Geol Survey

RELATION BETWEEN EARTH RESISTIVITY and GLACIAL DEPOSITS
Near Shelbyville, Illinois

James E. Hackett

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ABSTRACT

This report describes the results of an integrated geologic and earth-resistivity study made in search for water-yielding deposits in the glacial drift near Shelbyville, Illinois.

The nature of the depth-profile curves, obtained by the standard Wenner configuration and by variations in the magnitude of apparent resistivities, determined five resistivity zones, each of which is restricted to a specific geologic environment. The relationship between earth resistivity and geologic environment thus shown demonstrates that earth resistivity is a valuable geologic tool when adequate geologic control is used. However, some limitations to the use of earth-resistivity methods in groundwater exploration are noted.

The close relationship of earth resistivity to geologic environment and the failure of earth resistivity to respond to certain hydrologic and geologic features generally assumed to be determinable by earth-resistivity methods indicate that geologic factors (porosity, formation factor, and presence of conductive solids) operating independently of water quality must have an important influence on apparent resistivity in areas containing potable groundwater. Further quantitative investigations of these geologic factors is needed, therefore, for more accurate interpretations of earth-resistivity data, heretofore interpreted mainly on the basis of water-quality variations.

INTRODUCTION

For 25 years the Illinois State Geological Survey has used earth-resistivity methods to explore glacial deposits for water-yielding materials. The results of these surveys consistently have shown the need for adequate geologic control to facilitate the interpretation of the resistivity data (Buhle, 1953). Earth-resistivity investigators generally consider only the effect of water quality on the apparent resistivity, and give little or no consideration to the effect of geologic factors operating independently of water quality. A recent earth-resistivity investigation in the vicinity of Shelbyville demonstrates the close relationship of geologic and resistivity data. This study indicates the need, in earth-resistivity investigations, for consideration of geologic factors that affect apparent resistivity, particularly in areas where groundwater is not highly mineralized. It also indicates the limitations of earth-resistivity methods when adequate geologic control is lacking.

Shelbyville is in south-central Illinois, about 95 miles northeast of St. Louis, Missouri (fig. 1). The area investigated in this study covers about 36 square

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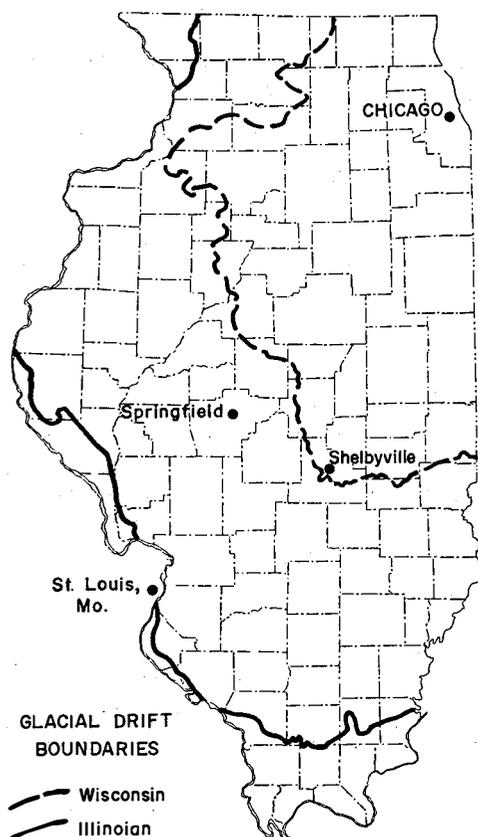
Fig. 1. - Index map of Illinois showing location of Shelbyville
in relation to the Wisconsin and Illinoian drift boundaries.

miles around Shelbyville, including the east half of T. 11 N., R. 4 E., and the
west half of T. 11 N., R. 3 E. (pl. 1 and fig. 3).

Prior to this investigation two earth-resistivity surveys in search of wa-
ter-yielding deposits were conducted in the Shelbyville area by M. B. Buhle of
the Geological Survey. The first survey, in 1946, was made for the Shelbyville
municipal airport in an area of about four square miles west of Shelbyville.
The second survey, in 1951, was for the city of Shelbyville to locate supplemen-
tary supplies of groundwater for municipal purposes, principally in the bottom-
lands of the Kaskaskia River immediately east of the city. Measurements also
were made at scattered locations north and west of the city to connect with and
extend the area covered by the airport survey.

The glacial geology near Shelbyville has been studied over a long period.
The Shelbyville morainic system was named from the morainal deposits at
Shelbyville and was designated by Leverett (1897) as the first substage of the
Early Wisconsin drift sheets. Leverett (1899) provided a detailed description
of the glacial deposits in the Shelbyville area and commented on the lack of
Shelbyville outwash deposits in the valley of the Kaskaskia River. In 1929 the
Shelbyville ice-tongue deposits and related outwash deposits were recognized

and mapped. The mapping was done by Earl T. Apfel, under the direction of George E. Ekblaw of the Geological Survey, as part of an investigation of the road materials resources of Illinois.

I am grateful to the city officials of Shelbyville for their cooperation during this study. The Baker Well Drilling Company, Layne-Western of St. Louis, S & F Drilling Company, Sims Drilling Company, and Stevens Drilling Company provided logs of water wells and test holes and samples of drill cuttings, invaluable as sources of subsurface geologic information.

M. B. Buhle and other members of the Survey's Division of Groundwater Geology and Geophysical Exploration provided many helpful suggestions and criticisms. George E. Ekblaw of the Survey provided many helpful suggestions concerning the interpretation and correlation of the glacial deposits. The chemical analyses and the measurements of specific resistances of water samples were made by L. M. Henley, assistant chemist of the Illinois State Water Survey.

GEOLOGY OF THE SHELBYVILLE AREA

Glacial deposits of the Illinoian and Wisconsin stages occur within the Shelbyville area. During the early Tazewell (Shelbyville) substage of the Wisconsin stage, a glacier advanced into the area from the northeast as far as the site of the city of Shelbyville (fig. 3), where it built a substantial terminal moraine. In its advance the Shelbyville glacier overlapped the older Illinoian glacial deposits that are exposed throughout the southwestern part of the area.

A narrow tongue of Shelbyville till protrudes southwestward from the terminal moraine and fills a pre-Shelbyville valley in the surface of the Illinoian till plain, indicating that the Shelbyville ice was very mobile and sensitive to pre-existing topographic relief. Terraces of outwash related to the Shelbyville ice flank the valley walls of the Kaskaskia River and its tributary, Robinson Creek, and Recent alluvial deposits occupy the lower floodplain levels. That these unconsolidated deposits are relatively thin is shown by the fact that bedrock of Pennsylvanian age crops out locally on the glaciated upland, along the valley walls, and on the terraces.

Logs and drill cuttings collected from rotary-drill test holes and wells help to reveal a more complete geologic picture. Test-hole and well data disclose that the surface of the bedrock is cut by a deep valley that is recognized (Horberg, 1950) as the head of the preglacial Kaskaskia Valley system. The valley drained southwestward under what is now the western limits of the city of Shelbyville to about the center of the south edge of sec. 23, T. 11 N., R. 3 E. South of sec. 23 the present course of Robinson Creek follows closely the course of the preglacial drainage. This deep valley influenced ice movement, drainage, and deposition of sediment during the glacial advances.

Although Illinoian and older glacial advances are recorded in the preglacial Kaskaskia Valley, no significant coarse-textured outwash deposits associated with these early glaciations have been recognized in the Shelbyville area. The materials deposited in the old valley by pre-Wisconsin ice advances are chiefly glacial till.

By the end of the Illinoian glacial stage the preglacial channel had been partly filled, thus causing the drainage pattern during the Sangamon interglacial

stage to differ from the preglacial pattern. The principal changes were local departures of the Kaskaskia River from its preglacial course and the development of the valley of Robinson Creek. A marked departure of the Kaskaskia River is evident in sec. 26. Glacial material deposited in the valley in the SW 1/4 sec. 26 caused the river to swing in an arc through the SW 1/4 of sec. 25 and the north part of sec. 35. Later, during either Sangamon or the early part of Wisconsin time, at least by early Shelbyville time, the river had resumed the more direct route through the west half of sec. 26.

After the Illinoian glacier retreated but before the Shelbyville glacier advanced, generally fine-textured alluvium was deposited in the drainage valleys. Its age has not definitely been determined but may include deposits of Sangamon, Farmdale, and Iowan age.

Advance of the Shelbyville glacier caused additional drainage changes and was accompanied by deposition of coarse-textured outwash, principally associated with the protruding ice tongue and limited to the valleys.

Study of drill cuttings show that the Shelbyville ice tongue advanced twice into the Sangamon-age valley of the Kaskaskia River and that both times outwash was deposited in the drainage valleys when the ice retreated. The first advance of the ice tongue left on the pre-Shelbyville surface a relatively thin veneer of till that did not appreciably alter the drainage, so that the outwash following the first advance was concentrated along the pre-Shelbyville Kaskaskia Valley.

The extent of ice withdrawal after this initial advance is not known, but the presence of intraglacial outwash in test holes in the southwest part of Shelbyville indicates that the ice tongue withdrew at least that far. However, the rapid thinning of intraglacial outwash and increasingly poorer sorting northeastward indicates that the ice did not retreat far nor for long duration and did not involve a major withdrawal of the entire Shelbyville glacier.

Readvance of the ice tongue did not completely bury the old course of the Kaskaskia River southwest of Shelbyville, but it did eliminate it as the major drainage as far south as Robinson Creek. While this portion of the valley was blocked by glacial ice and debris, meltwater from the ice front began carving the present valley of the Kaskaskia River through the bedrock upland northeast of the center of sec. 25, and by the time the Shelbyville glacier had melted from the area the new valley of the Kaskaskia River was established. Southwestward from the center of sec. 25, the Kaskaskia follows the valley formed during the Sangamon interglacial stage.

The earlier outwash deposit is locally more than 40 feet thick. The later outwash locally overlies the till and forms broad terraces at the junction of the Kaskaskia River and Robinson Creek. At some places, as in the vicinity of the N 1/4 corner of sec. 26, the later outwash lies directly upon the earlier outwash so that more than 60 feet of continuous sand and gravel deposits extend from near the present surface to the top of bedrock.

Sand and gravel outwash from the retreating Shelbyville glacier was carried in part through the present Kaskaskia valley and in part along the east side of the ice tongue, between the ice and the old valley wall bordering the Illinoian drift upland. A coarse-textured sand-and-gravel deposit of late Shelbyville outwash forms the extensive terrace in the broad valley area northeast of the junc-
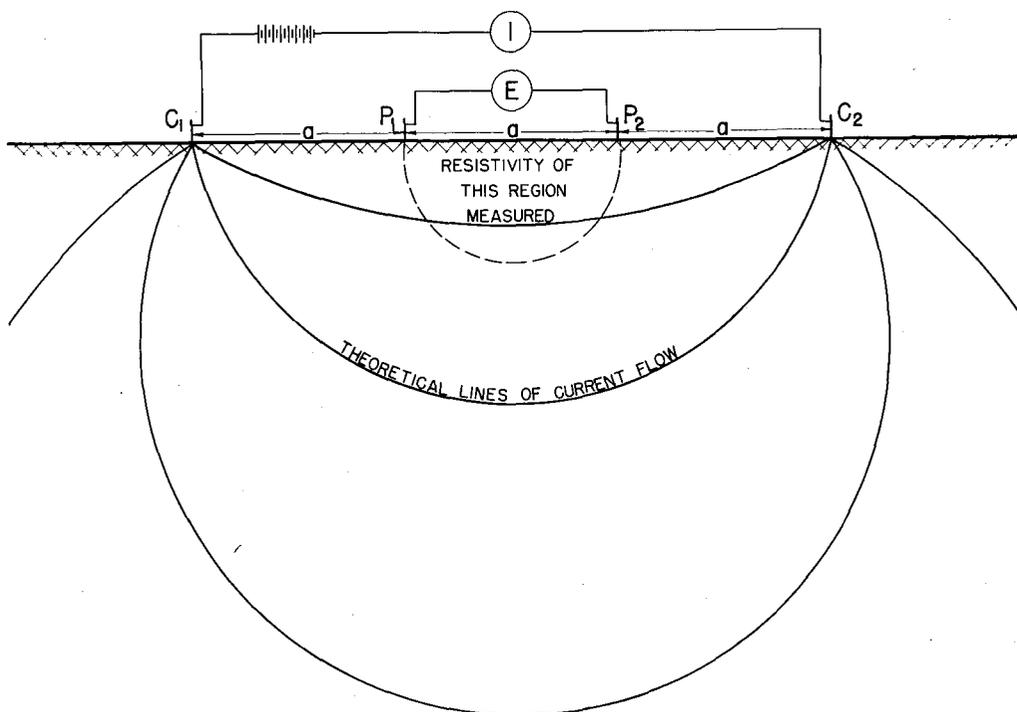
Fig. 2. - Wenner four-electrode configuration.

tion of the Kaskaskia River and Robinson Creek. Locally this deposit is more than 30 feet thick and is overlain by floodplain deposits of fine sand and silt that average about 5 feet thick. Related terrace deposits also are present in the Robinson Creek valley west of secs. 23 and 26. The materials underlying these terraces along Robinson Creek become increasingly finer upstream, indicating that they were deposited in a backwater environment. The terraces along the Kaskaskia River northeast of the center of sec. 25 generally are underlain by a thin layer of coarse-textured outwash on Pennsylvanian bedrock.

Post-Shelbyville alluvial deposits, generally finer-textured than the Shelbyville outwash, occur in the bottomlands of the area. In the Robinson Creek drainage area the alluvium is fine sand and silt, but in the Kaskaskia Valley, although the alluvial deposits are mostly fine-textured, some are coarser as a result of local or intermittent increases in current velocity of the depositing stream. The total thickness of post-Shelbyville alluvial deposits along the Kaskaskia River rarely is more than 25 feet.

EARTH RESISTIVITY
Equipment and Methods

The equipment used in earth-resistivity studies at the Illinois State Geological Survey is modified from the commutated direct-current circuits developed by O. H. Gish and W. J. Rooney (Gish and Rooney, 1925). A twelve-volt wet-cell storage battery supplies power to a synchronous vibrator that provides alternating current at 16 to 20 cycles per second. In field operation the Wenner

electrode configuration (Wenner, 1916) of four equally spaced electrodes set in a straight line is used (fig. 2). The current is applied to the two outside steel electrodes (C_1, C_2) and the drop in electrical potential between the two inside copper electrodes (P_1, P_2) is measured. The potential drop is measured by a specially calibrated potentiometer and the apparent earth resistivity is read directly in ohm-centimeters.

The depth of current penetration is related to the horizontal distance between electrodes ("a" in fig. 2) and to variations in resistivity of materials through which the current passes. A rule-of-thumb assumption is that the depth of penetration is approximately equal to "a," the electrode spacing. Although many workers, for example Wollard and Hanson (1954), have shown that this is not strictly true, it is a satisfactory assumption for practical application.

With the Wenner configuration, apparent resistivity measurements may be made either by the depth-profile method or by the step-traverse method. In the depth-profile method a series of measurements is taken at different distances between electrodes and, as the distance is changed, variation in the character of materials with depth produces changes in the apparent-resistivity values. The measurement at each electrode separation is a product of the specific resistances of all materials present, from the surface to the depth of current penetration. As the depth of current penetration is increased, changes in apparent resistivity are expressed as a smooth curve or depth profile. The depth profile may therefore be used as an indication of geologic changes with depth.

In the step-traverse method a series of measurements at a constant electrode-spacing is taken at closely spaced intervals along a line of traverse. This method is applicable where variations in apparent resistivity are associated with horizontal changes in geology at a constant depth.

In the Shelbyville resistivity study, depth profiles were taken at sufficiently close intervals to show general horizontal variations in apparent earth resistivity. By this method a three-dimensional representation of apparent earth resistivity was obtained.

Field Methods

In areas of flat terrain and along section-line roads, earth-resistivity stations were spaced at distances of 500 to 1250 feet. In bottomland or alluvial terrace areas and in other areas where horizontal variations in geologic conditions required, the distance between resistivity stations varied from 150 to 500 feet. Resistivity readings also were made where specific geologic control, such as test-hole or well information, was available. In this investigation and previous surveys a total of 229 earth-resistivity depth-profile measurements were made in the Shelbyville area.

At most locations depth-profile measurements were taken at 10-foot electrode-spacing intervals, beginning with an electrode separation of 10 feet and increasing it to a maximum determined by the characteristics of the depth-profile curve and by knowledge of geologic conditions.

Earth-resistivity measurements cannot be made where there are steel-post fences, such buried metal pipes as gas or water mains, or other conductors that would disturb the electrical fields or natural resistance of earth materials.

This limitation restricts the use of the earth-resistivity method in urban areas where buried conductors are prevalent.

Interpretations

A number of methods of interpreting earth-resistivity depth-profile curves have been developed and an excellent discussion of the various methods and their evaluation is given by Roman (1952). To date, no one method that is universally applicable has been found. It is therefore necessary to determine for each area the most satisfactory method of interpretation.

In this study no quantitative method of determining vertical changes in geology or depth to water table was found to be consistently reliable. Under some conditions earth resistivity did not indicate marked changes known to be present in the character of glacial materials at relatively shallow depths, demonstrating serious limitations of the use of earth resistivity in areas where the geology is not well known.

Resistivity Zones

Specific zones characterized by similar depth-profile curves and/or magnitude of apparent resistivity measurements are mapped on plate 1. These zones of similar apparent-resistivity characteristics are related to the geologic environment within which they occur. Relation of earth resistivity to the geologic environment is shown by comparison of the areal distribution of the resistivity zones (pl. 1) with the surficial geologic map (fig. 3), by comparison of apparent resistivity depth profiles with logs of test holes at the same location, and by comparison of a cross section of apparent resistivity with a geologic cross section along the same line (pl. 1).

Zone I

Earth-resistivity measurements in Zone I are sensitive to variations in the lithology of the underlying alluvial materials. As shown by depth-profile curve D. P. 76-51 (pl. 1), flat, featureless depth-profile curves with a magnitude of apparent resistivities of generally less than 4,000 ohm-cm. are associated with fine-textured alluvium of fine sand or silt. Where coarse-textured alluvial deposits predominate, the depth profiles (D. P. 24-54, pl. 1) show higher apparent resistivities for the coarse-textured alluvial material. Apparent resistivities in such coarse-textured alluvium have a magnitude up to 15,000 ohm-cm. Because availability of groundwater within Zone I is directly related to the texture of the alluvial material, this ability of earth resistivity to distinguish texture makes it a useful tool for locating sites at which to test drill for water supplies.

Zone I includes the post-Shelbyville alluvial deposits within the Kaskaskia River Valley. The alluvial deposits are mostly fine-textured, and bedrock lies at depths generally less than 25 feet. The thinness and shallow depth of the permeable deposits restricts the usefulness of these materials for large-scale groundwater development.

Earth-resistivity values from the terrace surfaces in the Kaskaskia River Valley adjacent to Zone I are inconsistent and no characteristic earth-resistivity features were recognized. This inconsistency probably is due to variations in the lithology of the shallow Pennsylvanian bedrock.
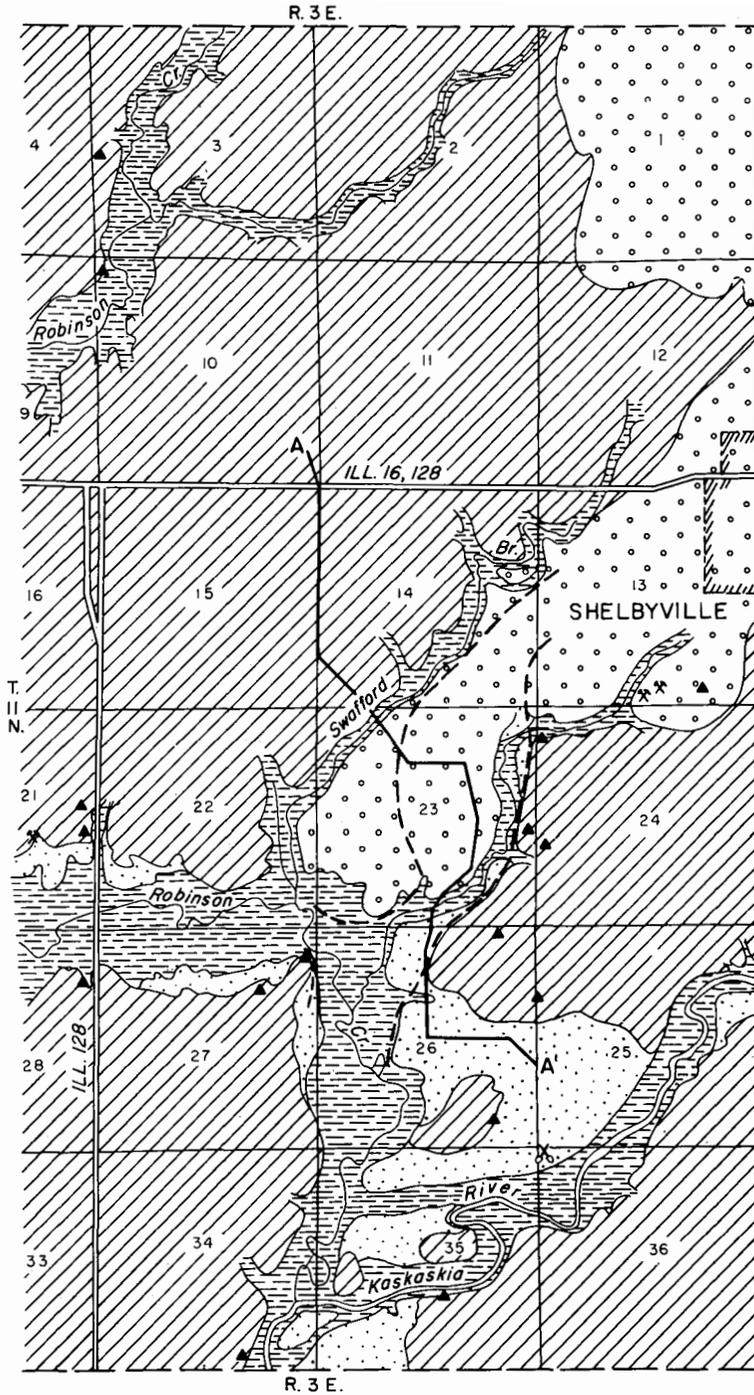
Fig. 3A. - Glacial geology of the Shelbyville area, west part.
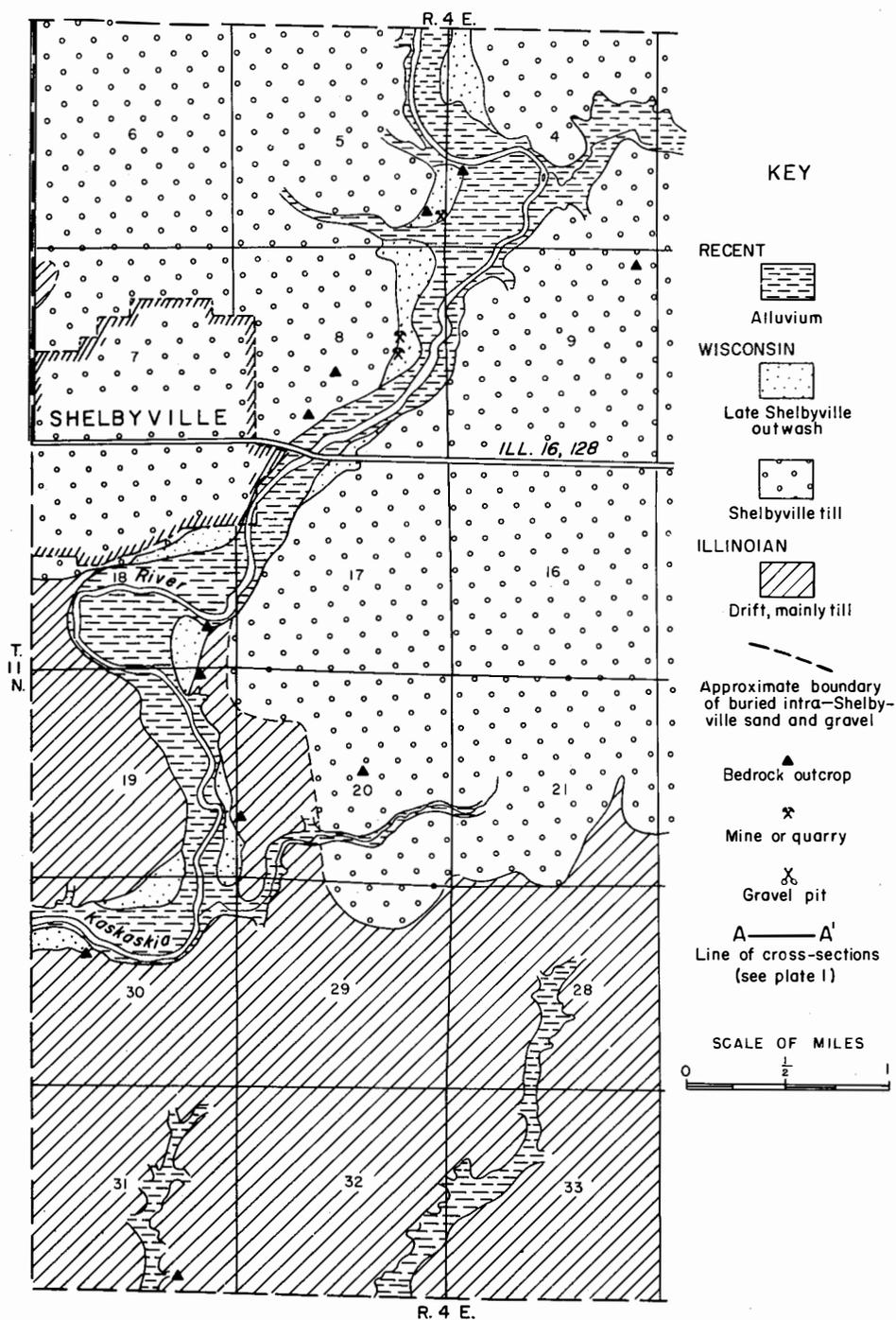
Fig. 3B. - Glacial geology of the Shelbyville area, east part.

Zone II

Earth-resistivity measurements in Zone II are characterized by apparent
resistivities of very high magnitude. These apparent resistivities appear to be
caused by a near-surface deposit of coarse-textured sand and gravel. Maxi-
mum apparent-resistivity values in Zone II range from 15,000 ohm-cm. to more
than 40,000 ohm-cm. Depth-profile curves (D. P. 56-54, and D. P. 38-54, pl.
1) are of high relief and have a general form of lower resistivity values at the
upper and lower portions of the curve and higher apparent-resistivity values
in the middle portion. However, the breadth of the middle portion of the curve
is not an indication of the thickness of the deposit.

Test drilling showed that there was no relation between the magnitude of
the apparent resistivities and the suitability of the material as a source of
groundwater for large-scale development. For example, D. P. 38-54 on plate
1 is a resistivity depth profile in the area where the city of Shelbyville develop-
ed a municipal groundwater supply. Apparent resistivities of 16,000 ohm-cm.
were measured at this station. However, at D. P. 56-54, where test drilling
penetrated a deposit of coarse-textured material with a transmissability too
low to be considered satisfactory, values of 33,000 ohm-cm. were observed.
The apparent differences in the form of the two depth-profile curves do not in-
dicate areas of thicker accumulations of sand and gravel. At other sites with-
in Zone II, where resistivity depth profiles were similar to D. P. 38-54 in gen-
eral form and magnitude of apparent resistivities, test drilling penetrated
coarse-textured material similar in thickness and character to that penetrated
at the site of D. P. 56-54. Apparently within resistivity Zone II it is not pos-
sible to outline areas of thicker sand and gravel accumulations by earth-resis-
tivity methods.

Surficial and subsurface geologic information shows that Zone II is restrict-
ed to the area underlain by the late Shelbyville outwash deposited during the
final retreat of the Shelbyville glacier from the area. This outwash is consist-
ently coarse-textured but is poorly sorted and contains some fine-grained sedi-
ments. The deposit is more than 30 feet thick in some places but averages about
20 feet and is overlain by a thin cover of sandy silt that averages about 5 feet
thick.

The late Shelbyville outwash directly overlies the earlier intraglacial out-
wash in the municipal well field and therefore the thickness of the sand and
gravel is greater here than elsewhere. The resistivity measurements obtained
in Zone II are apparently the reflection of the late Shelbyville outwash and they
are not materially influenced by the underlying intraglacial outwash.

Zone III

Earth-resistivity measurements in Zone III are characterized by smooth
curves of low relief (D. P. 7-55, pl. 1) with maximum apparent resistivities of
about 6,000 ohm-cm. The apparent resistivities are of a relatively low order
of magnitude, even though they are obtained from a near-surface deposit of sand
and gravel with an average thickness of about 40 feet. The thickness of the silt
or, locally, glacial till, over the sand and gravel deposit ranges from about 10
to 25 feet. The thickness of cover overlying the deposit is a critical factor for,
where the thickness of the glacial till cover exceeds about 25 feet, the depth-

profile curve is characteristic of Zone IV. Earth-resistivity measurements characteristic of Zone III are obtained where a cover of less than 25 feet of Shelbyville glacial till or post-Shelbyville fine-textured alluvium overlies the intraglacial Shelbyville outwash, which from test drilling appears to be finer textured and generally thicker than the late Shelbyville outwash.

Zone IV

Earth resistivities in Zone IV are characterized by nearly featureless depth profiles (D. P. 12-55 and D. P. 4-54, pl. 1) with apparent resistivity values ranging from about 4,500 ohm-cm. to about 6,000 ohm-cm. Variations in apparent resistivity on the depth profile apparently are not related to any significant geologic feature.

Zone IV lies within the area covered by the Shelbyville glacier and is therefore characteristic of the Shelbyville till in this area. The intraglacial outwash deposit cannot be distinguished by earth-resistivity methods, as is shown by comparison of the earth resistivity and geologic cross sections on plate 1. A typical depth-profile curve in the area underlain by the intraglacial outwash within the Shelbyville glacial till is shown by D. P. 12-55. Earth resistivities of similar magnitude and general character also were obtained at the site of D. P. 4-54 where test drilling revealed no evidence of the intraglacial outwash. This obviously is a limitation of the use of earth resistivity in search for buried sand and gravel deposits. Earlier investigations in the Shelbyville area to find groundwater supplies for airport and municipal purposes did not reveal this potential groundwater source because subsurface geologic information was lacking and earth-resistivity methods failed to detect the intraglacial outwash deposit.

The magnitude of earth resistivities generally obtained in Zone IV is about the same as in Zone III. Therefore it seems that the Shelbyville intraglacial outwash deposit and the Shelbyville glacial till have similar apparent resistivities. It is also possible that the silt and till overlying the intraglacial deposit have acted as an electric shunt, thereby masking the presence of a more electrically resistant body below.

Zone V

Earth resistivity in Zone V is characterized by nearly featureless depth profiles with apparent resistivities of low magnitude (D. P. 51-46, pl. 1). The depth-profile curves generally show an increase of apparent resistivities with depth up to a maximum of about 4,500 ohm-cm. At shallow depths the apparent resistivities generally are less than 3,000 ohm-cm. Locally there may be reversals of this condition and the depth profile will have relatively high apparent resistivities (up to 8,000 ohm-cm.) at short electrode separations and lower apparent resistivities at longer electrode separations. Such occurrences are limited in areal extent and generally are restricted to knolls and small ridges.

Zone V occurs within the area of the Illinoian glacial drift where it is thin and underlain by Pennsylvanian bedrock. The Illinoian glacial drift consists largely of a silty glacial till upon which a deep clayey soil profile has developed. The relatively thick clayey B horizon of the soil profile may in part explain the very low apparent resistivities characteristic of the Illinoian glacial drift in the

Shelbyville area. The resistivity depth profiles indicate that the underlying Pennsylvanian bedrock has a slightly higher apparent resistivity than the Illinoian glacial drift.

The local reversals of the depth profiles are related to small surficial deposits of gravel that occur as low knolls and ridges on the Illinoian surface.

Factors That Affect Apparent Resistivity

The fundamental factors that affect the values of apparent resistivities obtained by earth-resistivity methods can be classified as follows: 1) water saturation, 2) water quality, and 3) geologic factors. Results of earth-resistivity studies in the Shelbyville area show variable response to these factors. The influence of each factor is discussed below.

Water saturation

The presence of water is a primary factor in the conductance of an electric current through earth materials. All other factors being equal, and assuming the water to have sufficient ions in solution to make it a conducting medium, the apparent resistivity of water-saturated materials will be lower than the apparent resistivity of unsaturated materials. On the basis of this principle it has been widely assumed that earth-resistivity methods can be universally used to determine the position of the water table. However, the significance of hygroscopic and pellicular water in the vadose zone, and of the height of the capillary fringe in fine-grained materials, often has been neglected.

As stated above, in the Shelbyville area there is no consistently reliable method of determining depth to the water table by resistivity. Inspection of the depth-profile curves on plate 1 shows little indication of the influence of the water table on the apparent resistivities. The influence of the water table should be expressed as a deflection of the curve toward lower resistivity because of the higher conductivity of saturated materials. In many instances, such as at D. P. 56-54, there is a marked increase in the apparent resistivities at the approximate level of the water table. Similar relationships were observed in resistivity studies in the Kansas River Valley (Merriam, 1954), where these effects were concluded to be due to the influence of the water table. However, I believe that in the Shelbyville area such effects are the result of lithologic changes or other geologic factors that coincidentally cause an increase in apparent resistivities at about water-table level.

Water quality

The ionic content of the water contained in earth material is the major controlling factor of the ability of that material to conduct an electric current. It has been demonstrated, both in earth-resistivity studies and in studies of electric logs, that as the salinity of the water in a formation increases, the apparent resistivity decreases. The effect of water quality on apparent resistivities is so influential that many workers in earth resistivity have considered it as the only factor.

In order to establish whether or not the differences in apparent resistivities of the late Shelbyville outwash deposit in resistivity Zone II and the intraglacial outwash deposit in resistivity Zones III and IV are related to differences

in water quality, analyses of water from these formations (table 1) were com-
pared.

Analyses 1 and 2 are from farm wells in resistivity Zone IV (pl. 1). These
wells obtain water supplies from the intraglacial outwash deposit. Analyses 3
through 6 are of water obtained from Shelbyville municipal test wells in resis-
tivity Zone II. Analysis 7 is from an undrained gravel pit in the late Shelbyville
outwash in resistivity Zone II. The low total-mineral content of analysis 7,
compared with the other analyses, suggests that the water in the gravel pit is
diluted by surface water and is therefore not a valid indicator of the water in
the sand and gravel deposit of resistivity Zone II. With the exception of anal-
ysis 7, analyses of water obtained from the sand and gravel deposits underlying
resistivity Zone II show a total-mineral content and specific resistance between
those obtained from the sand and gravel deposit that underlies resistivity Zones
III and IV. It is therefore concluded that differences in the apparent resistivity
of the Shelbyville intraglacial outwash deposit in resistivity Zones III and IV
and of the late Shelbyville outwash in resistivity Zone II can not be explained
by differences in the quality of water contained in these formations.

Geologic factors

Factors, other than water saturation and water quality, that may affect ap-
parent earth resistivity generally have been ignored by earth-resistivity in-
vestigators. Results of earth-resistivity investigations near Shelbyville sug-
gest that other factors are affecting the apparent resistivities and that their ef-
fects are appreciable.

In a discussion on the interpretation of electric logs, Wyllie (1954) discusses
the following factors that must be considered as contributing to the apparent
resistivity: 1) presence of conducting fluids, 2) salinity and temperature of for-
mation water, 3) oil and gas or other nonconducting fluids, 4) rock structure,
and 5) conductive solids. Factors 1 and 2, with the exception of temperature,
have been discussed above. The range in groundwater temperature in the Shel-
byville area is assumed to be negligible and requires no further discussion.
The effect of oil and gas, or other conducting fluids, although applicable in some
earth-resistivity investigations, do not apply in the Shelbyville area. Factors
4 and 5 are, however, functions of the geology and require careful consideration.

Rock structure. - Other things being equal, the greater the amount of con-
ducting fluid in an earth material the lower will be its resistivity. In water-
saturated materials, the amount of conducting fluid is controlled by the effective
(interconnected) porosity. In unconsolidated glacial materials the porosity is
a function of the sorting of the deposit and the packing and shape of the grains.
Variations of these elements in a deposit may therefore produce variations in
the apparent resistivity.

An important element in the apparent resistivity is the so-called "forma-
tion factor" of electric-log interpretation. The formation factor is dependent
not only upon the porosity but also upon the shape of the rock pores and the man-
ner in which they are disposed and interconnected. Very different formation
factors may be obtained from deposits with the same effective porosity. Fur-
thermore, the formation factor is independent of water quality (Wyllie, 1954).
To determine quantitatively the resistivity of a rock saturated with conductive

fluid, the resistivity of the conductive fluid is multiplied by the formation fac-
tor.

That the formation factor appreciably affects the apparent resistivity is
shown by the magnitude of the formation factors of various rock types. The
formation factors of sandstone formations range from a minimum of about five
to a maximum of several hundred. Those of limestones and dolomites range
from a minimum of about ten to many thousands where porosities are small
(Wyllie, 1954). The range in the formation factors of unconsolidated glacial
sands and gravels is not known but is likely to be somewhat similar to the range
in values for sandstone formations.

According to the quantitative relation expressed above, the influence of the
formation factor increases as the resistivity of the conducting fluid increases.
It therefore follows that apparent resistivities, obtained by earth-resistivity
methods in areas where groundwater is only slightly mineralized, will be strong-
ly influenced by variations in the formation factors of the deposits. It also can
be demonstrated that the effect of the variation in water quality on apparent re-
sistivity is controlled by the magnitude of the formation factor. In areas where
both quantities are variable, their combined effects may be additive or they may
tend to cancel each other.

Conductive solids. - The presence of conductive solids, principally clay
minerals, is another geologic factor that affects the apparent resistivities ob-
tained by earth-resistivity measurements. Results of experimental studies
(Patnode and Wyllie, 1950) demonstrate that materials that contain wet clays
or other conductive solids may have appreciable conductivity. These studies
also show that the conductivity of the solid materials is additive to the conduc-
tivity of the fluid medium and is essentially independent of the salinity of the
fluid. Although the effect of conductive solids on apparent resistivities is slight
when the conductive fluid is highly saline water of low resistivity, the effect of
the conductive solids increases in importance as the resistivity of the conduc-
tive fluid is increased.

The presence of clay minerals in a deposit will, therefore, tend to lower
the apparent resistivity of that deposit. The quantity of clay minerals present
will establish the maximum apparent resistivity of a deposit regardless of the
quality of the water.

In unconsolidated glacial deposits, clay minerals are commonly dispersed
throughout the materials as coatings on grains, as disseminated aggregates,
and in beds or lenses. In glacial drift the salinity of the water is generally low
and therefore of a relatively high resistivity. Apparent-resistivity measure-
ments obtained by earth-resistivity methods in these areas must be influenced
by the presence of conductive solids.

Application to the Shelbyville area. - The consistent relation of character-
istic earth-resistivity responses to specific geologic environments, as well as
various responses between and within glacial deposits not explainable by var-
iations in water quality, indicate that geologic factors affecting apparent resis-
tivities are an important influence on the earth-resistivity measurements ob-
tained in the Shelbyville area.

Differences in the apparent resistivities between the Shelbyville intraglacial
outwash and the late Shelbyville outwash may be the result of intrinsic differ-

ences in the porosities, the formation factors, or the presence of conductive
solids. The relatively low apparent resistivity of the Shelbyville intraglacial
outwash deposit is most likely a result of geologic factors, and the lack of dis-
tinction of this deposit in Zone IV is due to a lack of electrical contrast between
it and the overlying Shelbyville till.

Lack of correlation in the late Shelbyville outwash between areas of highest
est resistivities and the presence of thicker or more permeable sections may
be explained in part as variations of porosity and formation factor.

The well developed B horizon of clay concentration in the Illinoian drift
may explain in large part the difference in apparent resistivity between the
Shelbyville glacial till in resistivity Zone IV and the Illinoian glacial drift in
resistivity Zone V. However, possible differences in water quality in the two
deposits were not investigated in this study and therefore the reasons for the
differences in apparent resistivities cannot be readily evaluated.

SUMMARY AND CONCLUSIONS

Earth-resistivity zones are shown to be closely related to glacial features
near Shelbyville, Illinois. This relationship points out strongly the necessity
for a detailed knowledge of geologic conditions when earth-resistivity data are
being interpreted. Where sufficient geologic control is available, earth resis-
tivity can be a useful tool in geologic interpretations.

Certain limitations to the use of earth resistivity for groundwater explor-
ation were noted in the Shelbyville area. In only one resistivity zone was earth
resistivity selective in determining the best sites to test drill for water-yield-
ing material. In the other resistivity zones there was little or no relationship
between the earth-resistivity measurements and the presence of the most suit-
able water-yielding sand and gravel deposits. Either the earth-resistivity meas-
urements failed to reveal the presence of suitable material, even at relatively
shallow depth, or did not discriminate between areas of thicker, more permeable
materials and areas of thinner, less permeable materials.

It is shown that certain geologic factors can contribute in a large measure
to determining apparent resistivities in earth-resistivity investigations. It is
concluded that in the Shelbyville area, where groundwater is of relatively low
mineral content, these geologic factors are at least as important as, if not more
important than, water quality in producing the earth-resistivity effects observed.
Further studies, especially quantitative, of the effect of geologic factors in
earth-resistivity investigations are warranted. These studies are of great im-
portance in areas containing potable groundwater.

Table 1. – Chemical Analyses of Groundwater from Shelbyville Intraglacial
Outwash and Late Shelbyville Outwash Deposits
(in parts per million)
(chemical analyses by L. M. Henley, Illinois State Water Survey)

Analysis No.	Lab No.	Turbidity	Fe	Na	Cl	SO_4	Mn	Fl	NO_3	Alk.* (as $CaCO_3$)	Hd.*	TMC*	Specific Resistance ohm-cm.
1	140406	13	2.4	92.0	61.0	26.0	-	-	-	440	352	563	1060 ohm at 24.5°C
2	140407	1	0.9	3.0	4.0	59.0	-	-	-	264	324	334	1700 ohm at 24.7°C
3	136472	0	0.1	-	12.0	-	0.1	0.3	4.2	304	380	421	1320 ohm at 25.9°C
4†	137848	2	0.1	0.0	24.0	87.3	0.4	0.1	2.2	348	474	508	
5	136376	13	0.2	-	33.0	-	0.3	0.1	5.7	360	448	504	1095 ohm at 26.3°C
6	138899	1	tr.	-	19.0	-	-	0.1	13.7	292	400	476	1166 ohm at 25.8°C
7	140410	26	0.7	2.0	6.0	27.0	-	-	-	168	200	205	2750 ohm at 25.0°C

* Alk. – alkalinity; Hd. – hardness; TMC – total mineral content.
† Analysis 4 also contained (in parts per million) 117.6 Ca, 43.7 Mg, 0.5 NH_4, 16.5 SiO_2.

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