway, thin interbedded layers of shale and limestone are exposed in cuts. In several areas, water seeping from the cut slopes could be noted, particularly after periods of rain. The embankments had apparently been constructed from this shale-limestone material. The shale weathers rather quickly to a heavy clay while the limestone is more resistant. This site is described in more detail in a report entitled *I 75 Kenton County Slide*, dated September 1968.

The tracer method was used at this site more extensively than at the other two slides. This slide was considered to be ideal for tracer testing due to the various existing drainage conditions. Introduction of fluorescent dyes into suspected sources of seepage water began in May 1964 and continued at various times through May 1968. Continuous observations of seepage water at the toe of the slide never indicated a trace of the dye. It was concluded that the dye was absorbed by the soil or diluted by the large volume of water present so that its concentration in the seepage water at the toe could not be detected. Absorption of the dye by the soil was not unexpected, considering the great length of the drainage path from suspected source to toe.

CLARK COUNTY SITE - The slide at this site is located in a short fill section near the Powell County line between Stations 633+00 and 635+00 on the Mountain Parkway. Soon after the highway was opened to traffic, a 50-foot section of the right (eastbound) shoulder subsided slightly. Since that time, the area of subsidence increased during periods of wet weather so that both right (eastbound) traffic lanes, and to a lesser extent the left (westbound) traffic lanes, have become involved. Maintenance operations have included mudjacking and patching to maintain the proper grade.

The geological formations exposed by the cut in the vicinity of Station 636+00 indicate that the strata in the vicinity of the slide dip slightly from southeast to northwest (the direction of decreasing stations). Above an approximate elevation of 715 feet is the Ohio Black Shale, and below an elevation of 705 feet is a greenish shale which weathers readily into a plastic clay. The green shale appears to be about 15 to 20 feet thick in the vicinity of the slide. Between the black shale and the green shale is a sandy limestone which is thought to be the Duffin layer. The lower part of the layer is composed of a hard limestone conglomerate over a cherty limestone, both about eight inches thick. The upper part of the layer is sandy limestone interbedded with black shale.

In September 1966, hydrated lime was placed just below the surface at a median inlet and two ditch inlets at Station 625+00 where water was observed disappearing into the ground. Water samples were obtained from drill holes at frequent intervals over a period of several months and tested in the laboratory for ph, conductivity, calcium content, etc. Analysis of the water samples did not indicate any change due to lime. This indicates that the suspected water probably finds its way to the spring box at Station 631+80, which, as indicated by the large flow, is functioning properly.

WATER TABLE OBSERVATION

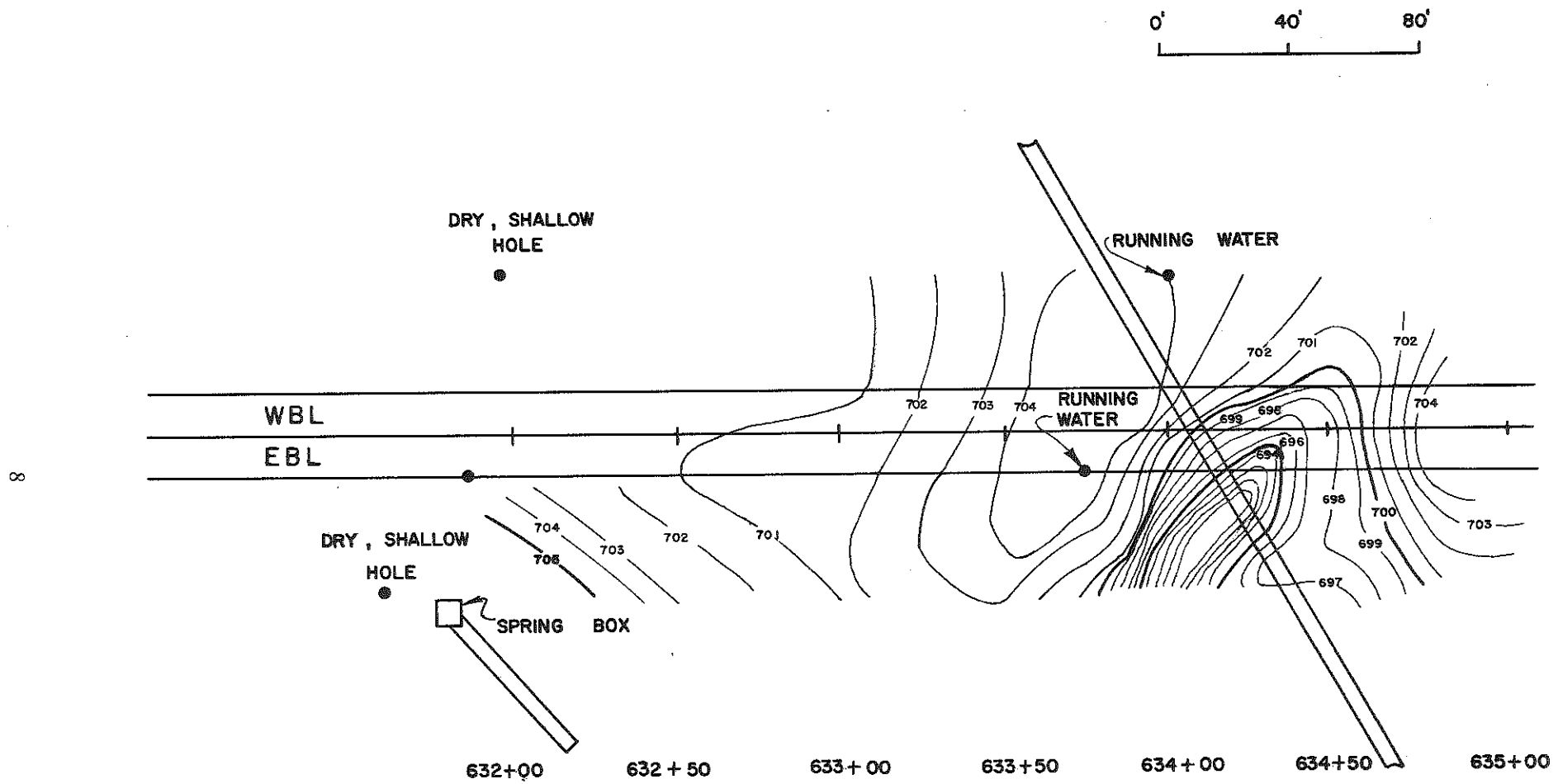
The auger-hole method used to observe water table levels was found to be, as expected, a good and reliable one. The continuous water table measurements in the drill holes at all sites permitted the plotting of water table contour maps which showed the water table gradients. The latter, in turn, indicated the direction of movement of the ground water at each site. This method, although reliable, involves extensive drilling, and thus, is time-consuming and expensive. Three sites of potential landslides on two highways in Kentucky were investigated. These investigations were made to determine corrective measures for stabilizing the embankment as well as to study this method of tracing seepage waters.

No attempt was made to calculate the actual hydraulic conductivity because the interest was in determining maximum water table gradients and directions of flow rather than the velocity of the flow. The rate of flow would be useful in estimating the time needed for the embankment to become saturated; a knowledge of the maximum water table gradients and the direction of flow provided an accurate picture of the ground water movement.

CLARK COUNTY SITE - This site is on the Mountain Parkway in Clark County, between Stations 633+00 and 635+00, near the Clark-Powell County line. Detailed discussion of the site is given previously in this report in the section on **TRACERS**.

In the spring of 1966, 22 borings were made at the site for observations of water table elevations made at frequent time intervals for several months. These data are presented in the form of water table contours in Figure 3.

The water table contours for this site show a mound of ground water between Stations 633+50 and 634+00 and extending the entire width of the road. The contours indicate that the water is draining from the embankment in a southerly direction. Within the limits of the roadway (no exploratory holes were drilled beyond the shoulders), the ground water low point is in the eastbound lane near Station 634+00. This places the drainage outlet in the vicinity



of the 48-inch concrete culvert. Also, water continually entered the culvert through the tops of open joints, a further indication that the culvert serves as an outlet.

The water appears to be entering the embankment from the east. About 100 feet to the northeast is a pond with water at a normal pool of 705 feet. Thus, the pond is a likely source of seepage. It is possible, though, that the pond is not the source of seepage, but rather both the pond and embankment may be fed by ground water. At this site, the observation wells permitted a fairly accurate assessment of ground water conditions and the seepage water movement.

GRAYSON COUNTY SITE 1 - The slide at this site is located on the Western Kentucky Parkway, Milepost 83, westbound lane, between Stations 6198+00 and 6201+00. This area is located in the Western Coal Field and the materials involved are of Pennsylvanian age. The Caseyville Sandstone has been observed at lower elevations with the Tradewater Formation above it. At the highest elevations in this portion of the county, materials classified as the Carbondale Formation have been observed.

The Caseyville Sandstone is a cross-bedded, conglomeratic, medium to very coarse-grained sandstone inter-tonguing with shales. The middle portion contains several thin coal beds and thin layers of limestone. The Tradewater Formation is a series of interbedded sandstones and shales with occasional thin layers of limestone and thin coal beds. Locally, the sandstones may be relatively thick and well-cemented, ranging from very thin laminations to very thick, cross-bedded units. The shale, locally silty, is gray or black when unweathered but changes to slightly lighter colors when affected by water and air. The No. 1A coal is located near the base of the Tradewater Formation, and the No. 7 coal is located near the top. Underclays approximately a foot thick have been observed in association with coal beds throughout the formation. Layers of gray clay up to two feet thick have been noted in drill holes in the area. The Carbondale Formation is predominantly a shale or sandy shale with thin coal beds. The Sebree Sandstone, a cross-bedded, friable to well cemented, shaly quartz sandstone, is capped by the No. 9 coal bed.

The shales of the Tradewater Formation are paths along which subsurface waters may move. It is probable that this water may have been entrapped by the damming effect of the embankment, causing the embankment to become saturated and lose its strength.

Auger holes were drilled on both shoulders of the highway and on the median in the slide area. Water table levels in the drill holes were observed regularly between May and November 1967.

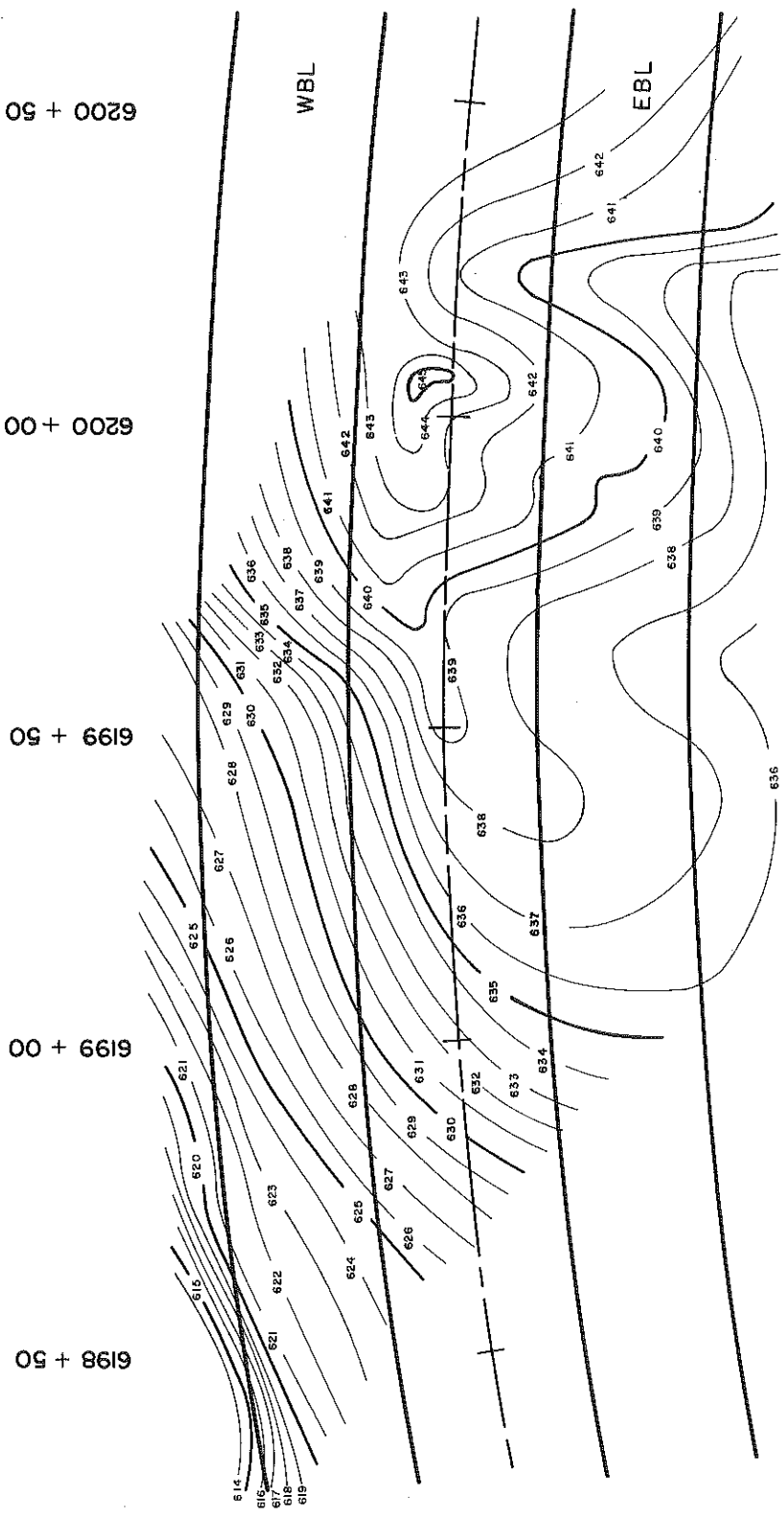
The water table contours at this site (Figure 4) show a mound of water between Stations 6199+50 and 6200+50 and including most of the median and part of the eastbound lanes. The water seems to be draining away from this mound in two directions - one towards the shoulder of the eastbound lane, and the other towards the shoulder of the westbound lane (the slide location). The drainage of water towards the south shoulder is due to the effect of the cut-off trench constructed parallel to the centerline of the embankment in the south ditch to intercept the ground water that seeps from the nearby hill. This keeps the water table under this shoulder always below the mound elevation. On the other hand, the drainage of water towards the north shoulder is due to the effect of the horizontal perforated pipes that were installed earlier in the slope of the embankment. Apparently the mound of water in the middle of the embankment is a result of continuous saturation of the embankment by water seeping from the nearby hill over the years since the highway was constructed and prior to the installation of drains. It is believed that it will take a similar time for the water to be dissipated.

GRAYSON COUNTY SITE 2 - The slide at this site is located on the Western Kentucky Parkway, Milepost 96, westbound lane, between Stations 6922+00 and 6923+75. A study of the geology of the area reveals the formation consists principally of shale with many zones of interbedded limestone and sandstone. The shale is generally gray to blue but includes conspicuous amounts of red and green color. Some of the shales weather into plastic clays.

The sandstone is believed to be of the Caseyville Formation of the Pennsylvanian System. It is a medium-grained, cross-bedded, and poorly cemented lenticular conglomerate. It is massive in places and underlies dissected uplands and ridgetops and caps isolated hilltops.

Under the sandstone is variegated shale with thin-bedded sandstone and limestone of the Leitchfield Formation of the Upper Chester Series, Mississippian System. Thickness varies because of pre-Pennsylvanian erosion. Near the lower portion is a gray, fine-grained, locally bituminous, sandstone and dark-gray shale. Lithology varies greatly within short distances. The topography of this sandstone and shale is gently rolling uplands and fairly steep slopes adjacent to stream valleys. Sandstone lenses, some massive, form small benches.

In 1966, a break in the westbound shoulder was observed in the slide area, and soon after that, observation wells were drilled in the eastbound and westbound shoulders to monitor the water table. Water table readings were taken



GRAYSON COUNTY
 WESTERN KENTUCKY PARKWAY
 MILEPOST 83

Figure 4. Water Table Contours, Grayson County Site 1

over a considerable time, and contour maps prepared.

The average of water table readings over a period of one year was plotted in the form of contours (Figure 5). The figure shows that water seeps from the nearby hill south of the eastbound shoulder between Stations 6923+00 and 6925+00 in a northwesterly direction. It also indicates that there is a mound of water along the westbound shoulder between Stations 6922+10 and 6923+15, and the water table drops gradually north and south of the mound. A study of the cross-sections of the embankment at the slide area revealed that the water table was always within the foundation, i.e., below the fill material.

ELECTRICAL RESISTIVITY

Special emphasis was placed on this method since previous studies indicated that it may provide, if completely developed, a fast, inexpensive, and reliable method for tracing and locating seepage water. Efforts were made to find a relationship between electrical resistivity of soil at different depths with corresponding moisture contents. Six sites were investigated by this method. They were carefully chosen to cover most of the geological areas in Kentucky (Figure 2). Data collected using the electrical resistivity method indicated that such data could be used effectively in planning a drilling program. Specific resistivity and cumulative resistivity were plotted as functions of depth. Hereafter, specific resistivity will be referred to as resistivity.

The apparent resistivity curves are of limited value since it is impossible to recognize water by a specific value of soil resistivity. It has been reported that water in the pores of soil changes the resistivity to such an extent that the resistivity of the earth minerals is almost negligible. Thus, the moisture content and electrical conductivity of water are the major factors that affect earth resistivity, and the specific value of resistivity will depend greatly on the conductivity of the pore water.

The smoother cumulative curves were all similar in shape. It is noted, however, that the slopes differed considerably, thus suggesting the possibility of analyzing the slopes. Accordingly, contours of the slopes of the accumulative resistivity versus depth curves were prepared for various depths and showed, very clearly, areas of high and low resistivity.

The variation in the resistivity from point to point in a particular stratum is of interest rather than the variation with depth. The variation with depth is likely to be complicated by differences in density, etc., whereas a change of resistivity between different points in the same stratum may be assumed to reflect variations of moisture content. Thus plots of contours were prepared for various depth intervals over which there was little or no change of slope.

Resistivity data were compared with the limited drill data obtained at the Caldwell, Lawrence, and Kenton County sites. This comparison showed good agreement in about 75 percent of the cases. Some of the disagreement, no doubt, was due to the fact that the drill hole locations and resistivity log locations did not exactly coincide. On the plots of contours of the slope of accumulative resistivity versus depth, some areas of extreme values of slope were noted for which there were no drill hole data for comparison.

LAWRENCE COUNTY SITE - This site is on US 23, approximately one mile north of Louisa. A detailed description of the site is presented earlier in this report.

An investigation was undertaken to establish a correlation between some function of resistivity and a corresponding measure of moisture content. Three methods used to determine representative moisture content values for a specified depth interval were:

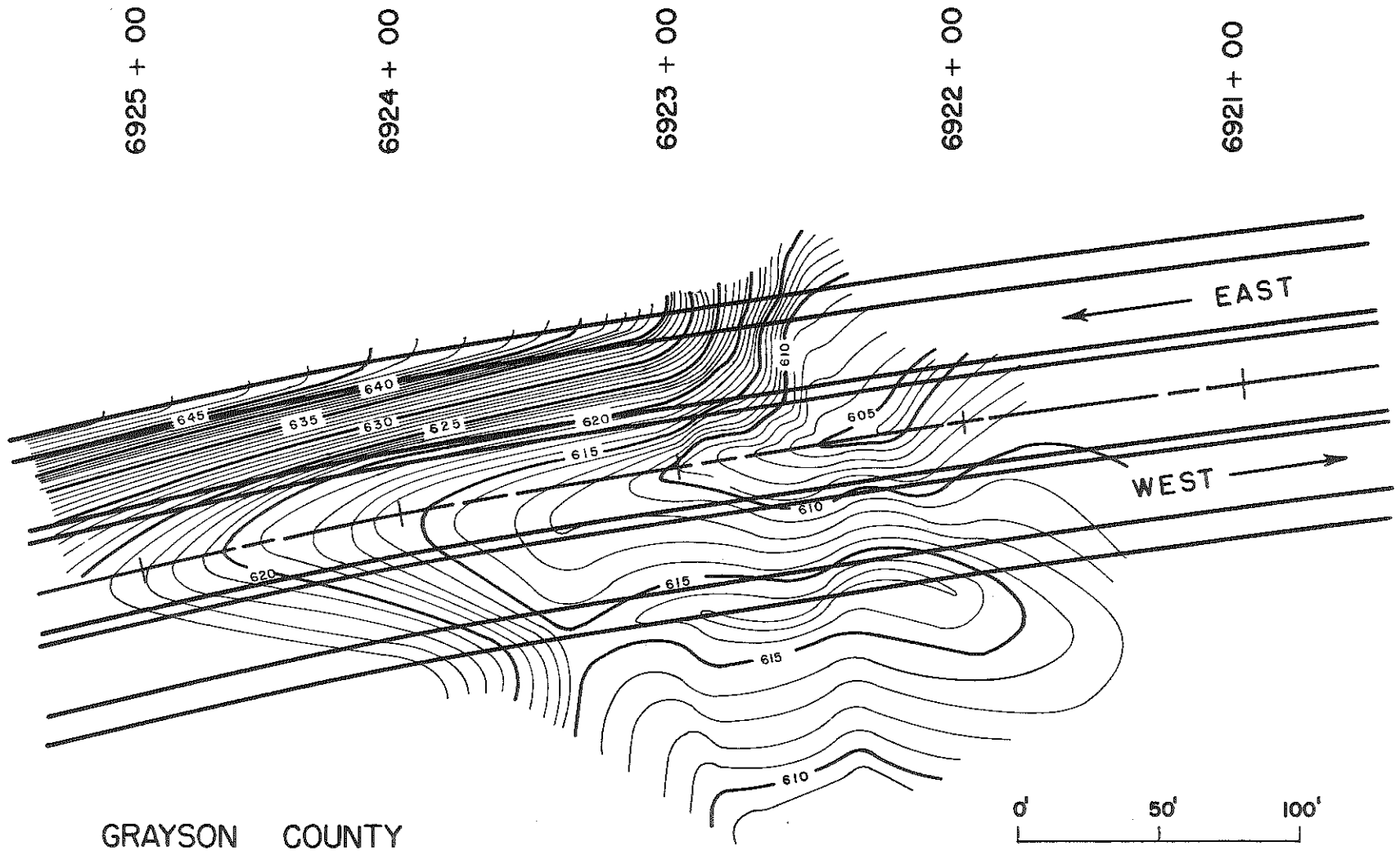
- 1) using the moisture content at the centroid of the zone of influence of the resistivity measurements (approximated by a semicircle) (see Figure 1),
- 2) using the moisture content at the specified depth, and
- 3) using the moisture content at the center of the specified depth interval.

Moisture content values were plotted against values of a resistivity function for the same depth interval.

Two methods used to determine representative functions of resistivity were:

- 1) using the ratio of the specified depth to the accumulative resistivity at that depth, and
- 2) using the specific resistivity at the specified depth.

Correlation curves of a function of resistivity vs moisture content, Figures 6 and 7, are very poor in that a great deal of scatter is present. However, the depth/accumulative resistivity-moisture content curves, Figure 6, show an



GRAYSON COUNTY
WESTERN KENTUCKY PARKWAY
MILEPOST 96

Figure 5. Water Table Contours, Grayson County Site 2

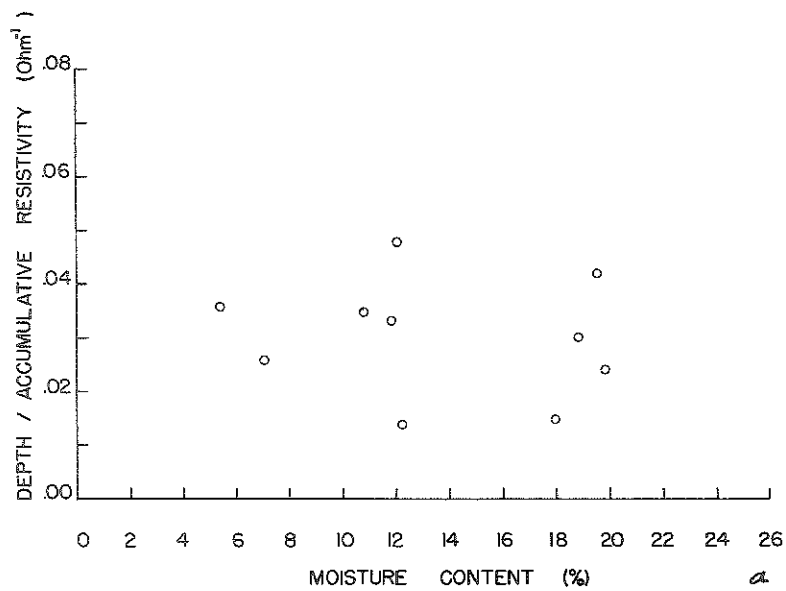


Figure 6a. 10-Foot Depth

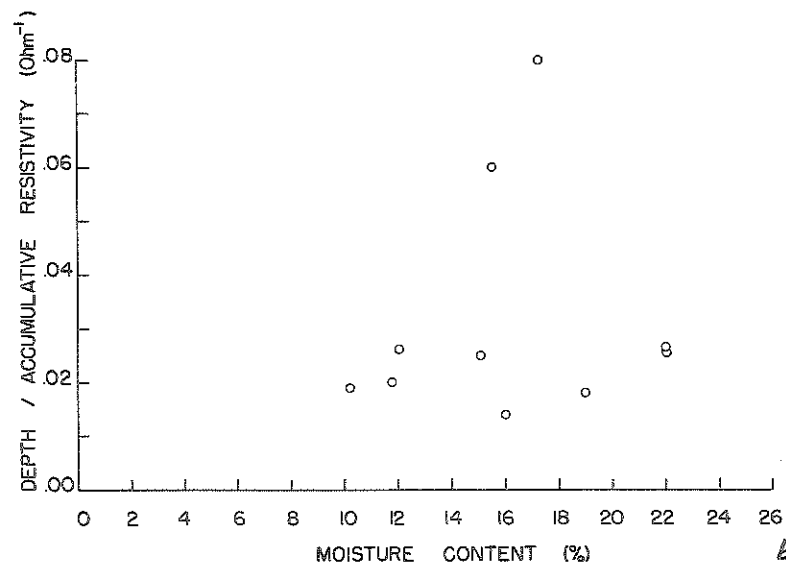


Figure 6b. 10-20 Foot Depth Interval

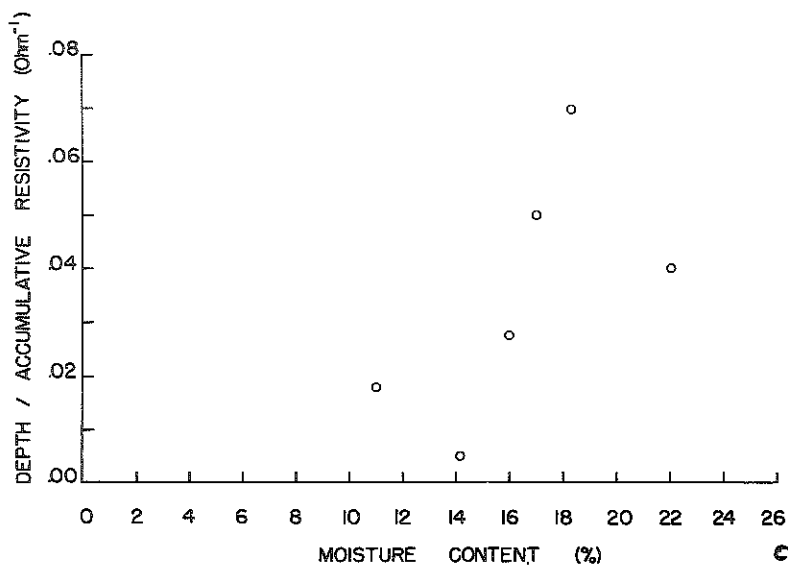


Figure 6c. 20-30 Foot Depth Interval

Figure 6. Depth/Accumulative Resistivity vs Moisture Content, Lawrence County Site

increase in the value of depth/accumulative resistivity for an increase in moisture content. Resistivity vs moisture content curves, Figure 7, on the other hand do not show any relationship between resistivity and moisture content.

Since the above depth/accumulative resistivity-moisture content curves do show a correlation between resistivity and moisture content, though disappointingly weak, it follows that a knowledge of the variation of resistivity over an area will reveal some information of the variation of moisture content over the same area. Obviously, the specific values of moisture content are not revealed by a knowledge of the specific values of resistivity. Even so, it would be of definite value to the engineer to know if some parts of the area under investigation have higher moisture contents than others. This information can be obtained by plotting contours of a function of resistivity. As noted previously, the slope of depth vs accumulative resistivity is a convenient function for this purpose. Figures 8 and 9 are contours of depth/accumulative resistivity for this site. In these figures, the higher values of the resistivity function corresponds to higher moisture contents. The contours indicate higher moisture contents in the area right of Stations 46+50 and 47+00, the area of failure, and thus show excellent agreement with actual conditions.

CLARK COUNTY SITE - This slide is on the Mountain Parkway near the Clark-Powell County line. A more detailed description of the slide area is presented earlier in this report.

Extensive resistivity measurements were made at this slide both in 1965 and 1966. The data from these measurements were utilized in an attempt to develop correlations between a function of resistivity and the corresponding moisture content values.

Correlation curves of functions of resistivity vs moisture content for this site, Figures 10 and 11, were less satisfactory than those for the Louisa site. Resistivity vs moisture content curves, Figure 10, exhibit so much scatter that no correlation is indicated. There seems to be a slight trend for an increase of resistivity with an increase in moisture content, which is contrary to expectations based on the hypothesis that the resistivity is inversely proportional to moisture content. Depth/accumulative resistivity vs moisture content curves, Figure 11, do not exhibit as much scatter as those for the Louisa site; however, the rate of change in the resistivity functions with changes in moisture content is very small.

Contours of depth/accumulative resistivity, Figures 12 and 13, again show areas of high and low resistivity. The contours for the 0-5 foot depth interval, Figure 12a, indicate high moisture contents at the toe left of Station 633+00 and at the toe right of Station 634+50. These areas are at the ends of a large concrete cross-drain pipe, which is known to be relatively wet.

The contours for the 5-20 foot depth interval, Figure 12b, also indicate that the slopes and toe areas are wetter than the roadway area, though the difference is not nearly as much as for the 0-5 foot interval. The contours below 20 feet, Figures 13a and 13b, show still less variation, with the slopes still indicated to be slightly wetter than the roadway area. An exception is at the centerline at Station 632+50 where a wet area is indicated. This is near a spring enclosed in a spring box, where higher moisture contents would be expected (see Figure 3). Thus, the depth/accumulative resistivity contours show excellent agreement with actual conditions.

CALDWELL COUNTY SITE - This slide is on the Western Kentucky Parkway at Milepost 7 near Princeton. Information about this site is presented elsewhere in this report. Extensive resistivity testing was performed at this site, and the data obtained were used in plotting resistivity graphs and contour maps.

Since no moisture contents were obtained at this site, no correlation curves could be plotted. However, resistivity values were compared with relative moisture contents obtained by observation of soil removed by augers from drill holes in the area above the slide. Figures 14 and 15 are contours of depth/accumulative resistivity for the wet area above the slide. The holes shown in Figure 16 were drilled along the ditch 47 feet right of the centerline. Figure 16 generally shows dry soil at shallow depths, and moist soil at moderate and deep depths. A comparison of depth/accumulative resistivity values, Figures 14 and 15, at the drill hole locations generally shows lower values in Figure 14 than in Figure 15, indicating lower moisture contents for the shallow depths of Figure 14 as being in agreement with the trend of Figure 16. Figures 14 and 15 show quite well areas of high and low resistivities. Since the contour values along the right ditch do compare well with meager relative moisture content data, the resistivity contours apparently reflect areas of high and low moisture contents.

SCOTT COUNTY SITE - This site in Scott County is located in the northbound lanes of I 75, Milepost 135, between Stations 202+00 and 205+00. The dominant formation of the area is the Lexington Limestone of Middle and Upper Ordovician age. The Lexington Limestone is composed of the Tanglewood Limestone (a slightly phosphatic limestone about 50 feet thick), the Millersburg Member (15-40 feet of argillaceous limestone and shale),

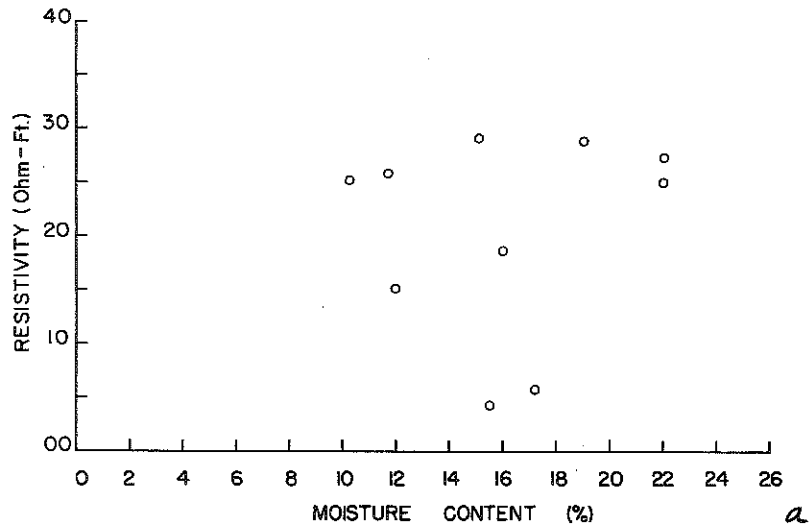


Figure 7a. Moisture Content at Centroid of 10-20 Foot Depth Interval

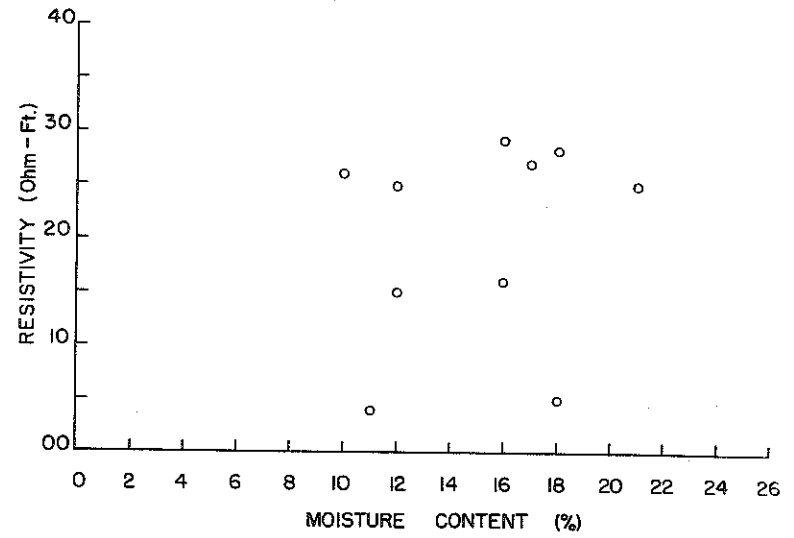


Figure 7b. Moisture Content at 20-Foot Depth

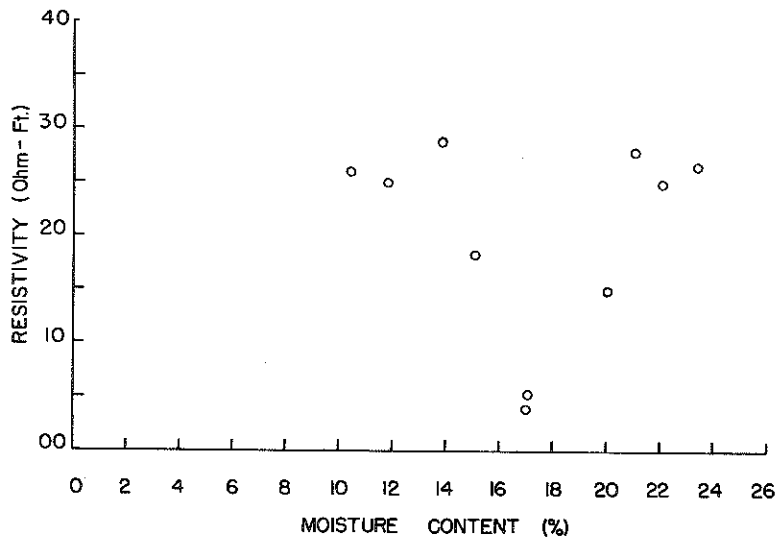


Figure 7c. Moisture Content at 20-Foot Depth

Figure 7. Resistivity at 20-foot Depth vs Moisture Content, Lawrence County Site

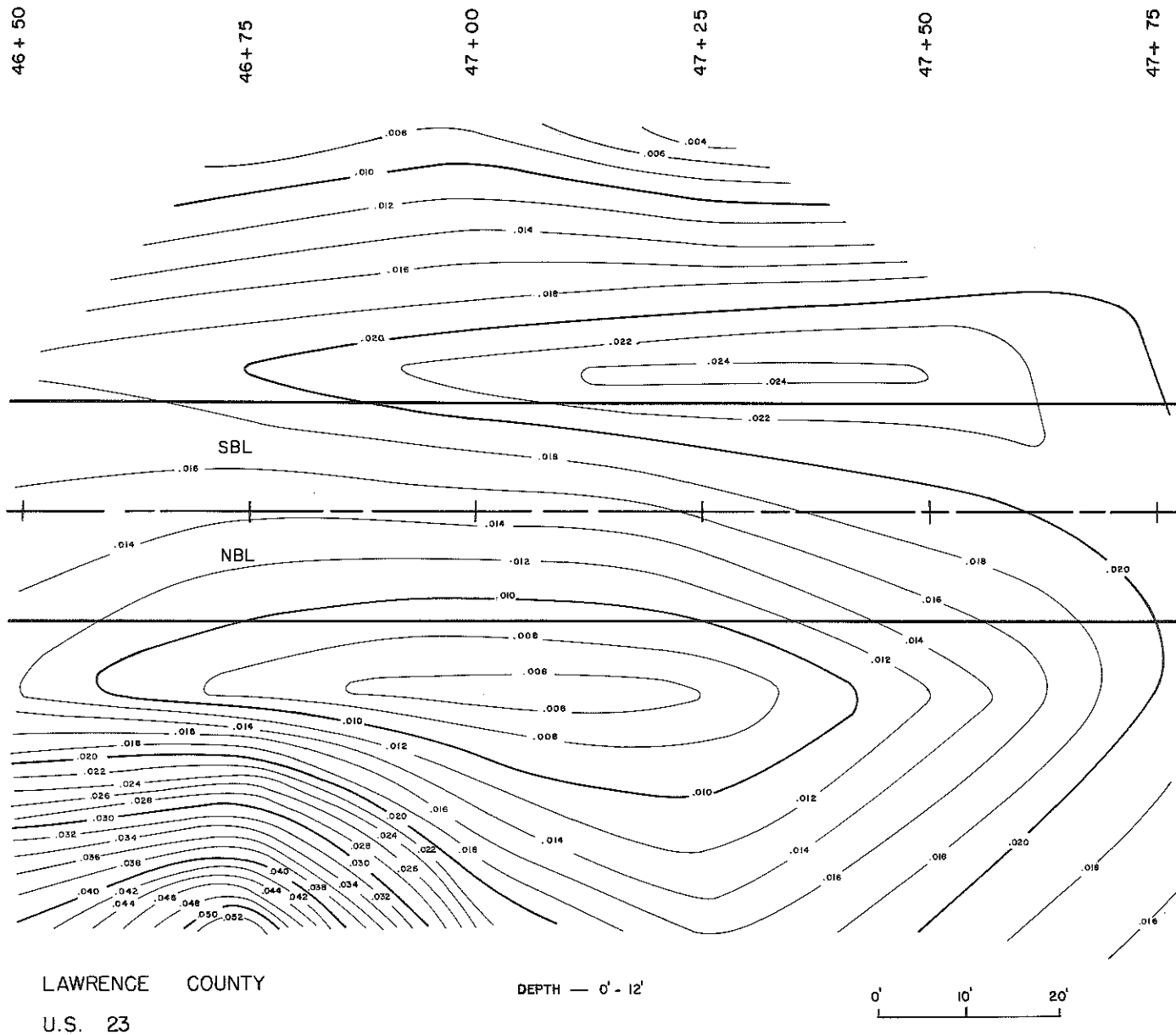


Figure 8. Contours of Depth/Accumulative Resistivity, Lawrence County Site

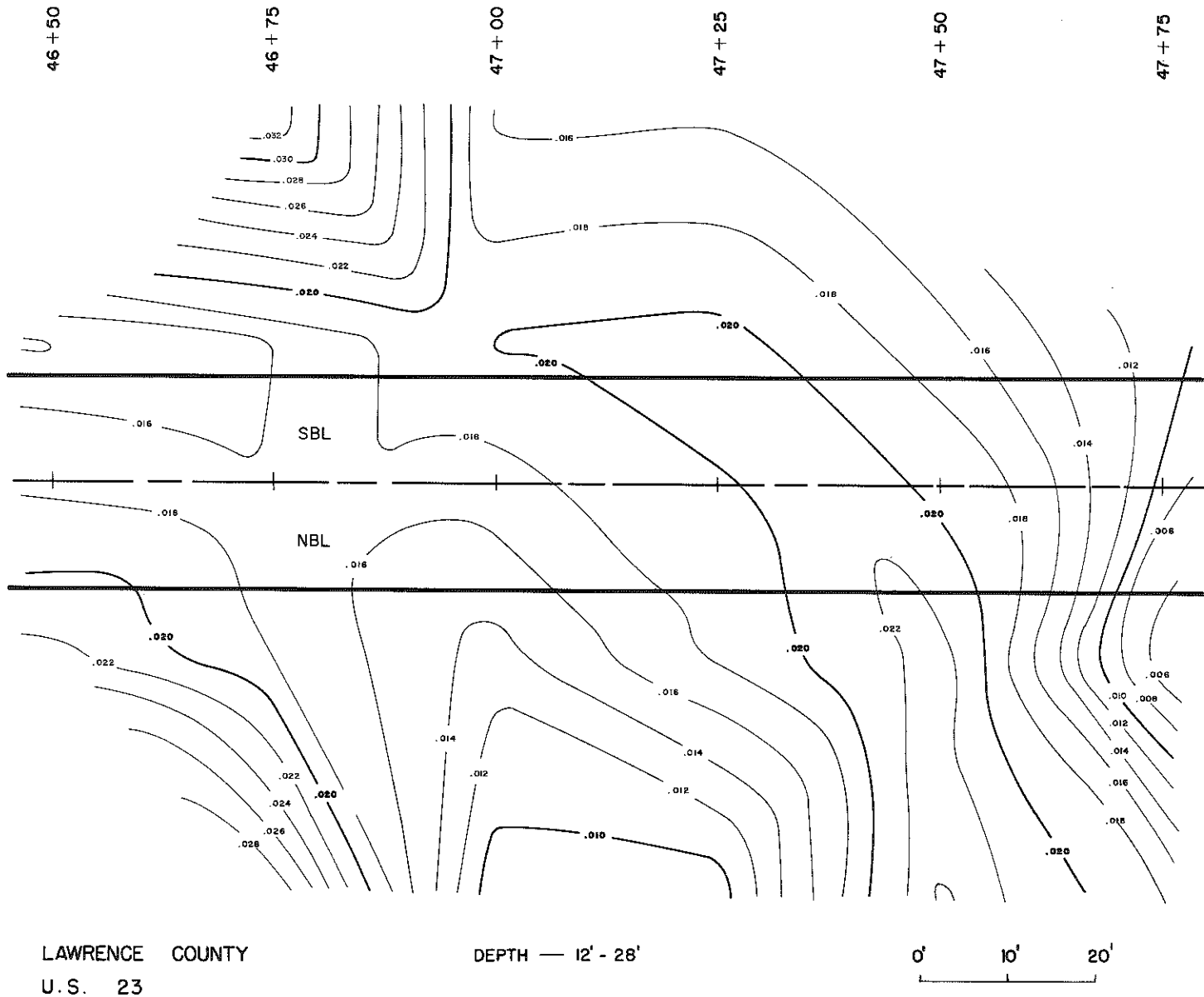


Figure 9. Contours of Depth/Accumulative Resistivity, Lawrence County Site

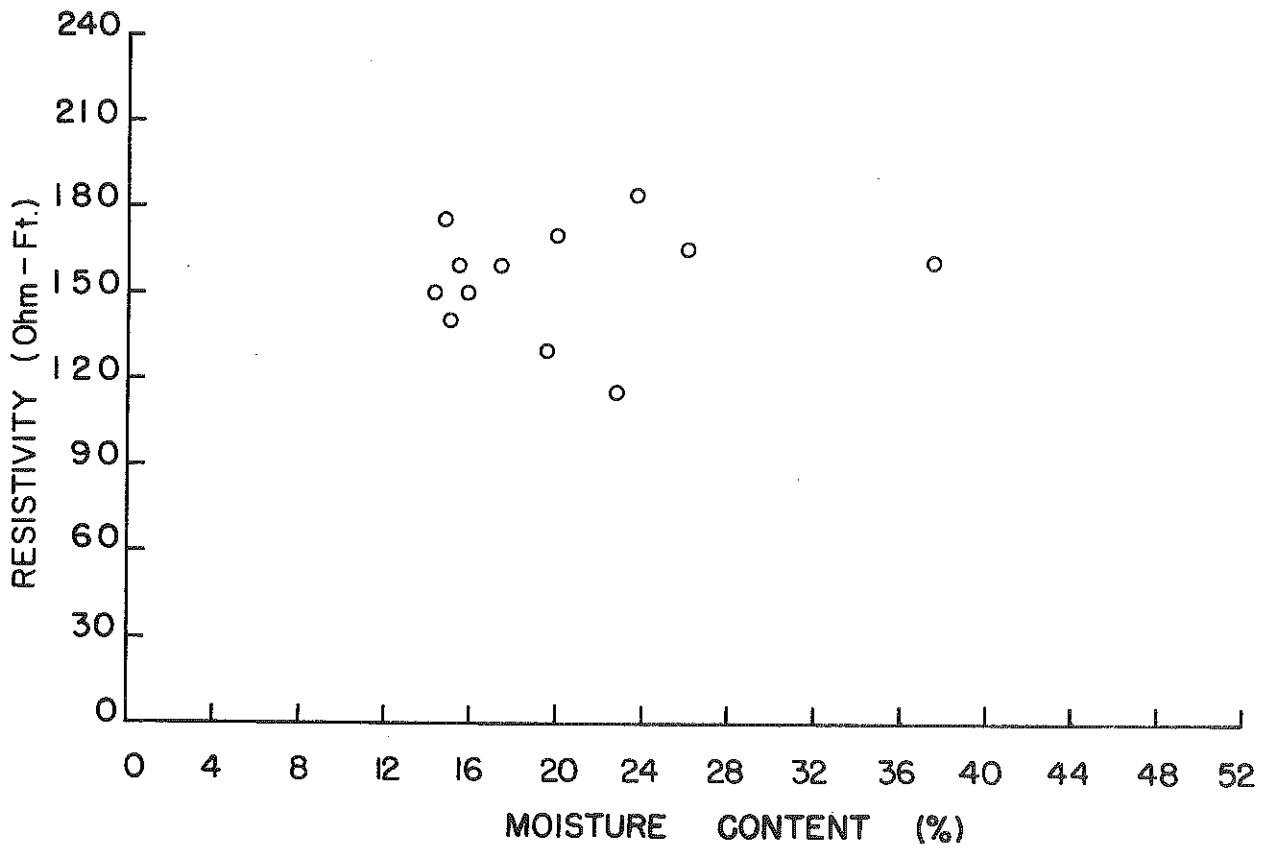


Figure 10a. 10-Foot Depth

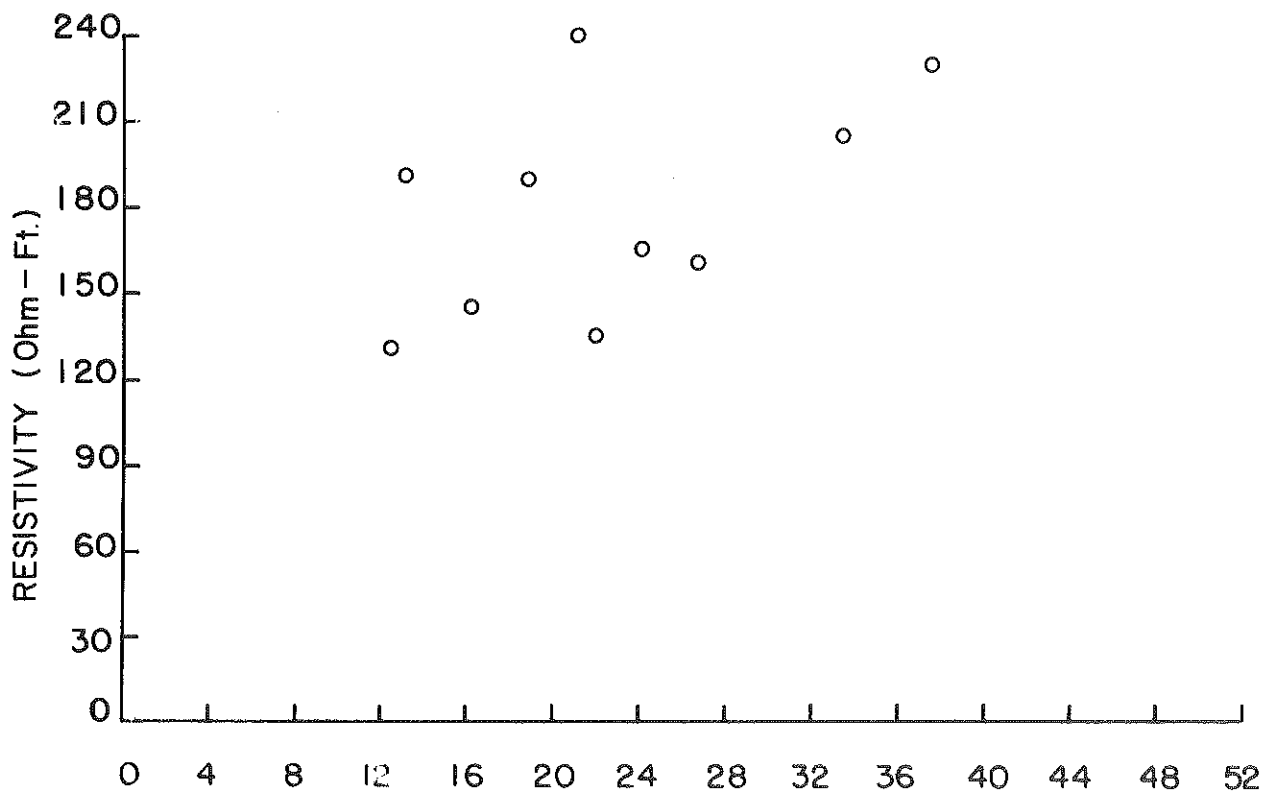


Figure 10b. 15-Foot Depth

Figure 10. Resistivity vs Moisture Content, Clark County Site

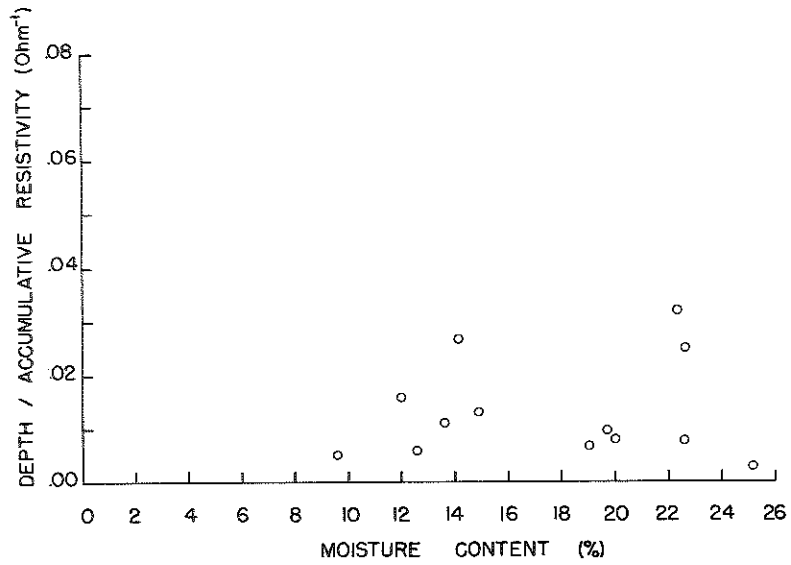


Figure 11a. 0-5 Foot Depth Interval

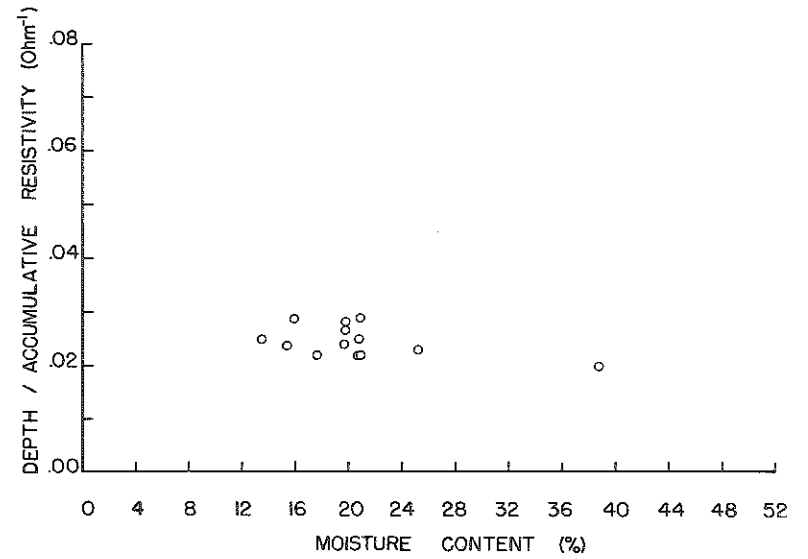


Figure 11b. 5-20 Foot Depth Interval

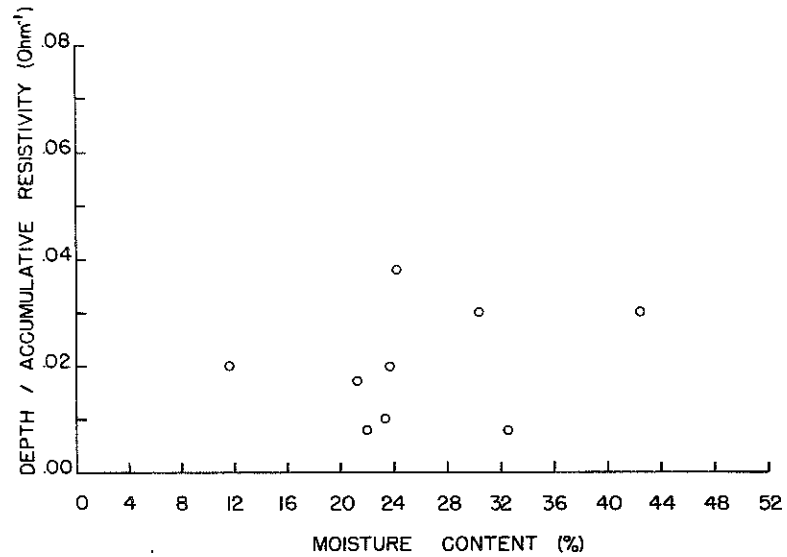


Figure 11c. 20-35 Foot Depth Interval

Figure 11. Depth/Accumulative Resistivity vs Moisture Content, Clark County Site

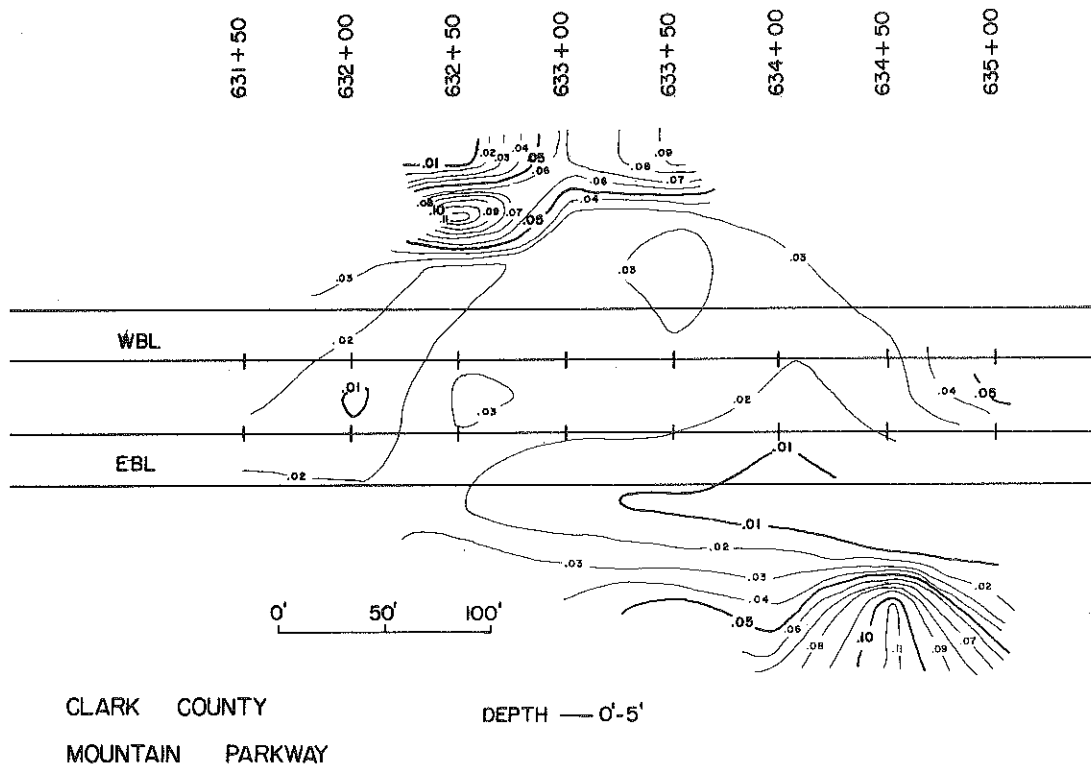


Figure 12a. 0-5 Foot Depth Interval

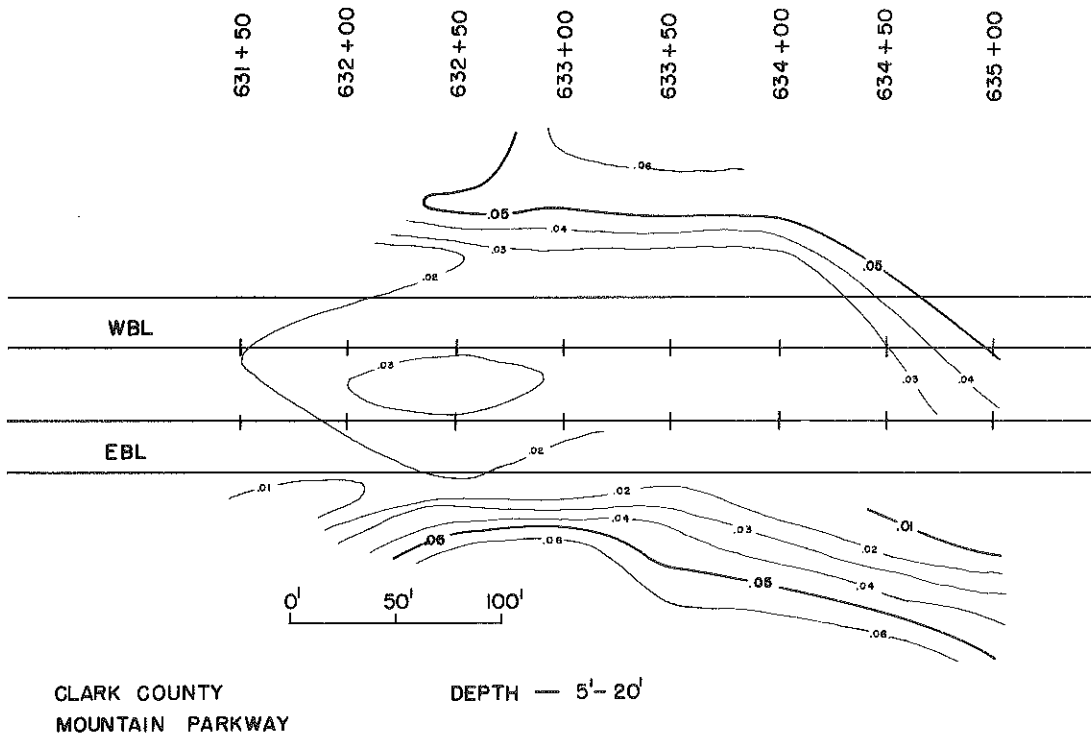
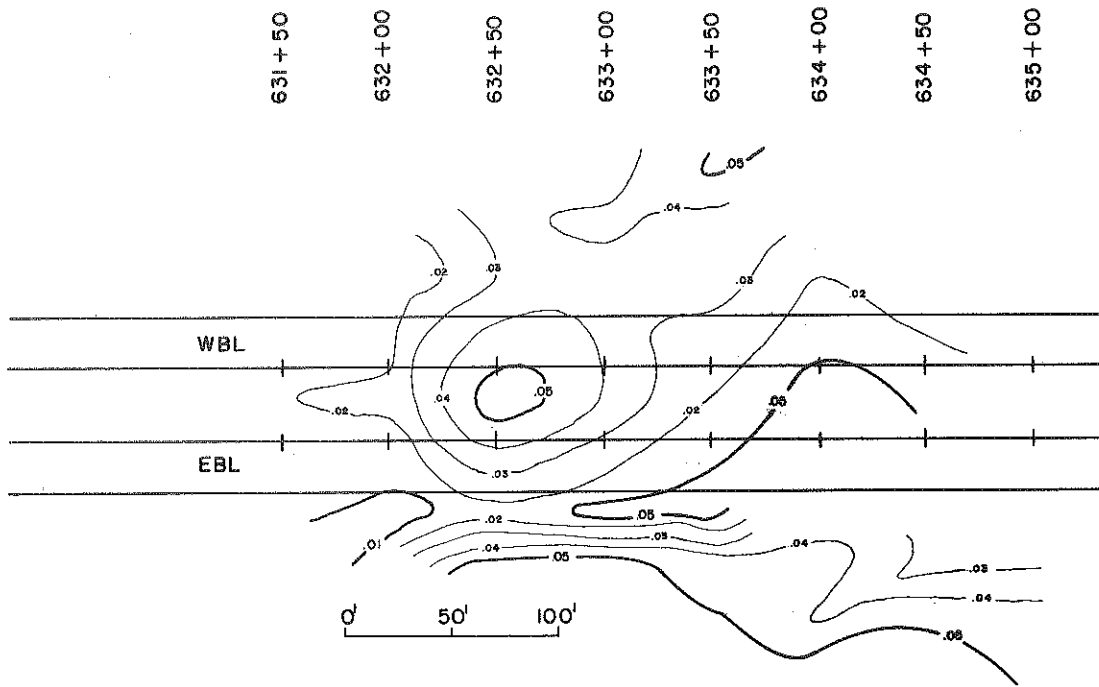


Figure 12b. 5-20 Foot Depth Interval

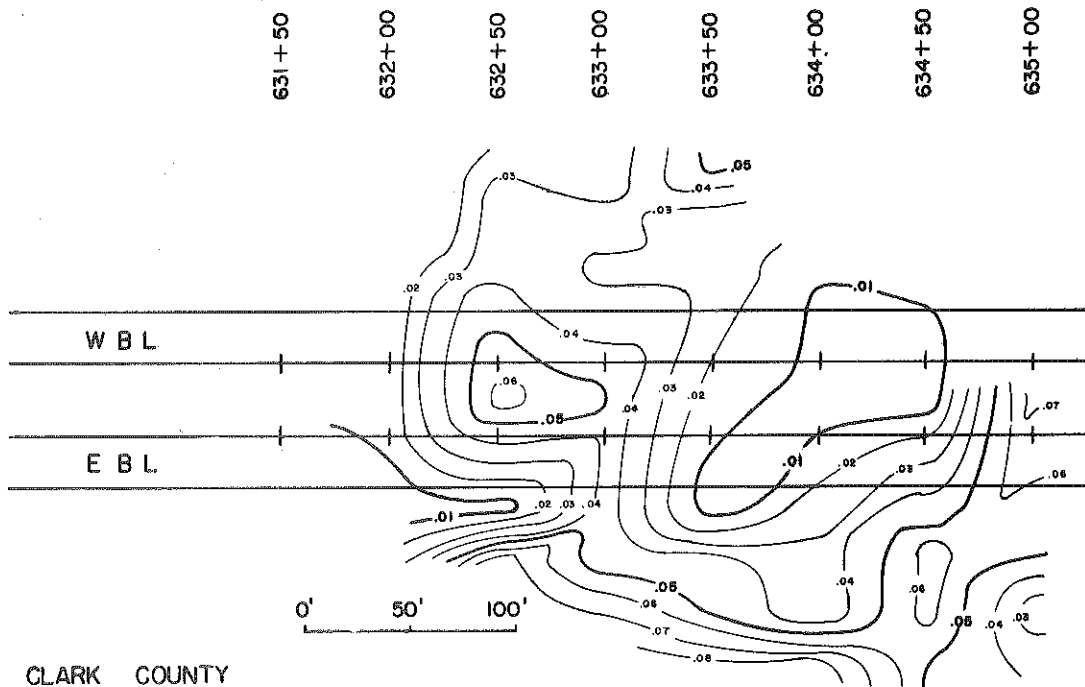
Figure 12. Contours of Depth/Accumulative Resistivity, Clark County Site



CLARK COUNTY
MOUN

DEPTH — 20'-35'

Figure 13a. 20-35 Foot Depth Interval



CLARK COUNTY
MOUNTAIN PARKWAY

DEPTH — 35'-40'

Figure 13b. 35-40 Foot Depth Interval

Figure 13. Contours of Depth/Accumulative Resistivity, Clark County Site

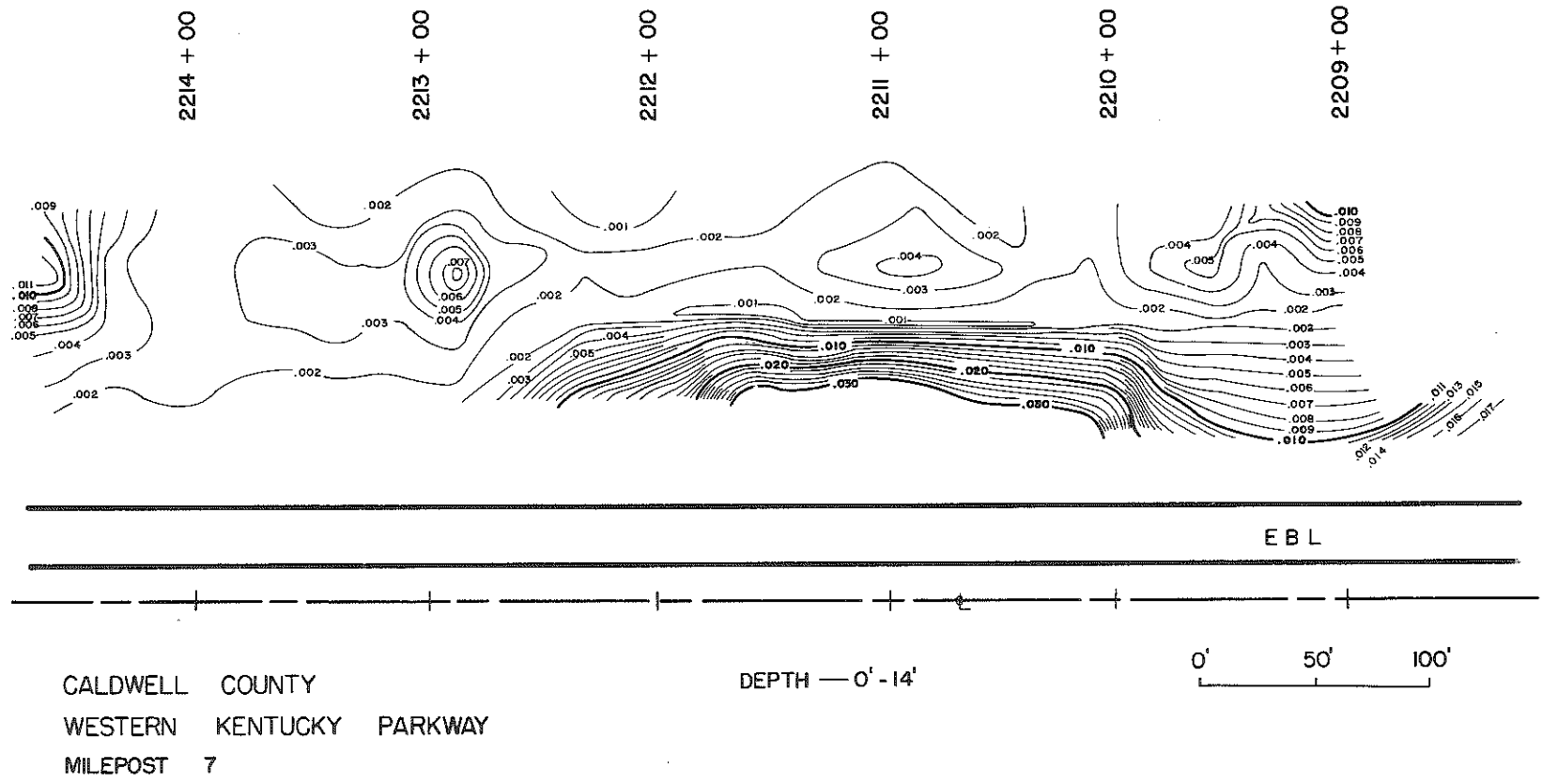


Figure 14. Contours of Depth/Accumulative Resistivity for 0-14 Foot Depth Interval, Caldwell County Site

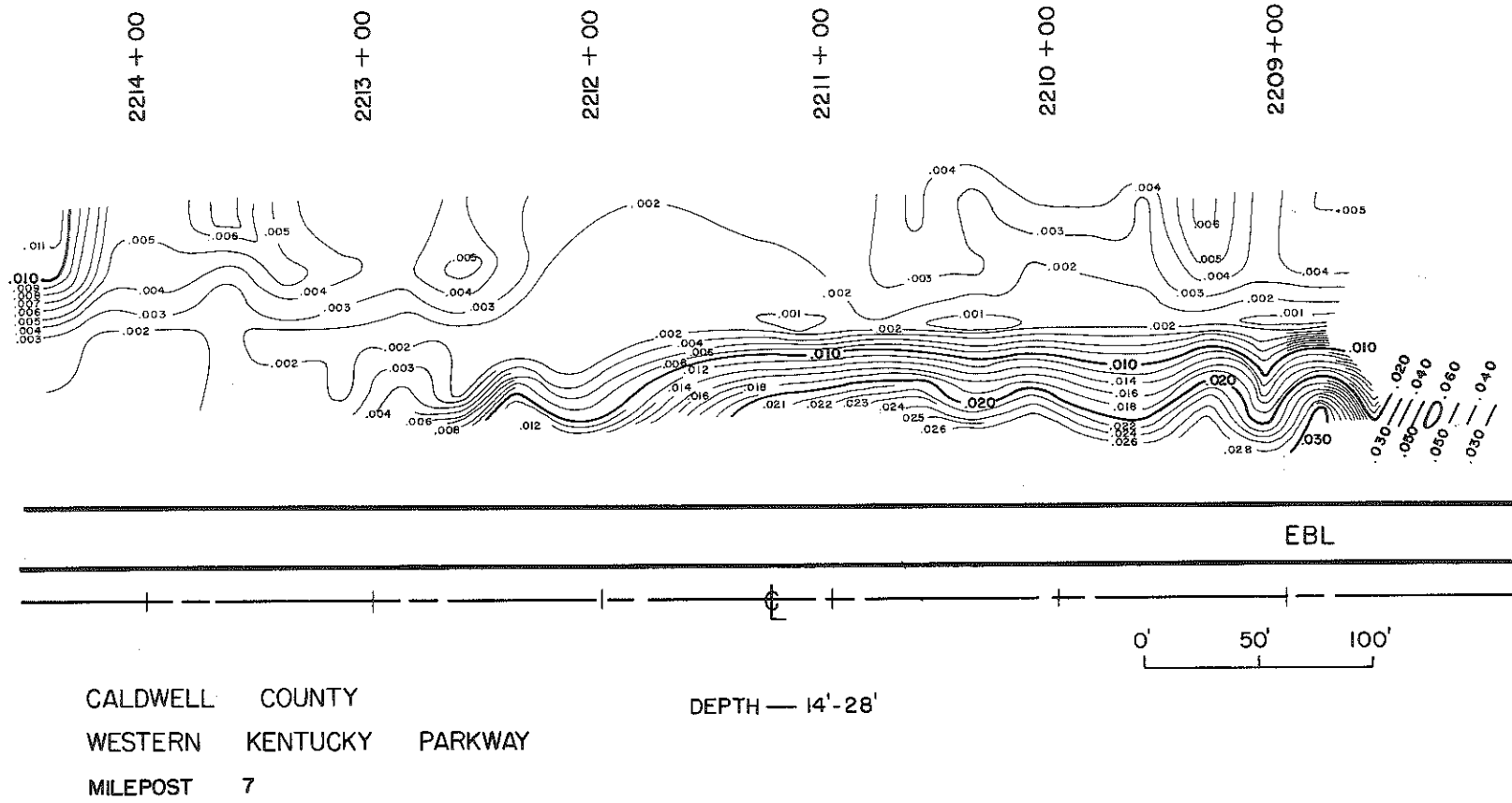


Figure 15. Contours of Depth/Accumulative Resistivity for 14-28 Foot Depth Interval, Caldwell County Site

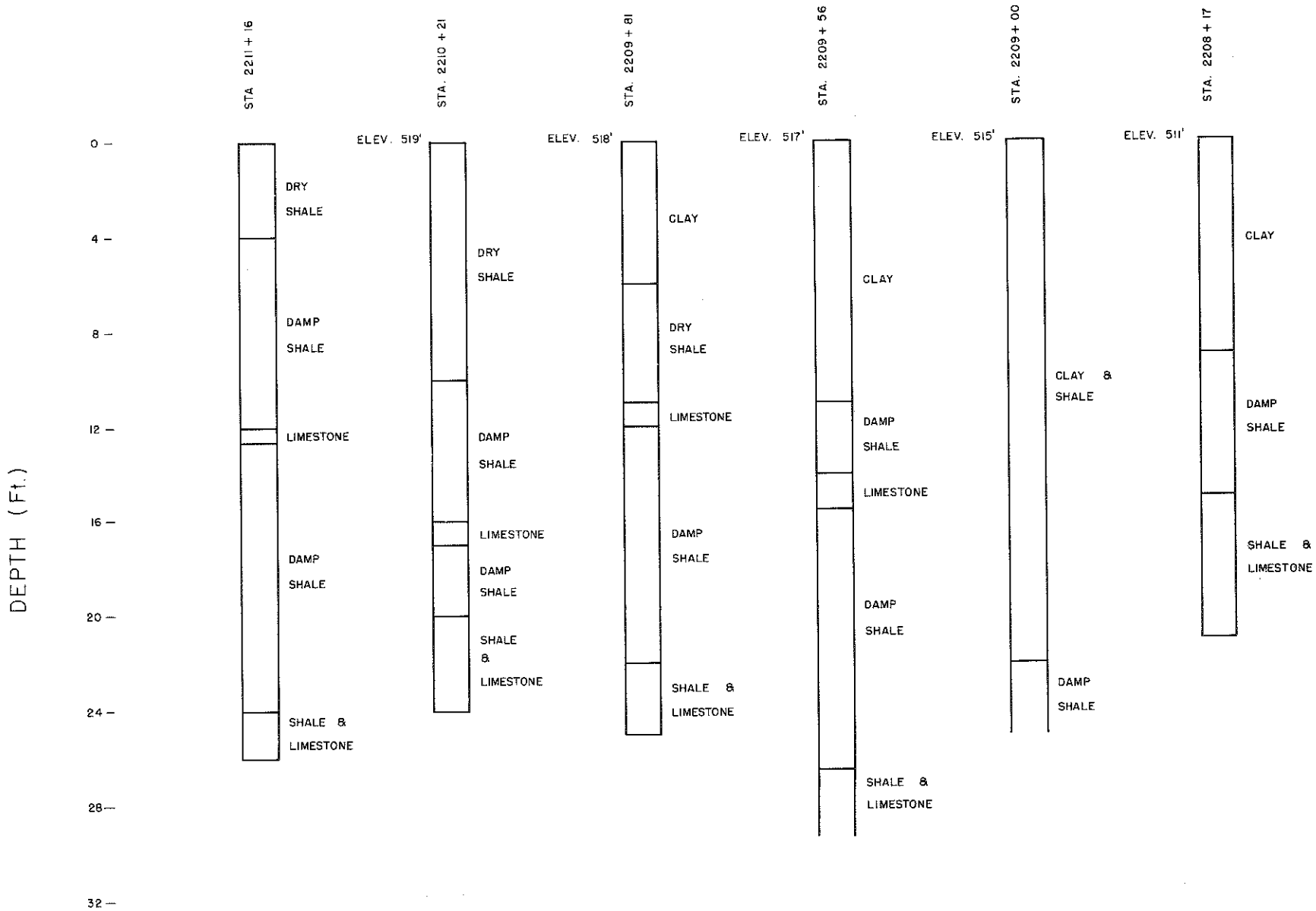


Figure 16. Soil Profile 47 Feet Right of Centerline, Caldwell County Site

the Brannon Member (interbedded limestone and shale up to 15 feet), and the Grier Limestone (a 60-80 foot deposit exposed in the deep valleys of the area).

The embankment at the slide area is constructed of material from cuts in the vicinity which exposes material believed to be of the Millersburg Member. It is composed of fossiliferous limestone and shale.

Resistivity tests were performed at this slide, and the data from these tests were, as for the previous slides, utilized to plot curves and contour maps in an effort to find a meaningful interpretation of resistivity readings in terms of moisture content.

Four resistivity contour maps, Figures 17 and 18, were plotted. Each map shows the resistivity contours of a different soil layer at the slide area. The curves plotted include depth/accumulative resistivity vs moisture content, Figure 19. These curves are again for different soil layers. The moisture contents of the soil at different points and depths were found in the laboratory by moisture content determination of soil samples taken by the split barrel sampler. Moisture contents are shown along with soil descriptions in Figure 20.

The correlation curves of depth/accumulative resistivity vs moisture content for this site, Figure 19, again exhibit a large degree of scatter. However, there is a definite and unmistakable trend of increasing values of depth/accumulative resistivity with increasing moisture content. Moisture contents from Figure 20a were compared with contour values along the median in Figure 17b while moisture contents from Figure 20b were compared with contour values along the northbound shoulder. The first comparison along the median shows agreement in the higher contour values (higher moisture contents) in the vicinity of Stations 203+50 and 204+00. Figure 20a also shows the highest moisture content is at Station 204+00.

A comparison of contour values along the median and the northbound shoulder indicated higher moisture contents beneath the northbound shoulder, contrary to actually observed moisture contents. It was noticed that all depth/accumulative resistivity values along the shoulder, Figure 17b, were considerably higher than those of all the other traverses. Factors believed to have caused the anomaly were the guardrails (metallic objects) along the edge of the shoulder and the fact that the electrodes used in resistivity measurements penetrated through the bituminous concrete shoulder and into the dense-graded aggregate base but not into the subgrade soil for this traverse only. In all other resistivity measurements, the electrodes penetrated the subgrade or embankment soil away from guardrails.

WOLFE COUNTY SITE - This slide is on KY 15 in Wolfe County between Campton and Jackson. It is located along the slope of the westbound lane between Stations 544+00 and 548+00.

As in previous slides, extensive electrical resistivity investigations were made. Since drilling equipment was not available at the time resistivity readings were made, it was not possible at this site to obtain moisture content data. Therefore, no correlation curves could be prepared. Depth/accumulative resistivity contours for different depths were plotted (Figures 21 and 22). Although the accuracy of these contours could not be evaluated, they again indicated areas of high and low moisture contents. The wet areas appeared to be along the eastbound shoulder in the vicinity of Stations 545+00 and 546+00 and in the area of the embankment north of the highway. Wet seepage zones were observed in the same area near the toe in the approximate center of the slide at the time resistivity testing was performed.

KENTON COUNTY SITE - This slide is on I 75 in Kenton County near Covington. A description of the slide is presented earlier in this report. Investigation with electrical resistivity equipment was made here, also. Resistivity readings were obtained on a 50-foot grid between Stations 487+00 and 492+00 and extending from 100 feet to 300 feet right of the centerline, thus covering virtually the entire fill slope.

No correlation curves were plotted due to the fact that no moisture content samples were obtained. However, visual descriptions of the relative wetness were made when holes were drilled in the slide area. Figure 23 shows log charts of drill holes made along two lines parallel to the centerline. Contours of depth/accumulative resistivity were plotted for different depths. Figure 24 shows these contours at two different depth intervals. These contour plots show some areas of high values of this resistivity function, indicating areas of high moisture content.

Unfortunately, the visual descriptions obtained from the drill holes were of limited usefulness. The drill holes were not sufficient in number to cover the slide area as thoroughly as did the resistivity measurements. This caused a lack of drill-hole information at some points that were indicated to be very wet by the resistivity method. Drill holes were not always deep enough for comparisons of the relative wetness of soil at deep depths.

Although it was not possible at this site to compare actual moisture contents with resistivity contour values and very little visual descriptive data were available at points indicated to be the wettest by resistivity contours, the available data do correlate very well, with relatively few exceptions.

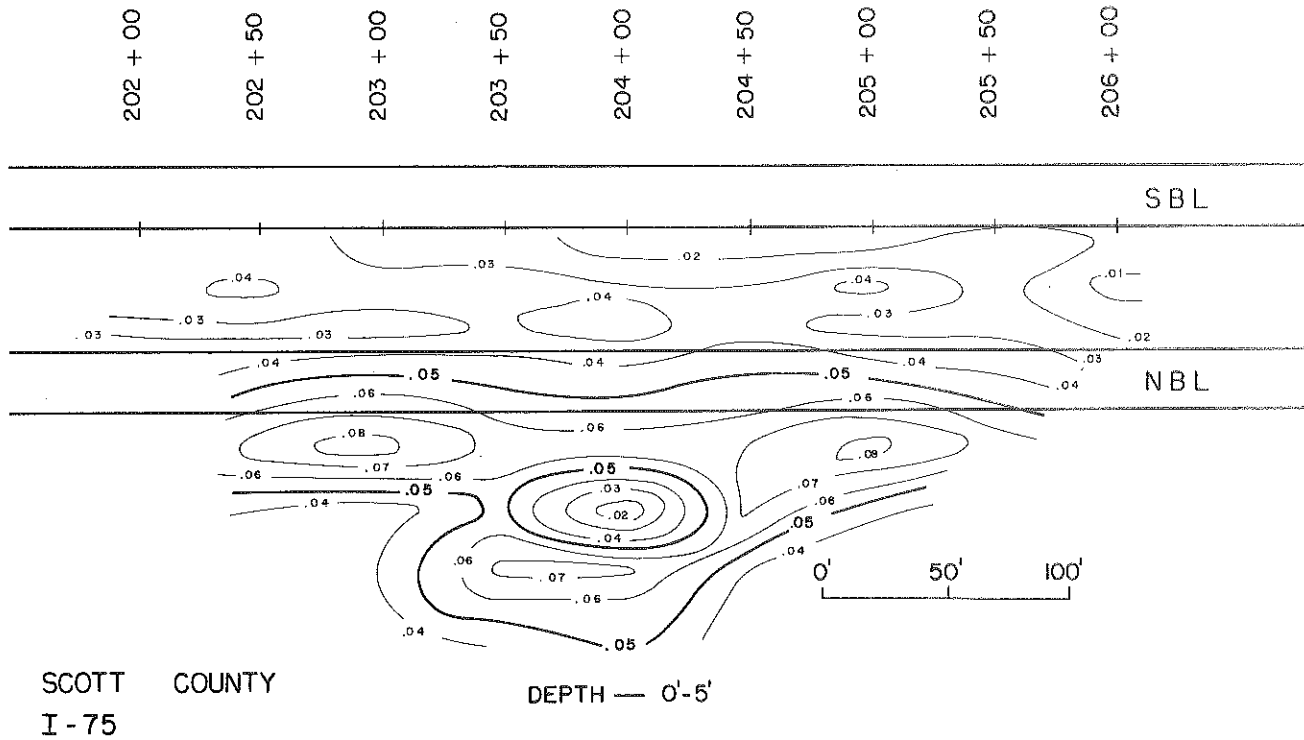


Figure 17a. 0-5 Foot Depth Interval

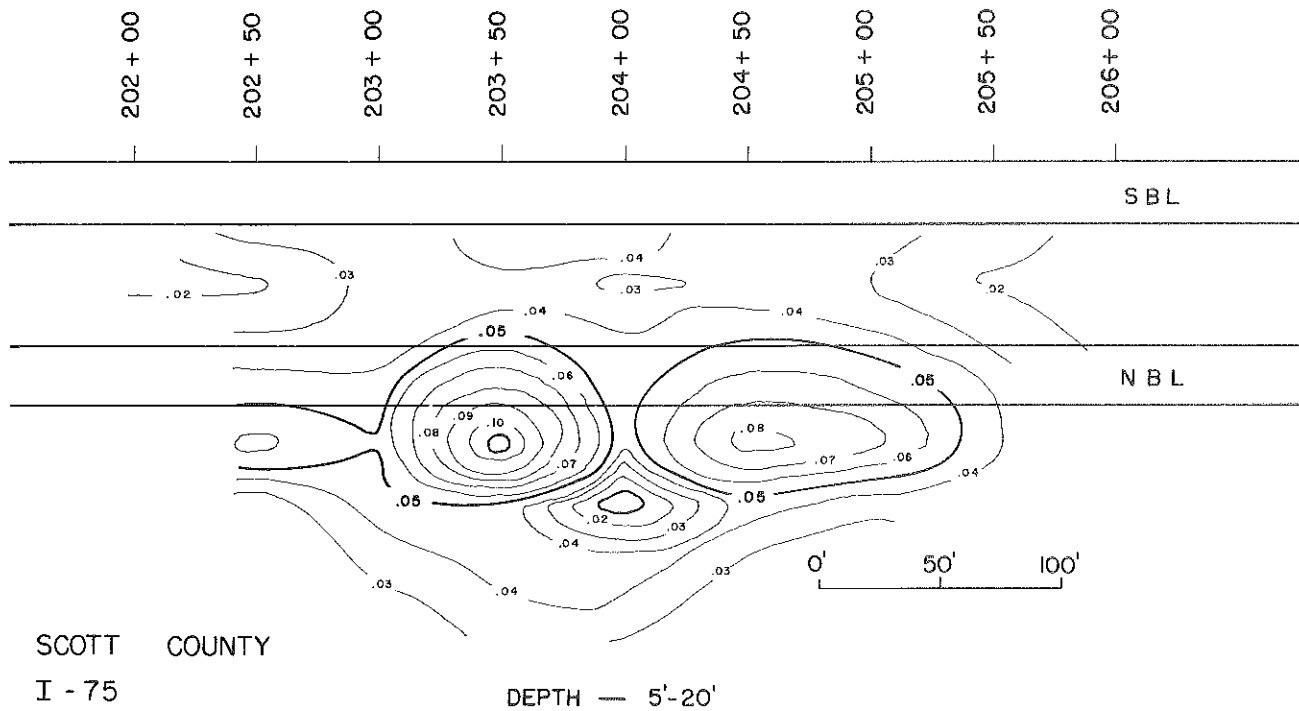
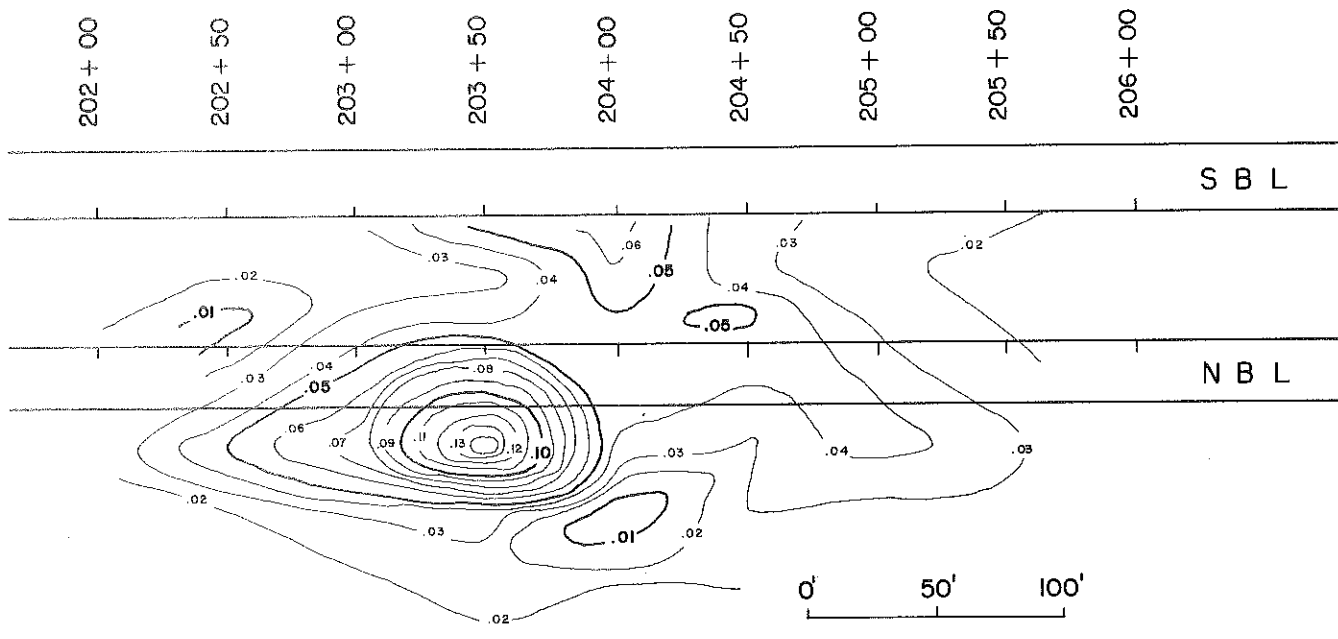


Figure 17b. 5-20 Foot Depth Interval

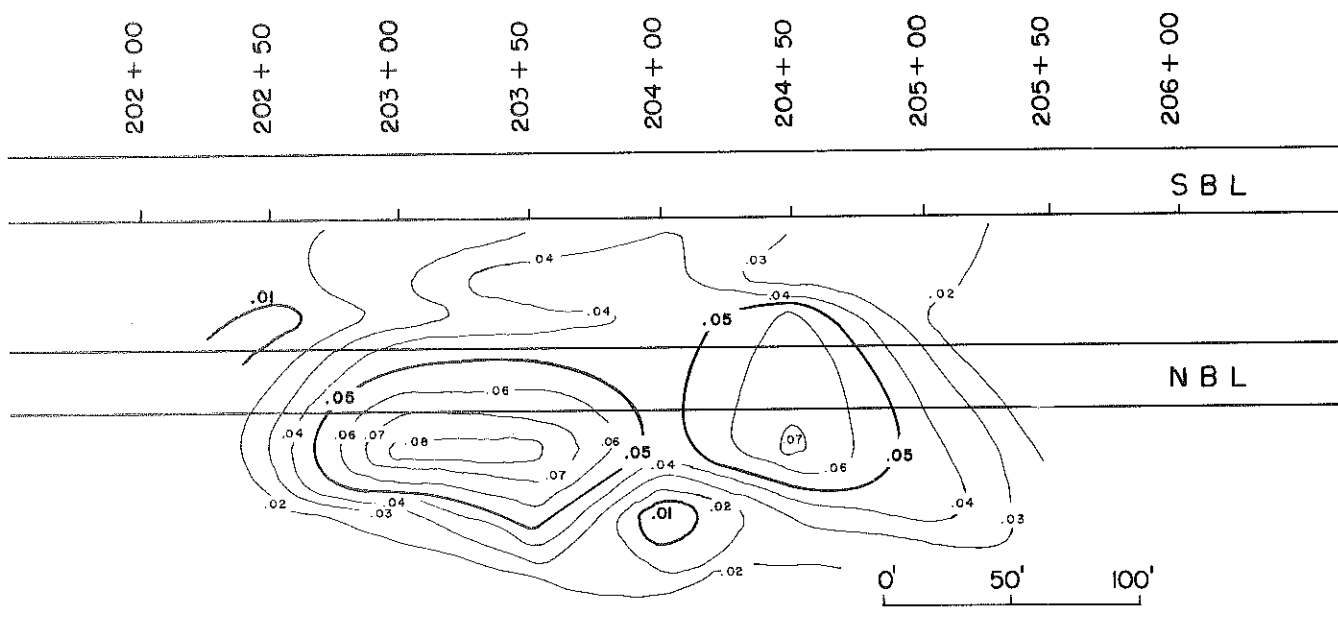
Figure 17. Contours of Depth/Accumulative Resistivity, Scott County Site



SCOTT COUNTY
I-75

DEPTH — 20'-35'

Figure 18a. 20-35 Foot Depth Interval



SCOTT COUNTY
I-75

DEPTH — 35'-40'

Figure 18b. 35-40 Foot Depth Interval

Figure 18. Contours of Depth/Accumulative Resistivity, Scott County Site

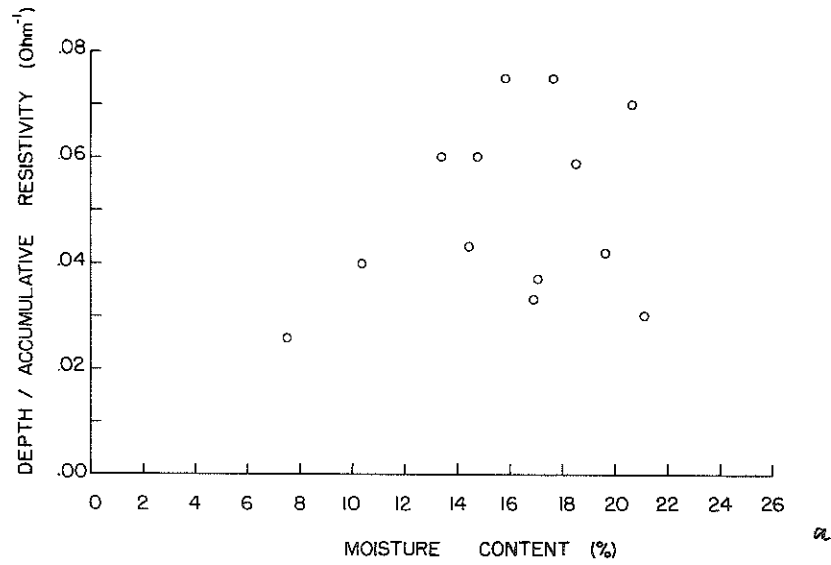


Figure 19a. 0-5 Foot Depth Interval

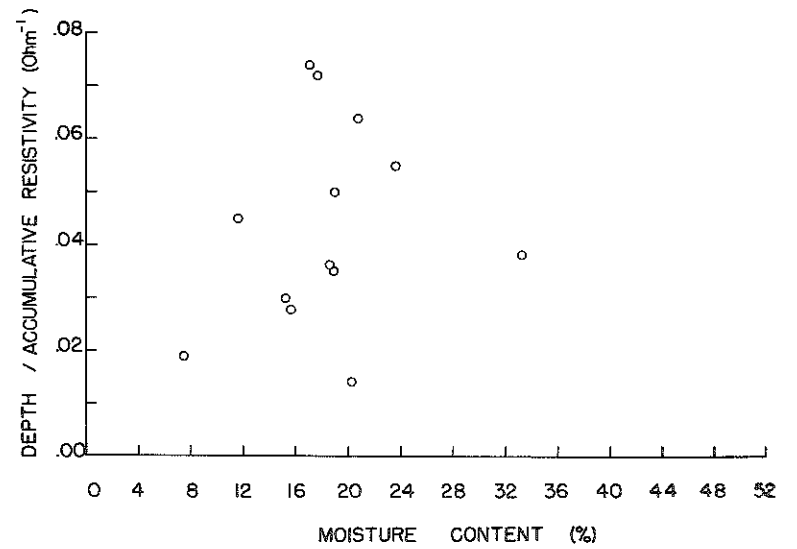


Figure 19b. 5-20 Foot Depth Interval

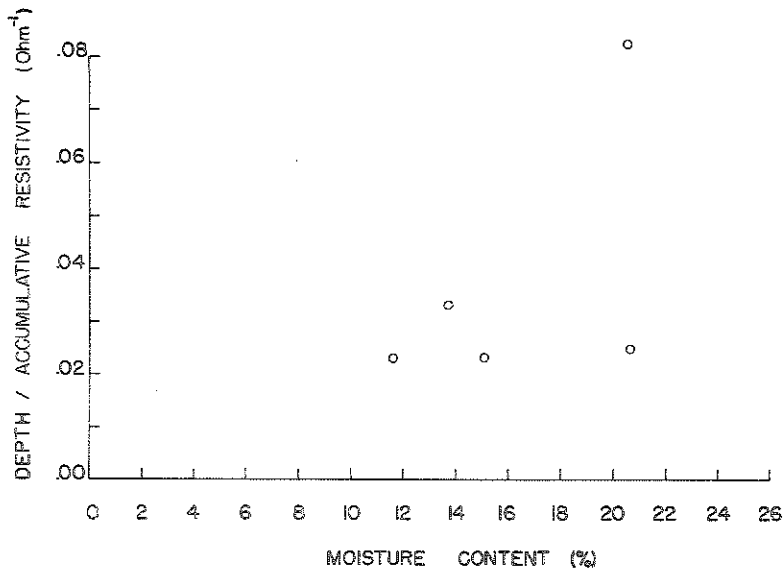


Figure 19c. 20-35 Foot Depth Interval

Figure 19. Depth/Accumulative Resistivity vs Moisture Content, Scott County Site

DEPTH (FT.)

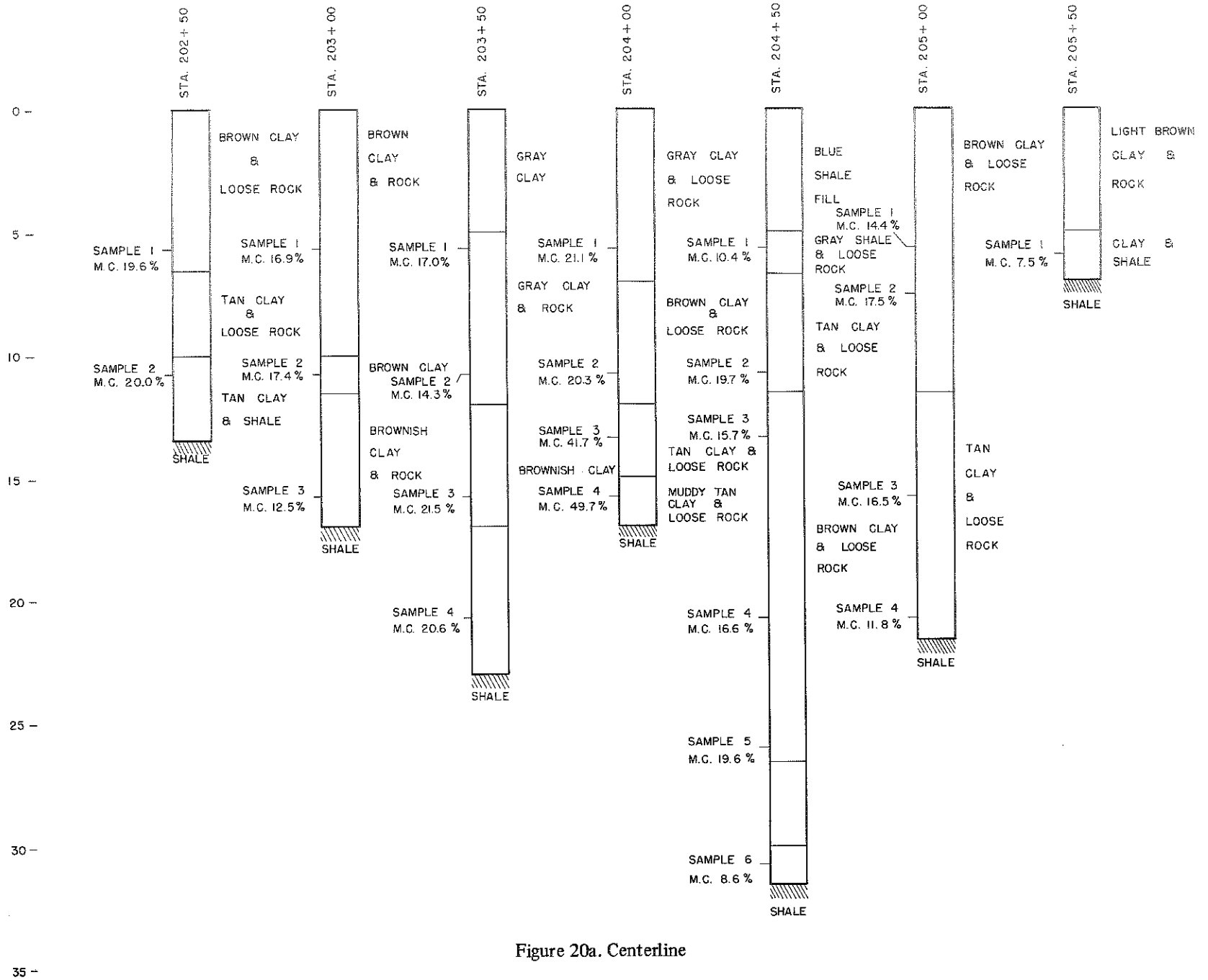


Figure 20a. Centerline

Figure 20. Soil Profiles, Scott County Site

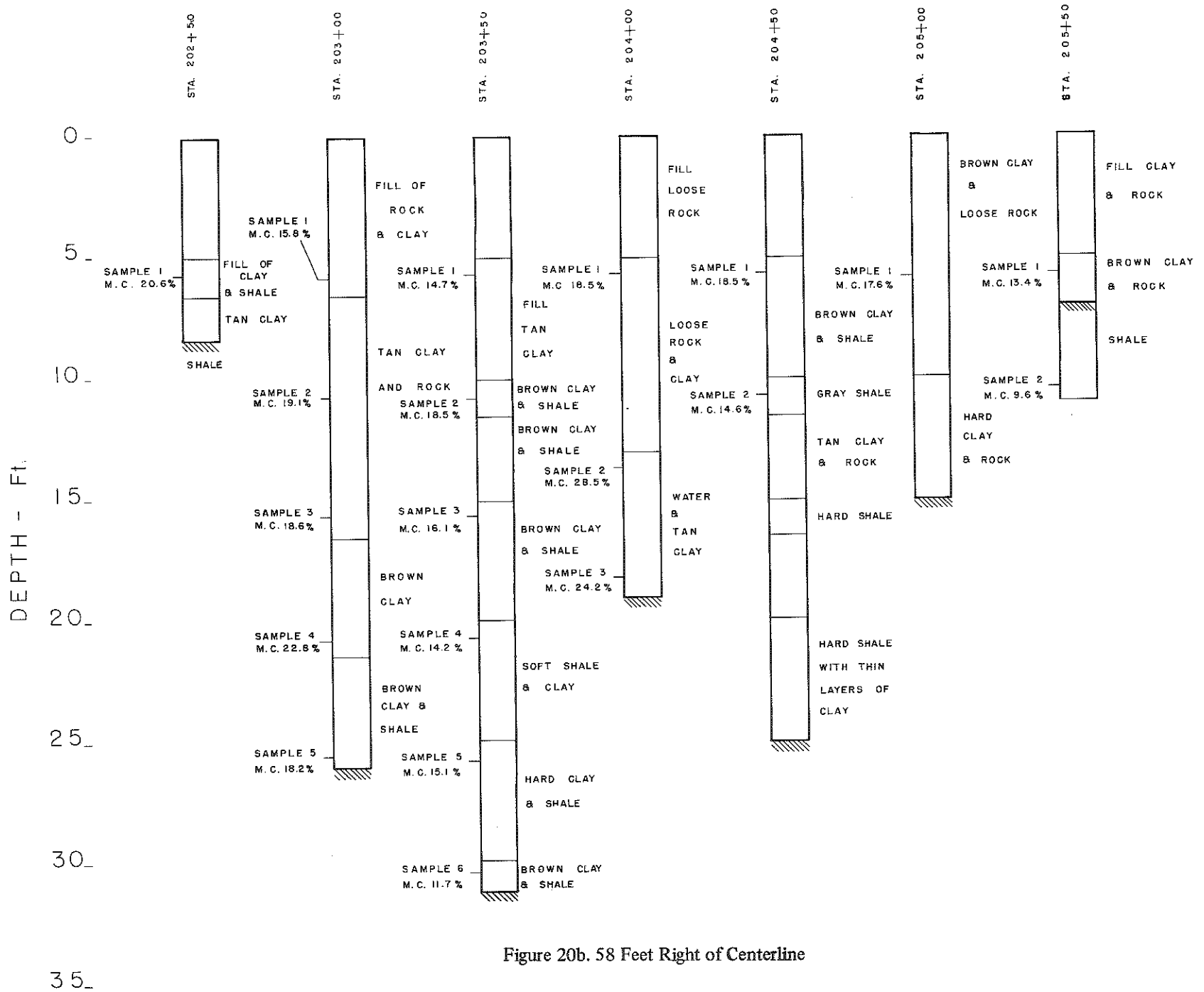


Figure 20b. 58 Feet Right of Centerline

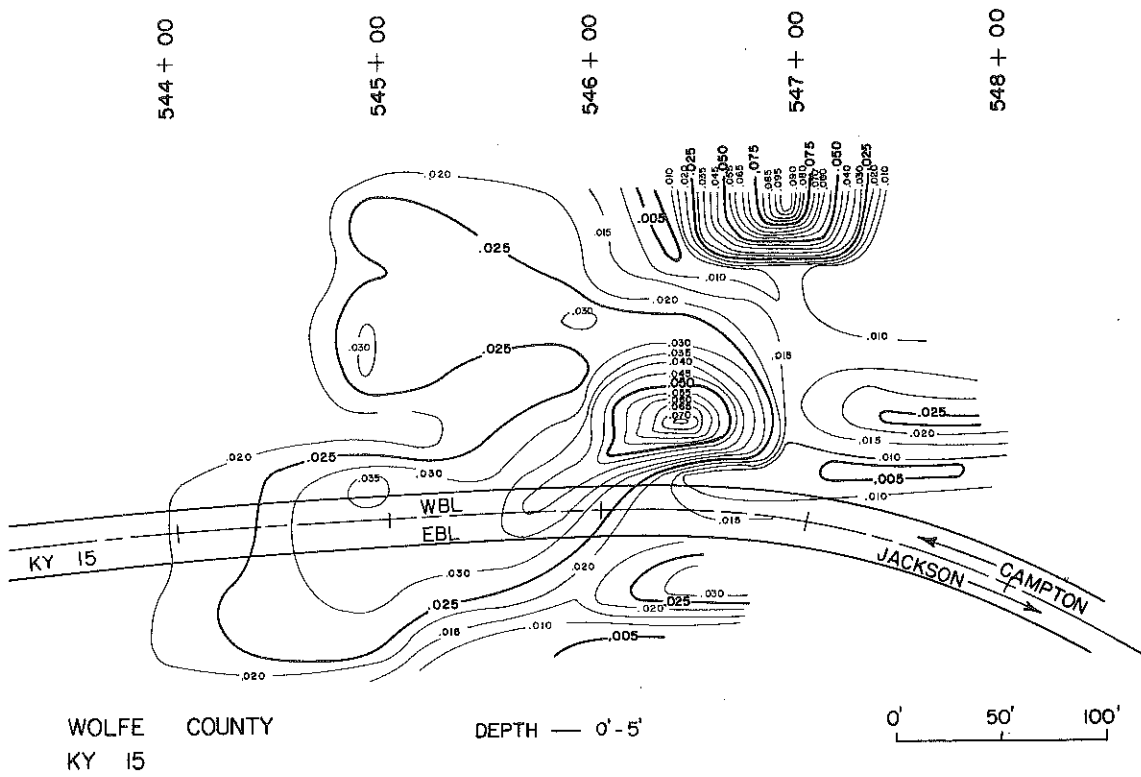


Figure 21a. 0.5 Foot Depth Interval

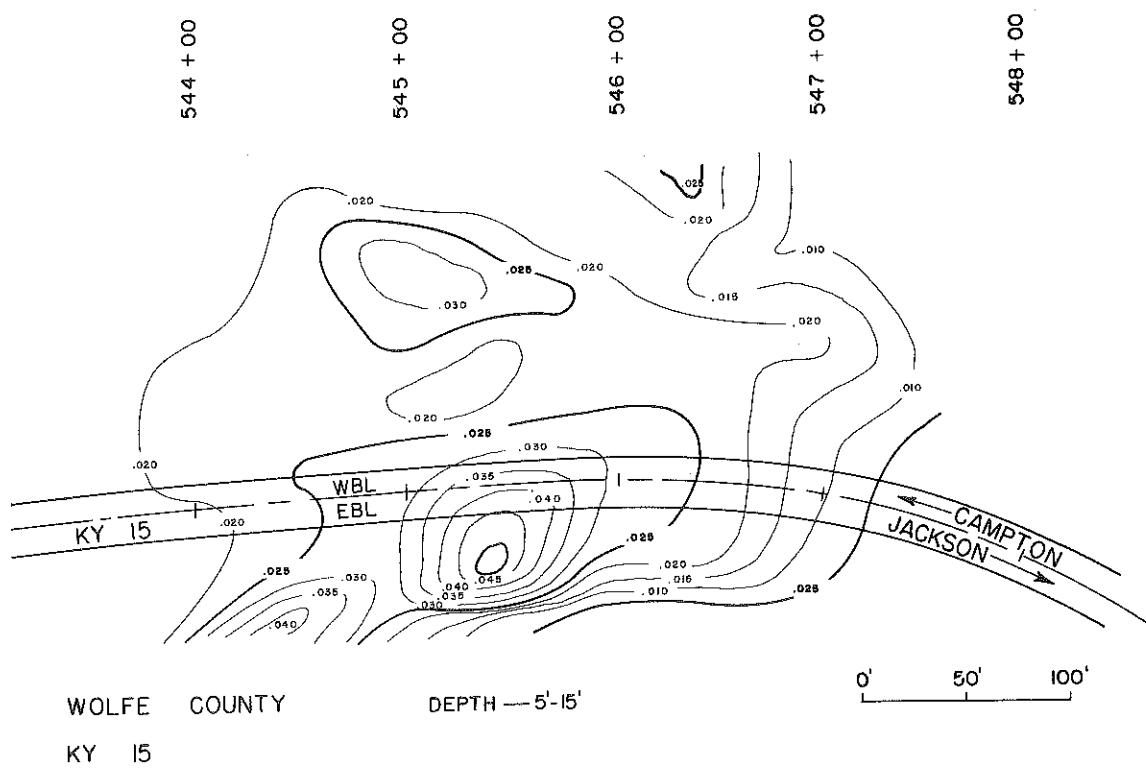


Figure 21b. 5-15 Foot Depth Interval

Figure 21. Contours of Depth/Accumulative Resistivity, Wolfe County Site

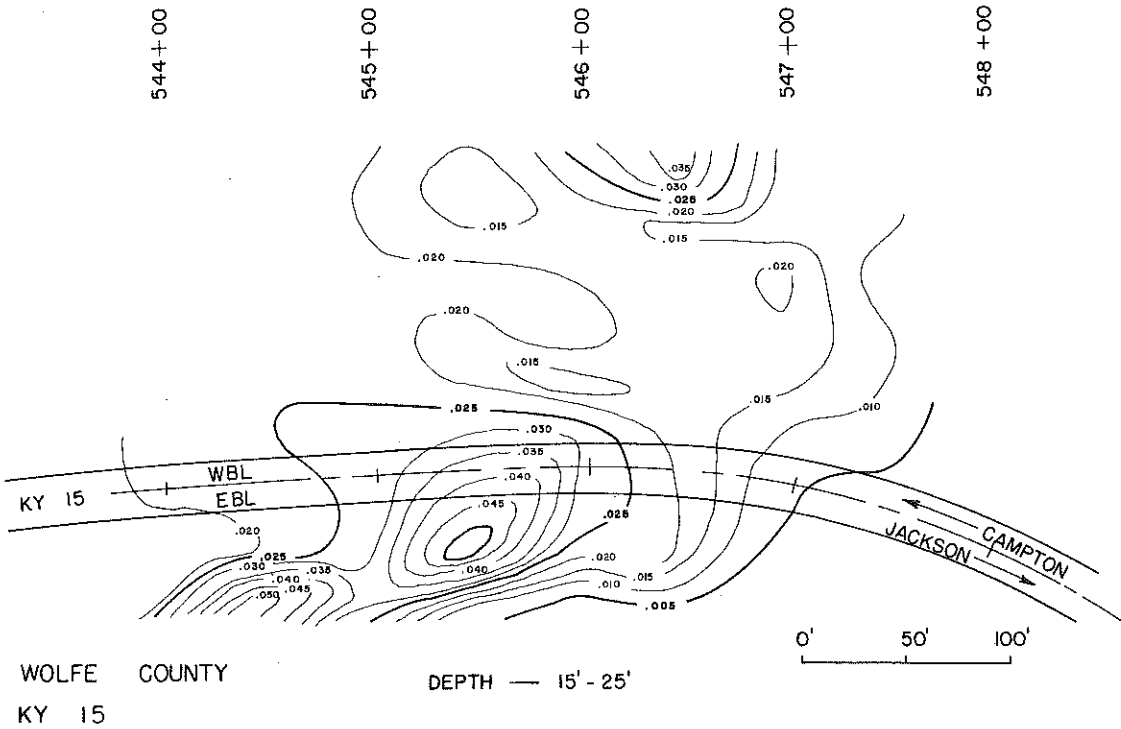


Figure 22a. 15-25 Foot Depth Interval

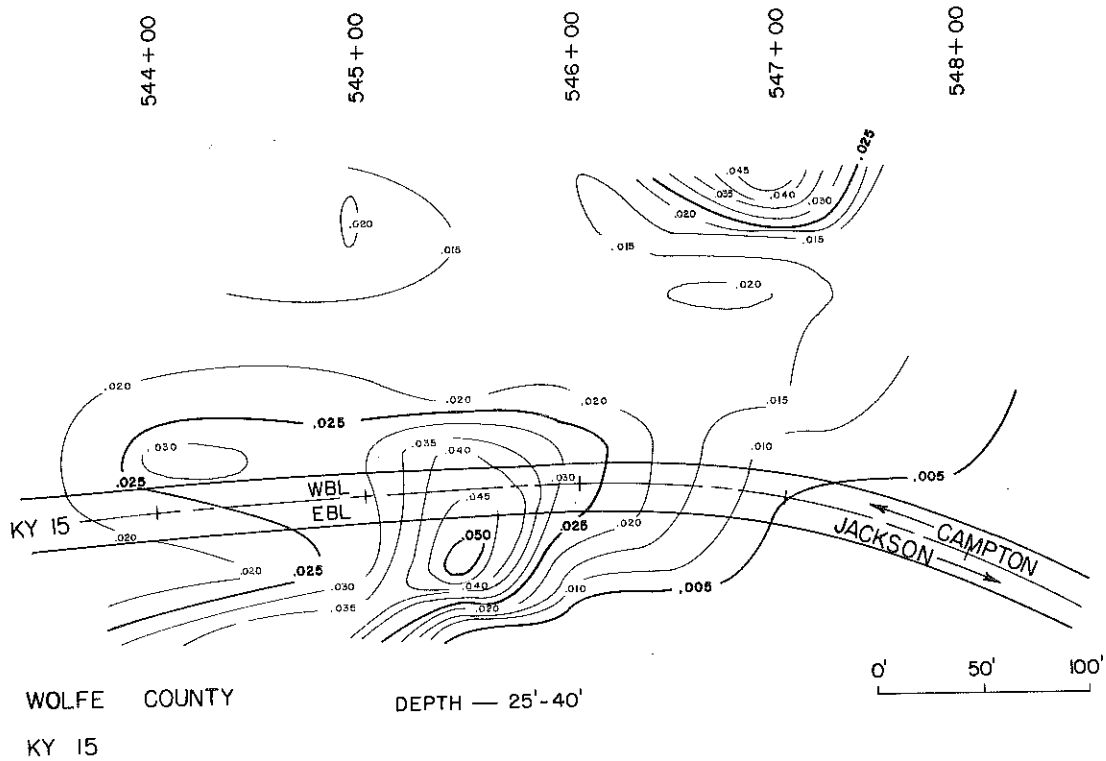


Figure 22b. 25-40 Foot Depth Interval

Figure 22. Contours of Depth/Accumulative Resistivity, Wolfe County Site

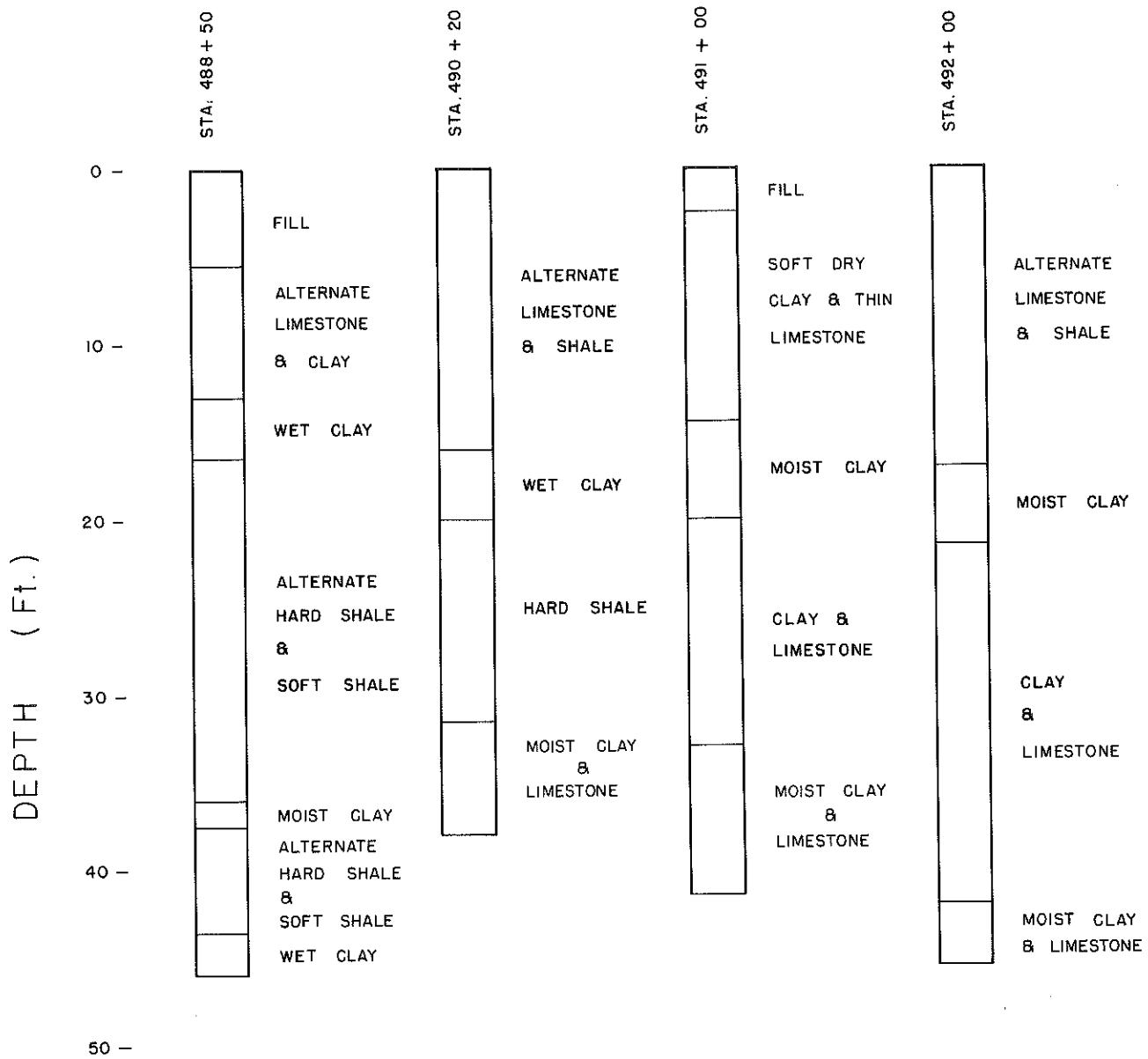


Figure 23a. 222 Feet Right of Centerline

Figure 23. Soil Profiles, Kenton County Site

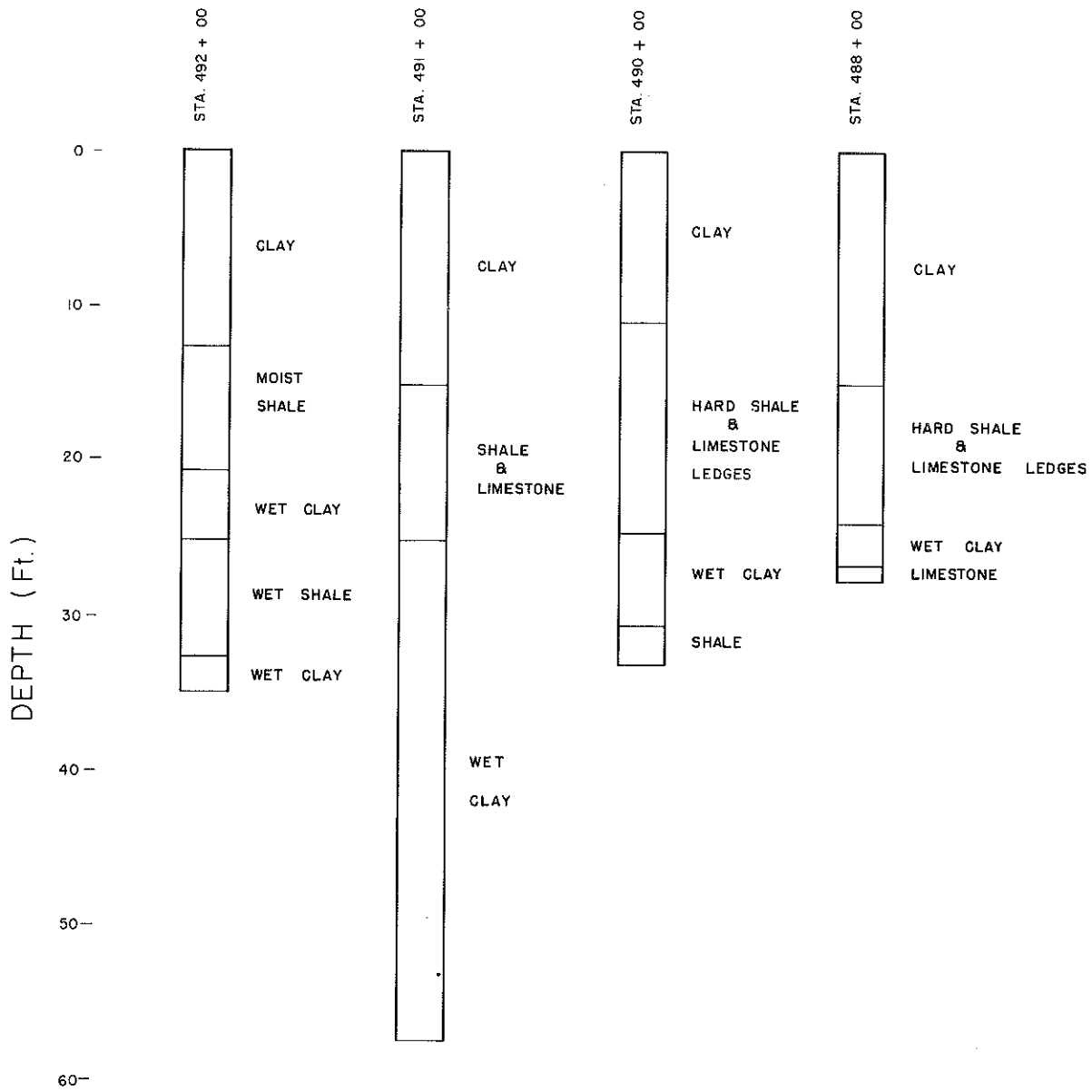


Figure 23b. 290 Feet Right of Centerline

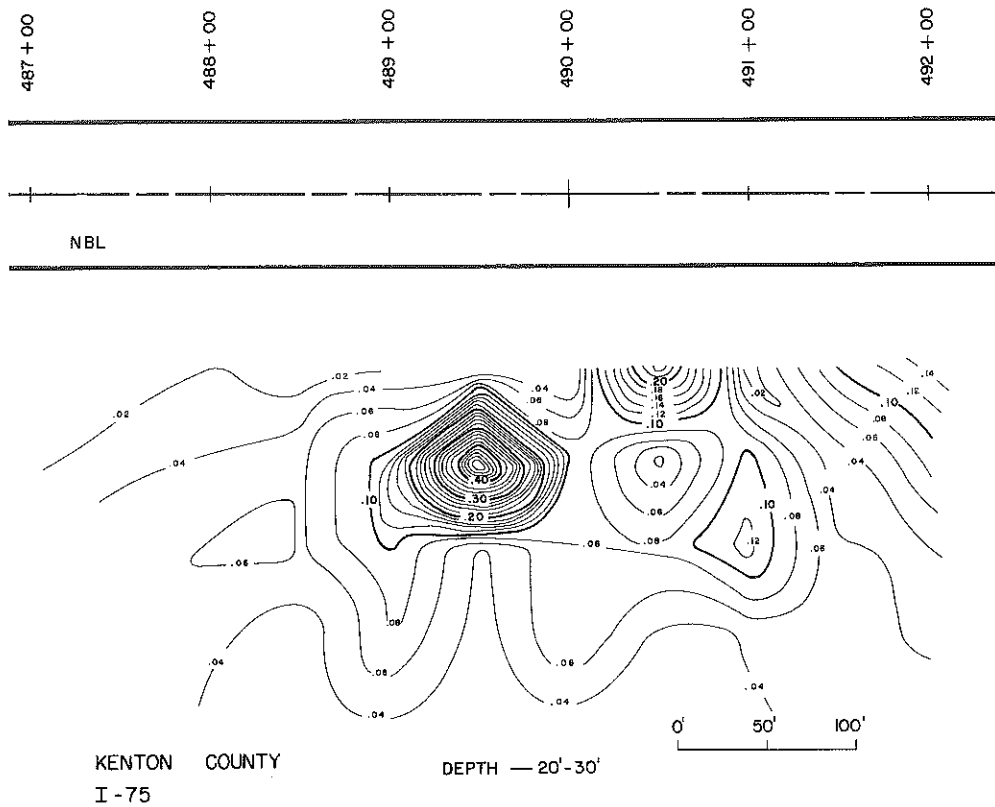


Figure 24a. 20-30 Foot Depth Interval

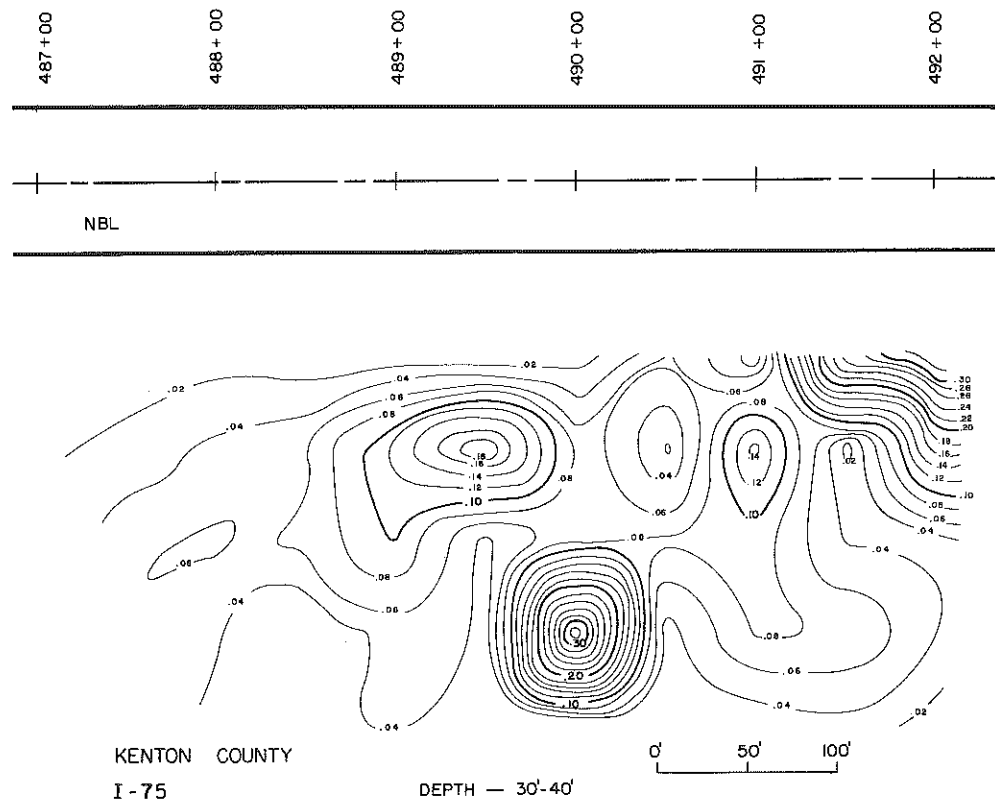


Figure 24b. 30-40 Foot Depth Interval

Figure 24. Contours of Depth/Accumulative Resistivity, Kenton County Site

SUMMARY

Clean, fine sand did not remove fluorescent dye from solution for moderate percolation distances, but the dye became somewhat less detectable due to its absorption by the sand for longer percolation distances. The conventional monitoring equipment (ultraviolet light) was not sufficiently efficient to monitor low concentrations of the dye. The tracer method was not dependable for the purpose of locating seepage waters and was shown to require further improvement. However, it was used to verify a suspected source of seepage when the ground water was believed to have traveled through defined channels or very porous material.

The water table observation method was the most definite and useful of the methods studied for tracing and locating seepage water.

The electrical resistivity method did not yield very accurate and dependable results. However, when the results were correlated with actual moisture conditions, they showed fairly good agreement.

Knowledge of the geology of the area under study and the electrical properties of the subsurface material prior to resistivity testing was essential in order to obtain more meaningful results. This suggested calibration tests with the resistivity apparatus over exposures of formations believed to be typical of those in the area of immediate interest. However, in the case of landslides, it was rather difficult to apply such calibration tests since each slide area had different subsurface conditions.

Several problems were encountered with the resistivity method. In the correlation study, the drill holes, for example, were not drilled at the exact locations where resistivity measurements were obtained. Because of this, considerable interpolation was needed to make correlations.

Factors which may have influenced the accuracy of the electrical resistivity method were:

- a. The inexperience of the operator.
- b. Moisture content samples were taken from specimens obtained at five to ten-foot intervals of depth and therefore did not necessarily represent the interval accurately.
- c. Many of the factors that could have distorted the resistivity, such as the existence of metallic objects (particularly guardrails), buried conductors, and fences were not avoided.

With more and better selection of sampling holes and resistivity observations, more useful results could be obtained from this method. Since the resistivity results show fair correlations with actual moisture conditions, it is concluded that this method could be used as a preliminary guide as to where drilling should be performed, and possibly to extend relative moisture content data to areas inaccessible to drilling equipment.

REFERENCES

1. Jones, W. V. and Peebles, J. J. *A Study of Ground Water Movement in Landslides*, Engineering Experiment Station Report, University of Idaho, June 1966.
2. Corey, J. C., *Evaluation of Dyes for Tracing Water Movement in Acid Soils*, **Soils Science**, Vol 100, No 3, September 1968.
3. Buhle, M. B. and Brueckmann, J. E. *Electrical Resistivity Surveying in Illinois*, **Circular 376**, Illinois State Geological Survey, 1964.
4. Abdun-Nur, E. A. and Wantland, D. I. *Electrical Resistivity Method Applied to the Investigation of Construction Materials Deposits*, **Proceedings**, First Pacific Area National Meeting, American Society for Testing Materials, San Francisco, October 1949.
5. Moore, R. W. *Geophysical Methods of Subsurface Exploration in Highway Construction*, **Public Roads**, Vol 26, No 3, August 1950.
6. Moore, R. W., *Geophysics Efficient in Exploring the Subsurface*, **Proceedings**, American Society of Civil Engineers, Vol 87, No SM3, June 1961.
7. Goodwin, W. A. *An Investigation of Bridge Foundation Conditions Through Boring and Geophysical Methods*, **Bulletin No 22**, The Engineering Experiment Station, University of Kentucky, December 1951.