Geological and Geophysical Study of the Preglacial Teays Valley in West-Central Ohio

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1460-E

Prepared in cooperation with the Ohio Department of Natural Resources, Division of Water

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

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By STANLEY E. NORRIS *and* H. CECIL SPICER

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GEOLOGICAL AND GEOPHYSICAL STUDY OF PREGLACIAL TEAYS VALLEY IN WEST-CENTRAL OHIO

By S. E. Norris and H. C. Spicer

ABSTRACT

The U. S. Geological Survey and the Division of Water, Ohio Department of Natural Resources, have explored, as part of a cooperative program of water-resources investigations, the buried Teays Valley of Tertiary age and associated deposits in three counties of west-central Ohio. Earth-resistivity methods were used to locate the buried Teays Valley and to trace its course before test drilling was begun. The apparent resistivity of the earth was computed by the Wenner formula; interpretation of the three resistivity curves obtained for each depth profile was by methods based on the theory of images. Computed resistivity values for the unconsolidated deposits ranged between 1,670 and 69,000 ohm cms; for the consolidated rocks the range was between about 2,500 and 41,000 ohm cms. Test holes drilled later at critical sites revealed the depth of the buried valley, its gradient and configuration, and the character of the valley-fill deposits.

The Teays River was the master stream for the drainage from a large part of the Appalachian region in late Tertiary time. It originated in the Piedmont Plateau of Virginia and North Carolina and flowed generally northwestward across West Virginia and southern Ohio where its course south of the glacial drift is revealed by abandoned valley segments and terrace remnants above the present drainage. In the area of glacial drift the course of the buried Teays Valley has been traced, largely from well records, across western Ohio, northern Indiana, and Illinois to the Mississippi embayment.

The Teays was a mature stream. Its valley in southern Ohio, where it is cut into shale and sandstone of Mississippian age, averages about 1½ miles in width, has a flat floor and steep sides, and is about 200 to 300 feet below the general level of the uplands. In west-central Ohio, where it is cut into limestone and dolomite of Silurian age, the buried Teays Valley is about 3,000 feet wide in the narrowest place, the valley walls are steep, and the valley floor is 400 feet or more below the general level of the bedrock surface. The gradient of the Teays Valley in southern Ohio is about 9 inches per mile; its gradient in the area of this investigation is about 10 inches per mile. The buried valley declines in altitude from 568 feet in south-central Madison County to 538 feet in southern Champaign County, over a channel distance of about 35 miles.

The Teays River was dammed somewhere in its lower course, possibly in northeastern Indiana, by a pre-Illinoian glacier. This ponded the waters and produced widespread finger lakes in the Teays Valley and its tributaries in which were laid down extensive deposits of finely laminated silts and clays. Stout and Schaaf (1931) named these silts and clays the Minford silt from exposures in southern Ohio. Test drilling has revealed that clay typical of the Minford at the type locality in southern Ohio is the principal deposit in the buried Teays Valley in west-central Ohio, in association with scattered deposits of fine-grained sand. The clay and the associated sand are assigned to the Minford silt. The clay is 264 feet thick at the London Prison Farm in western Madison County; its median thickness in 12 test holes is 100 feet. In most places the clay lies directly on the bedrock which, prior to the deposition, must in places have been swept clean of stream alluvium. The authors believe that this erosion occurred just before the ice dammed the Teays, when its flow was augmented by water diverted, through a col at Sardis in the Ohio Valley, from the basin of the northward-flowing Pittsburgh River, which was dammed a little earlier. The fine sand associated with the lacustrine clays in the area of this investigation is believed to have originated as glacial outwash and was contributed by meltwaters from the ice front, mingling with the finer grained sediments carried into the ponded Teays basin by headwater streams.

This investigation reveals that the fine-grained, unconsolidated deposits in the buried Teays Valley in west-central Ohio are not important as a source of ground water. Somewhere downstream, however, the predominantly lacustrine deposits in the buried valley give way to coarser grained deposits largely of glacial origin. The authors suggest a plan for prospecting the Teays Valley by geophysical methods and test drilling throughout the remainder of its course in Ohio to ascertain where it was dammed by the early glacier and where, as a consequence, it may contain outwash sands and gravels of possible importance as sources of ground-water supplies.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

The U. S. Geological Survey and the Division of Water, Ohio Department of Natural Resources, have for several years been systematically investigating the State's water resources on a cooperative basis. Several published reports, describing the geology and ground-water conditions in various Ohio counties, are among the results of this work. Detailed investigations have revealed the critical importance of buried valleys with respect to ground-water resources, for the most productive aquifiers in Ohio are sand and gravel deposits of glacial origin, partly or wholly filling ancient valleys. Buried valleys in some other areas, contain thick deposits of fine sand, silt, or clay that are difficult to develop in wells and that yield only small quantities of water. It becomes an essential part of water-resources investigations to map the buried valleys, determine their ages, and learn the origin and character of the deposits they contain. This paper presents recently gathered data, obtained for the most part by earth-resistivity prospecting and by test drilling concerning the buried Teays Valley and deposits associated with it in Madison, Clark, and

Champaign Counties, Ohio. This evidence forms the basis for a discussion of certain events in the history of the Pleistocene epoch. The report also exemplifies the use of earth-resistivity prospecting in the mapping of buried valleys in a limestone region.

DIVISION OF WORK AND ACKNOWLEDGMENTS

The geological portion of this paper was prepared by Stanley E. Norris, and the geophysical part was prepared by H. Cecil Spicer.

The authors are indebted to E. J. Schaefer, formerly district engineer, U. S. Geological Survey, under whose supervision most of the program was conducted; C. V. Youngquist, Chief, Ohio Division of Water; and R. J. Bernhagen, Chief, Ohio Division of Geological Survey, all of whom lent support and encouragement to the investigation. Geophysical observations were provided by G. J. Edwards, R. E. Miller, R. E. Marzluf, and others of the U. S. Geological Survey, and John Krolczyk of the Ohio Division of Water prepared the illustrations. Duncan McConnell, Professor and Chairman of the Department of Mineralogy, Ohio State University, made detailed examinations of samples of unconsolidated deposits from the test holes and very helpful comments on their general mineral composition and possible source rocks. John B. Droste, of the Department of Geology, University of Illinois, examined similar samples and reported on their clay minerals. W. N. Lockwood, of Ohio State University, made available detailed information on the character and occurrence of the Minford silt. The driller, D. J. Roe, Vandalia, Ohio, was careful to provide as much geologic data as possible in the course of drilling the test holes.

PRESENT INVESTIGATION

One outgrowth of the cooperative water-resources program in Ohio is a report on the water resources of Clark County (by Norris, S. E., Cross, W. P., Goldthwait, R. P., and Sanderson, E. E., 1952). The report includes a map, showing contours on the bedrock surface, based largely on driller's records of wells, but supplemented by test-hole data and exposures of the bedrock. The map reveals the principal buried valleys in Clark County and the main pattern followed by the former streams of the preglacial drainage systems. The course of the buried Teays Valley, where it traverses the northeastern part of the county, is clearly defined.

The Teays Valley deposits in eastern Clark County are not a source of ground-water supplies because in this area they consist largely of silt and clay. The silt and clay have caused several drilling failures which cost landowners and drillers considerable money. In each instance these drilling failures followed a similar pattern. Efforts to find water in the desired quantity at shallow depths in the glacial drift had been unsuccessful and the well was deepened substantially below the average depth of other wells in the area. The deeper drilling had carried it into the silt and clay, often reported as "quicksand" or "heaving sand." Drilling through the silt and clay or to drive casing with common churn-type or cable-tool drilling equipment was very slow and difficult, and eventually became impracticable or impossible. The well was abandoned, generally after several weeks of wasted effort. At least four such drilling failures occurred in the London (Madison County) area, and the depths of the unsuccessful wells ranged between 309 feet and 520 feet. None reached the consolidated rocks, though the deepest of the four wells is known now to have penetrated to within a few feet of the bedrock surface. It is ironic that the consolidated rocks in the buried-valley area where the wells were drilled are not water-bearing limestones, such as occur at shallower depths beneath the glacial drift in surrounding areas, but are relatively impermeable shales which are not a source of water.

In 1948, a cooperative investigation was begun in Champaign County, which bounds Clark County on the north. Field work immediately revealed that because few water wells reached bedrock in the western half of the county (owing to the very great thickness of the glacial drift) logs of existing wells would not reveal the buried bedrock topography in much detail. An attempt was made, therefore, to use earth-resistivity prospecting methods to determine the configuration of the bedrock surface.

A resistivity investigation was begun in Champaign County in the spring of 1949 by a field party under the supervision of H. Cecil Spicer, and later was extended into adjacent counties. Most of the work was done in central and southern Madison County and in southern Champaign County. About 125 resistivity determinations were made at several closely spaced sites to determine the width and shape of the buried valleys. A field survey of wells also was made, at least 2,500 well records were obtained and studied.

To supplement the resistivity work and to provide correlation between the apparent-resistivity curves and the local geology in the area of the main buried valley, test drilling by the hydraulic-rotary method was done on contract in the summers of 1952 and 1953. Eleven test holes were drilled to a total depth of 3,552 feet in unconsolidated deposits. The depth to bedrock at the test-hole sites ranged from 185 feet to 530 feet; the mean depth to bedrock was about 350 feet. In contrast with the results of attempts to use cable-tools to drill to bedrock in these buried-valley areas, each of the rotary-drilled test holes was completed in less than a week of actual drilling time, and at the London Prison Farm 530 feet of unconsolidated deposits were penetrated in a single day. The record of a test hole drilled in 1946 in Clark County by the City of Springfield was also used in the present study. This hole was started with cable-tool equipment and was completed with a rotary drilling machine. Bedrock was reached at the depth of 422 feet.

Considerable money was saved by the substitution of comparatively inexpensive resistivity determinations for costly test drilling at many points where subsurface information was needed. About 25 points could be examined by the resistivity method at the cost of the average drill hole, permitting very intensive preliminary investigation to be made of the thickness of the glacial drift, and preparation of a detailed contour map that showed clearly the course of the buried valley in much of the area. The map made it easy to locate the test holes along the axis of the valley, where the altitude of the bedrock is lowest.

RESISTIVITY STUDIES

EQUIPMENT AND FIELD METHODS

The sensitivity measurements were made with earth-resistivity apparatus of the Gish-Rooney type, modified by the addition of commutator speed control, quiet gear drive, and improved brushes and circuit controls all of which were found by field experience to be highly desirable.

Power for the motor drive on the commutator was obtained from the storage battery of the truck in which the instrument is mounted; power for the current circuit to energize the earth was supplied by a bank of super "B" batteries. This bank has two batteries wired in parallel in the range up to 180 volts in order to prolong their life and to provide the needed current. The maximum voltage used was seldom more than 180 volts but 720 volts was available from the bank for use under adverse conditions. Taps for the several voltages were brought out to selector switches and the amount of current flowing through the earth and through the current side of the instrument was adjusted by rheostats mounted on a control panel. A 0–1,000-volt meter was connected across the selector switches to indicate the impressed voltages in the earth.

The electrodes used for making contact with the earth for both potential and current were copper-clad steel rods about 26 inches long and ¾-inch in diameter, with a hexagonal steel driving head on one end and a sharpened point on the other. Bronze wire with synthetic rubber insulation over cotton wrap was used to connect the electrodes to the instrument. This wire was wound and transported on duralumin reels, the reels having a commutator-brush assembly for connecting the end of the wire to the electrode through the short lead and a 4-inch heavy-duty battery clip. The electrodes were "mudded in" at each setting to maintain good contact with the earth.

The greater part of the area of this investigation is farmland under cultivation and it was often difficult to find suitable areas of adequate size to accomodate a 1,000-foot-interval depth profile. Manmade conductors, such as power lines, gas and water mains, telephone cables, and metal fences, often interfered with the locations of the electrode line centers. Many partly completed sets of observations for a depth profile were abandoned because of such interference. Some of the depth profiles probably contain similar but unrecognized interference that has caused some misinterpretation of the curves.

Depth profiles were made throughout this study to get information as to the character and thickness of the materials beneath the surface. Electrodes were set in the earth in accordance with the modification of the Wenner arrangement proposed by Lee (1929). Measurements of potential were made both by Wenner (1915) and by Lee (1929) techniques, giving three measurements at each interval. The apparent resistivity was computed by the Wenner formula $\rho=2\pi a\frac{E}{I}$ for all the observations because it spreads the curves on the chart, making them easier to examine and to interpret. The curve form, however, remains the same. The three resistivity curves (full, P–1, and P–2) obtained for each depth profile are shown on plate 7.

INTERPRETATION OF APPARENT-RESISTIVITY CURVES

The procedures by which the apparent-resistivity curves for this investigation were interpreted are described only briefly here. The method of interpretation is based primarily on the theory of images given by Jeans (1925) and others, which method applies to curves for two or more layers. The technique demands a knowledge of the theoretical aspects of resistivity curves (Hummel 1931). Two-layer resistivity curves and two methods of interpreting them are discussed by Roman (1931, 1934, 1941). Wetzel and McMurry (1937, p. 329–341) describe three-layer resistivity curves. The use of the Roman two-layer curves and the Wetzel and McMurry three-layer curves as an aid to the interpretations of curves for three and more layers is explained by Watson and Johnson (1938, p. 7–21). The treatment of potential theory is discussed by Watson (1934), and additional material on the interpretation of multiple-layer resistivity curves is given by Spicer (1950, 1952) and Edwards (1951). Tagg (1937) describes a method useful in the interpretation of certain types of resistivity curves, and gives examples of its application.

Both theory and model measurements indicate that surface-resistivity curves should be a series of smooth curves for two, three, and more layers and should be amenable to the interpretative procedures referred to above.

PREVIOUS WORK

The abandoned valley system in West Virginia, formerly called the old Kanawha system and now the Teays system, has been under scrutiny for almost 70 years by geologists studying drainage changes produced by Pleistocene glaciation. The upper Teays Valley system was discussed as early as 1884 by I. C. White. White (1896) discussed also the terrace deposits of the Monongahela River and concluded that the deposits were laid down in lakes formed when the northward-flowing streams were dammed by ice. Other theories to account for the presence of fine-grained waterlaid deposits in the abandoned valleys were advanced by M. R. Campbell (1902) and E. W. Shaw (1911).

The Teays Valley system was also described by G. F. Wright (1890). Wright traced the course of the main abandoned valley in West Virginia northwestward to the Ohio Valley at Huntington. Edward Orton (1874) noted the large abandoned valley in the vicinity of Waverly. He contrasted the insignificant size of the stream that presently occupies this channel with the much larger size of the river by which it must have been produced.

L. G. Westgate (1893) discussed the regional aspects of post-Paleozoic drainage. T. C. Chamberlin and Frank Leverett (1894) described the drainage features of the upper Ohio Basin. According to them the upper drainage of the present Ohio Basin was to the north in Tertiary time. Frank Leverett (1895) discovered the connection between the Teays system and the abandoned valley that diverges from the Ohio Valley at Wheelersburg about 10 miles east of Portsmouth. This valley is traced northward to the vicinity of Waverly, where Orton studied it.

W. G. Tight of Denison (Ohio) University did most to correlate and expound these early works on the preglacial drainage systems, and proposed the course now generally accepted for the Teays River in Ohio. Tight's report (1903) on drainage modifications in southeastern Ohio and adjacent parts of West Virginia and Kentucky has become the basis for most subsequent work on the preglacial drainage history of the Ohio Basin.

The most important detailed work on the preglacial drainage systems in Ohio was by Wilber Stout, formerly State Geologist of Ohio. Stout's major contribution to this study was prepared jointly with

Karl Ver Steeg and G. F. Lamb (1943). They worked out in great detail the pattern of the preglacial drainage lines, following in part that proposed by Tight for the lower course of the master stream of the Teays system from the vicinity of Chillicothe to the Indiana line. The course, as they have traced it, is directly through the area of the present report.

Beyond the western border of Ohio the lower course of the Teays Valley has been traced across Indiana and Illinois to the Mississippi embayment, chiefly by M. M. Fidlar, W. J. Wayne, and Leland Horberg. The most comprehensive of these works is by Horberg (1954) who discussed the drainage history of a large part of the Central Lowland province and presented a large-scale bedrock-contour map of Illinois.

DESCRIPTION OF THE AREA

GEOGRAPHY

The area of this investigation includes 1,332 square miles in west-central Ohio, divided about equally among Champaign, Clark, and Madison Counties (fig. 16). The population of the area, according ot the 1950 census, is 160,754. The largest city is Springfield, the county seat of Clark County, about 45 miles west of Columbus, the State Capital. Springfield is an important manufacturing center, with a population of 78,508.

Most of the rural area is under cultivation. The average size of the farms ranges from 102 acres in Clark County to 191 acres in Madison County. The principal crops are corn, wheat, and soybeans.

TOPOGRAPHY AND DRAINAGE

The area included in this investigation lies entirely within the Central Lowland physiographic province. The land is generally flat, except along the streams and in areas of glacial moraines. Wide stretches of upland occur between the streams, which flow in wide valleys having bottoms 60 to 200 feet below the crests of the adjacent uplands. The area slopes gradually and generally southeastward, away from the highlands that lie just north of Champaign County and which include the highest point (about 1,550 feet sea level) within the State. The highest point in the three-county area is about 1,225 feet above sea level, in western Champaign County, and the lowest is about 830 feet above sea level, in southeastern Madison County.

The Mad River and its tributaries drain most of the western part of the area, and the Scioto River and its tributaries drain most of the eastern part. All the streams flow generally southward and for

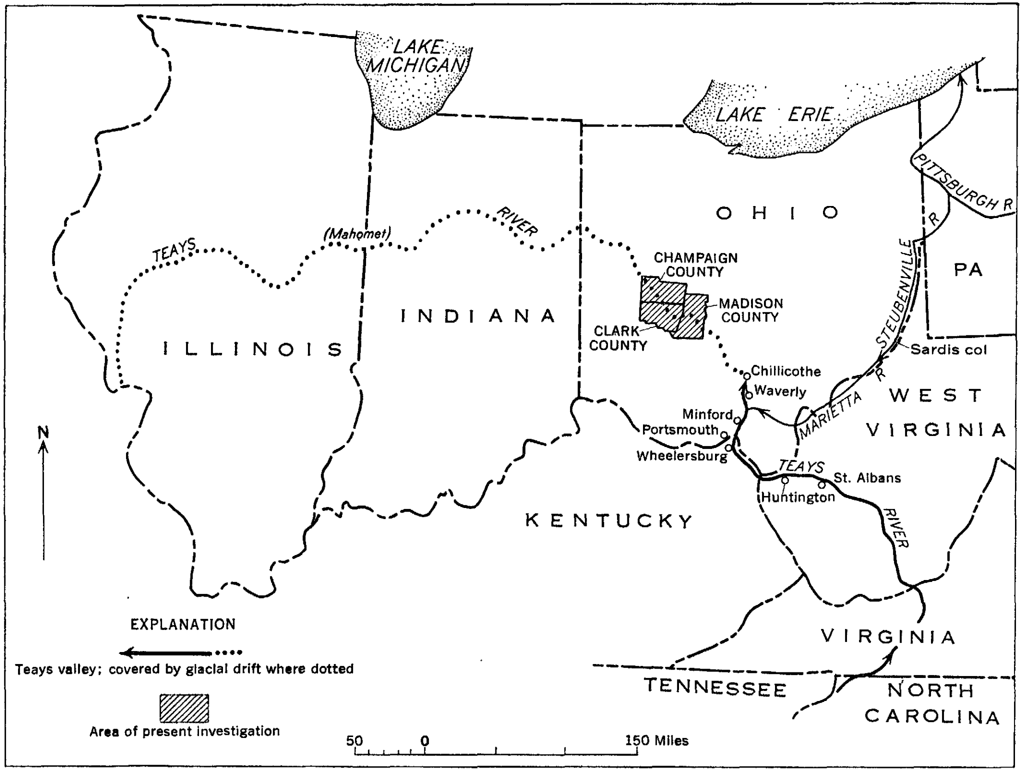

FIGURE 16.—Map of part of Eastern United States showing courses of principal preglacial rivers and area of this investigation.

the most part they occupy valleys abandoned by preglacial streams and filled to about their present levels by Pleistocene deposits.

STRUCTURE AND STRATIGRAPHY

The crest of the northward-plunging Cincinnati anticline follows a line that trends slightly east of north through the western edge of Clark and Champaign Counties. Most of the area of this investigation, therefore, lies on the eastern flank of the anticline near its crest. The dip of the strata is very slight but increases to the east. In Montgomery County, which borders the area on the west, the rocks are nearly horizontal. From the middle of Montgomery County to the eastern edge of Madison County, the dip averages about 13 feet per mile to the northeast (Norris, 1951, p. 15).

Sedimentary rocks of Ordovician, Silurian, and Devonian ages crop out beneath the glacial drift in west-central Ohio, the oldest rocks occurring along the crest of the Cincinnati anticline and in the deeper buried valleys, where the younger strata have been removed by erosion. Progressively younger rocks form the bedrock surface in the area down the dip on the eastern flank of the anticline.

Ordovician rocks crop out at the bedrock surface in southwestern Clark County and in buried valleys as far east as central Madison County. The bedrock in most of the remainder of the tri-county area consists of limestone and dolomite of Silurian age; in ascending order, these strata include beds of Clinton age and rocks of the Niagara and Cayuga groups. In the extreme eastern part of Madison County and in a small area in northern Champaign County the bedrock is the Columbus limestone of Middle Devonian age.

There is a great difference between the physical properties of the Ordovician rocks and those of the Silurian and Devonian rocks. The Silurian and Devonian rocks consist largely of fairly pure crystalline light-colored thick-bedded to massive limestone or dolomitic limestone, sufficiently resistant to form overhanging cliffs in areas where it and the Ordovician strata are exposed together. The Ordovician rocks consist of several hundred feet of soft, greenish-blue, calcareous shale, interbedded with thin hard layers of very fossiliferous argillaceous limestone. The limestone beds average 1 to 5 inches in thickness and, in places, make up 25 to 50 percent of the whole sequence.

The Ordovician rocks and the Silurian and Devonian rocks also differ in their water-bearing properties. The Silurian limestones generally are good sources of ground water for farm and home use and yield as much as 400 gallons a minute to wells in some places in Madison County. The Ordovician shales and shaly limestones, on the contrary, do not yield much water. The limestone layers are dense and relatively impermeable. The interbedded claylike shale is fine grained and also impermeable. Practically the only storage of water in the Ordovician rocks is near the surface where weathering has opened fracture or bedding planes. Because of the poor circulation any water found in the Ordovician rocks is likely to be mineralized, either sulfurous or salty.

BEDROCK SURFACE

Plate 8 is based on drillers' records of wells, the locations of bedrock exposures, and the records of the test holes drilled or referred to in this investigation. It shows the locations where these data were obtained, and contours on the bedrock surface in Champaign, Clark, and Madison Counties. The results of the earth-resistivity determinations at sites other than those confirmed by drilling have been used only as a general guide. Also shown on plate 8 are the logs of the test holes.

The contour map shows that the area prior to Pleistocene glaciation was relatively flat upland, deeply incised by broad steep-sided valleys. The altitude of the bedrock surface ranges generally from 900 to 1,000 feet in most of the area and reaches 1,100 feet in east-central Champaign County. According to Fenneman (1938, p. 431, 443, 501, 504) this surface represents a well-developed peneplain, correlative with that which appears on rocks of the Borden group in southern Indiana, on rocks of Pottsville age in southern Indiana, and in the Bluegrass district of Kentucky. This is the Lexington peneplain, which was uplifted in several stages, the last rise occurring in late Tertiary time, resulting in the deep trenching of valleys and the development of the Parker Strath, the name given the level of the abandoned Teays Valley and its principal tributaries in the Allegheny Plateau.

In southern Ohio the hills bordering the Teays Valley rise from 200 to 300 feet above the valley floor and maximum relief on the bedrock exceeds 600 feet. In west-central Ohio the buried Teays level is at least 400 feet lower than the general surface of the Lexington peneplain (pl. 8). Before its cycle was disrupted the Teays River flowed across this area in a series of gentle meanders, deeply entrenched between valley walls in places more than a mile apart. The topography of west-central Ohio must then have resembled parts of the present Highland Rim and Bluegrass sections, which are noted for meanders within rock walls (Fenneman, 1938, p. 445).

PLEISTOCENE DEPOSITS

The drift that lies at the surface in the area is of Pleistocene (Wisconsin) age. Two distinct drift sheets are distinguishable locally corresponding to early and late Wisconsin time (Goldthwait, 1950, p. 13). Separate ice advances in Wisconsin time are also indicated by widespread deposits of outwash gravels overlain by till (Goldthwait, 1948, p. 34; 1950, p. 18; 1952, p. 46). Drift of pre-Wisconsin age is not found at the surface in this area although older drift, presumably of Illinoian age, is exposed in southern Montgomery County, to the southwest (Goldthwait, 1948, p. 31).

The late Wisconsin glacier was split by highlands north of Champaign County into two great lobes that advanced southward down the Miami and Scioto valleys and spread outward to coalesce in the central part of the area of this investigation (Goldthwait, 1950, p. 14; 1952, p. 44). Most of the interlobate drift consists of end-moraine deposits that cover eastern Champaign and Clark Counties. Subsidiary deposits of similar origin, shaped like long, narrow crescents, extend from this central morainic mass into adjoining counties where they stand a few feet or a few tens of feet above the otherwise flat till plain.

When the glaciers retreated, melt waters were discharged down the valleys and partly filled them with sand and gravel outwash. The most extensive deposits underlie the broad lowlands of the Mad River valley and of its principal tributaries. Extensive outwash deposits occur also in the Scioto River valley and in other valleys. Less extensive outwash deposits, in the form of terrace deposits above the present drainage, occur in some areas.

In south-central Madison County, where most of the earth-resistivity measurements were made, the stratigraphic sequence of the unconsolidated deposits is relatively simple and generally uniform. In areas where the bedrock surface comprised former uplands or drainage divides, the glacial till that forms the ground moraine is about 100 to 200 feet thick, and generally rests on the bedrock. The till commonly is interbedded with, and in places is underlain by, sand and gravel deposits from which many rural wells derive small water supplies. In the areas underlain by the buried Teays Valley the uppermost unconsolidated deposits also consist chiefly of till, ranging to 200 feet or more in thickness, extending from the surface downward to a level somewhat below that of the former uplands. Below this level the buried valley generally contains thick and extensive deposits of clay, in places interbedded with, or underlain by, fine sand. This clay and the associated fine sand are assigned to the Minford silt, whose type locality is in the Teays Valley in the southern part of Ohio.

CORRELATION OF RESISTIVITY CURVES WITH LOCAL GEOLOGY

The electrical properties of the unconsolidated deposits in the buried Teays Valley, which make it possible to map the location of the buried channel, is the low resistivity of the clay that fills the lower part of the valley compared to the resistivity of the materials that generally make up the ground moraine and the resistivity of the limestone bedrock on the sides of the valley. Computed values for the clay range between 1,670 and 15,500 ohm cms; for the overlying till and gravel deposits the range is from 2,200 to about 69,000 ohm cms; and computed values obtained for the bedrock are also relatively high, ranging from about 13,600 to 41,000 ohm cms for the Silurian limestones and about 2,500 to 14,000 ohm cms for the Ordovician shales. A study of the soil resistivity reveals no obvious correlation with the position of the buried river channel. In Champaign County the soil resistivity ranges between 1,925 and 18,800 ohm cms, and in southern Madison County from 1,820 to 119,000 ohm cms.

The computed resistivity of the limestone bedrock in south-central Madison County ranges from 13,600 to 41,000 ohm cms at the several sites spaced across the buried valley over a distance of about 1½ miles. The highest computed values of resistivity were found where the depths to bedrock are shallow and the lowest values where the bedrock is deepest. This extreme variation in the computed resistivity of the limestones was not known until the test-drilling results were available, and it led previously to a misinterpretation of the materials at that site—those which formerly were thought to be sand and gravel desposits were found to be limestone having a resistivity of about equivalent value. Probably the lesser resistivity of the limestone in the deeper part of the buried valley is due to the presence of more solution channels than occur at shallower depths, where the limestone is less weathered and more dense, and consequently of higher resistivity. Such differential solution occurs in limestone in other regions in the unglaciated portion of the country—for example, in Kentucky, where a study by Hamilton (1948, p. 46) shows that the size and extent of solution openings in limestone depend upon the quantity of water involved and are, therefore, greater beneath the topographic lows.

The contrast in electrical properties between the unconsolidated materials in the buried valley and those that overlie former upland areas is illustrated by the representative resistivity curves shown on plate 7. Records made at the sites of test holes 8, 9, 10, and 11 are typical of areas where the bedrock is comparatively shallow, and records made at the sites of test holes 1, 3, 5, and 6 are typical of conditions in buried-valley areas. The differences between these two groups of curves are obvious and make the locating of the buried valley fairly easy in most places. Though it proved impossible to interpret accurately the depths to bedrock from the records at the deeper parts of the buried channel, the records did reveal the location of the channel. This is demonstrated by the records of the test holes, which were located on the basis of the resistivity determinations in the deepest parts of the channel, and in which minimum bedrock lows were reached. That minimum lows were indeed reached in these holes is shown both by the results of drilling across the valley at one place at closely spaced intervals and also by the fact that the gradient and the altitudes of the buried valley revealed by the test holes are in agreement with those established for the Teays Valley south of the glacial border.

The results of the resistivity measurements were anomalous in certain areas where the records did not seem to reflect accurately the underground geologic conditions or were difficult of interpretation. For example, the low resistivity of the bedrock in the deeper parts of the buried valley, which in places afforded no contrast to the overlying clay, led to the belief that the depth to bedrock was substantially greater in the channel than it was shown to be by the test holes. Also, because the resistivity of the Silurian limestones in the buried channel is less than the resistivity of the Ordovician shales, presumably because of the greater effects of solution in the limestone, it appeared also that the buried channel had a southward gradient. This led to a futile search for a theory to explain this apparent southward-flowing pre-Pleistocene drainage system and the whereabouts of the course of the Teays Valley after it left the Waverly area.

Anomalies were observed also at the sites of test holes 8, 10, and 11. At the site of test hole 8 the depth to bedrock was computed to be much less than it actually was because of the irregular layering in the upper beds of clay, sand, and gravel. Interpretations of the records obtained at the sites of test holes 10 and 11 revealed, with the accuracy expected, the depths to bedrock at these points but in each case the interpretations indicated the buried channel to lie to the south of its true position. Well records in the area did not make this a plausible interpretation, however, and indicated instead the probability that the buried channel was north of test-hole sites 10 and 11. On this basis the location of test hole 12 was chosen, in which the depth to bedrock was found to be within 6 feet of what it was computed to be in that vicinity on the basis of the known elevations of the buried channel and its gradient. And, finally, resistivity records obtained at two other sites about 3 miles east of test hole 12, in Pickaway and Franklin Counties (where all the geologic and drilling evidence indicate the channel to be) do not suggest its presence at all. Because in these particular areas the misinterpretations were critical with respect to the course of the buried valley the observers were misled into a fruitless search for the buried channel in surrounding areas. These additional determinations added considerable local detail to the bedrock contour map, which was helpful. However, inasmuch as they proved to be useless in solving the problem at hand, they reduced somewhat the difference in cost between resistivity prospecting and test drilling. However, resistivity prospecting remained much cheaper than drilling.

The reasons for these anomalous results are not known but they are probably caused by buried conductors or other manmade causes of interference that were not recognized in the field. This is now evident on the record obtained at the site of test hole 11 (pl. 7) for the lack of correlation is now known to have been caused by a distortion of the record, which in turn had been caused by a grounded metal fence. Such experiences demonstrate that resistivity interpretations should be correlated with drilling information and geologic data to obtain best results from the electrical method.

TEAYS DRAINAGE CYCLE

TEAYS VALLEY SYSTEM

South of the glacial border, best developed in West Virginia, are abandoned valleys that bear little or no relation to much of the present drainage. As described by Tight (1903, p. 48)—

> These valleys are the remnants of a very mature drainage system. In general, they are cut to depths of about 150 to 250 feet below the level of the uplands and, in places, are as much as 150 feet above the present streams.

The floors of these ancient valley remnants are very flat and well graded. When correlated they form a dendritic system, with accordant tributaries, obviously produced as the result of normal stream erosion, probably in pre-Pleistocene time. The valley system was abandoned, according to generally accepted theory, when the drainage was deflected by one or more of the glacial advances, which forced the streams into new courses.

The principal valley of the abandoned drainage system is called the Teays, named from a deserted valley segment near St. Albans, W. Va. The ancestoral Teays River, according to Tight (1903, p. 26) came into existence near the close of Tertiary time with the elevation of an extensive peneplain. The Teays River originated east of the Blue Ridge escarpment in the Piedmont Plateau of Virginia and North Carolina and, in its upper reaches, the river and its tributaries flowed in the courses now occupied by streams of the present Kanawha River system. The Teays River departed from the course of the Kanawha River below St. Albans and from there to the Ohio Valley at Huntington it flowed in the wide abandoned valley that gives the system its name. From Huntington to Wheelersburg, about 10 miles south of Portsmouth, the course of the old Teays River generally was the same as that of the present Ohio River, as revealed by high-level terraces and abandoned valley remnants. From Wheelersburg the course of the Teays River, according to Tight (1903, p. 57), was northward through a broad abandoned valley to Waverly. This valley, which roughly parallels the course of the present Scioto Valley, averages about 1½ miles in width, has a flat floor and steep sides, and is cut about 200 to 300 feet below the general level of the uplands. It is correlated with that part of the Teays Valley above Wheelersburg on the basis of its gradient and the deposits found in it (Tight, 1903, p. 58; Stout, Ver Steeg, and Lamb, 1943, p. 64–65). The gradient of the Teays Valley floor is about 9 inches per mile between St. Albans and Waverly. At St. Albans the altitude is about 675 feet sea level; at Waverly the valley floor is about 600 feet above sea level.

The course of the Teays River beyond Waverly was for a long time a matter of conjecture. According to Tight (1903, p. 75), the route northward as far as the vicinity of Chillicothe was evident from the slope of the valley floor. Near Chillicothe the abandoned valley passes into the glaciated part of the State and lies under the mantel of glacial drift. Tight (1894), p. 62, pl. V; 1897, p. 30) assumed that the Teays River flowed northward from Chillicothe to a point in central Pickaway County where he thought it joined with large tributaries and continued in a northwesterly direction through and beyond Madison, Clark, and Champaign Counties to the Indiana line in Mercer County. Leverett (1897, p. 21) suggested three other possibilities for the course of the Teays below Waverly in addition to the one proposed by Tight. Leverett's alternate possibilities for the lower course of the Teays were:

1. Southward down the Scioto from Waverly to the Ohio and thence down the Ohio.
2. Northward along the axis of the Ohio Basin to Lake Erie.
3. Northeastward past the Licking Reservoir and along the old valley (brought to notice by Prof. Tight in a former bulletin[1]) to the Muskingum at Dresden, thence northward along or near the present valleys of the Muskingum, Tuscarawas, and Cuyahoga to Lake Erie at Cleveland.

At the time of the work of Tight and Leverett few drilling records were available to furnish clues as to which, if any, of the possibilities cited above was correct.

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[1] Tight, 1894, p. 35.

Stout, Ver Steeg, and Lamb (1943, p. 53), on the basis of well records, agreed with Tight on the course of the Teays River beyond Chillicothe and traced its buried valley northwestward through and beyond Pickaway, Fayette, Madison, Clark, and Champaign Counties to the Indiana line in Mercer County. They gave the altitudes of the valley floor as 590 feet at Chillicothe; 572 feet near Atlanta, Pickaway County; 530 feet near London, Madison County; and 460 feet under the St. Marys Reservoir in Mercer County.

Beyond the Ohio line the course of the buried Teays Valley, as shown in figure 16, has been traced westward across northern Indiana and central Illinois into the Gulf embayment by way of the Mississippi Valley (Horberg, 1950, p. 67). The elevation of the valley in Indiana ranges from 463 feet above sea level in Jay County (Fidlar, 1943, p. 416), to 300 feet above sea level in Benton County (Leverett, 1895, p. 757). In Illinois, rock elevations along the valley, according to Horberg (1950, p. 68) "are less than 400 feet above sea level, or 200 to 300 feet below adjoining bedrock uplands." Horberg estimated the gradient of the valley floor to be 1.65 inches per mile over part of its course in Illinois and he states that the width of the buried channel ranges from 4 or 5 miles to about 15 miles.

MINFORD SILT AND THE CLOSING OF THE CYCLE

South of the glacial boundary over a wide area the Teays Valley and its tributaries contain extensive deposits of finely laminated clay, known as the Minford silt, named from exposures in Scioto County, where the deposits are described by Stout and Schaaf (1931, p. 667, 668), as follows:

> These silts are always highly laminated, the laminae being closely and regularly spaced. When moist the material will peel easily and smoothly along these planes. These silts are made up of very fine-grained particles. When soaked in water the mass readily breaks down to a thin slip. Further, on agitation, the particles are so fine that they may stay suspended for days. Very little coarse material is present and this is largely secondary in origin, such as gypsum crystals and small ferruginous concretions. In the semi-moist condition the material is tough and leathery in consistency. It parts readily along the laminations but tears stubbornly when broken across the bedding. When dry it is as hard and firm as some of the older shales. Rubbed with a cloth or with the hand, the surface of the material takes on a smooth, glossy polish. Upon the addition of the proper amount of water these silts have a very high plasticity as measured by most of the standard methods for determining that property. The plasticity, however, is somewhat false in that it is of the soapy, greasy kind instead of the sticky type. The feel of the material, either wet or dry, is soft and smooth like that of finely divided muscovite. For ease of identification and because of the excellent exposure in the cut of the Chesapeake & Ohio Railway at Minford in Harrison Township, Scioto County, this particular silt is here named Minford * * * Through inspection of Minford

silts by simple means, some information may be obtained regarding their mineral content and their general composition. They appear to contain little free silica, practically all of the silica being combined with other components to form complex silicates. No grit is evident when the silt is tested between the teeth or by other common methods. The fineness of grain, shown by the smoothness of the silt, by the ease with which it takes a polish and by the extended time of its suspension in water, shows that the minerals are of only such kinds as may readily be reduced by natural means to a high state of division. The soapy, greasy, plasticity of the material when wet is more suggestive of the properties of finely divided micas than of the real stickiness of the truly plastic bodies such as ball clay. Its marked absorptive properties indicate a large surface area per unit volume of material. These characteristics alone are sufficient to separate these silts from the common alluviums, shales, and varve clays.

The maximum thickness of Minford silt in southern Ohio is more than 80 feet. The highest altitude at which it has been reported is at least 860 feet (Fenneman, 1938, p. 304). The material commonly rests on fine sand or sandy silt which generally overlies the bedrock and which may represent part of the original stream alluvium. According to W. N. Lockwood,[2] the basal sand ranges in thickness from 0 to 6 feet in the Teays Valley in the Stockdale-Minford area in Scioto County, above the junction of the Marietta Valley. The basal sand is slightly thicker in the Teays Valley below the mouth of the Marietta River, according to Lockwood, and it is nearly 40 feet thick in the Marietta Valley about a mile above its mouth. The Marietta River was an important Teays tributary which flowed generally westward from near Marietta, Ohio, to a junction with the Teays in Pike County (see fig. 16). The significant point is that in many places the Minford rests directly on the bedrock surface which, prior to the deposition, must have been swept partially clean of coarser materials and stream alluvium.

The origin of the Minford silt and the reasons why the Teays Valley and other valleys were abandoned, are conjectural. Three hypotheses have been advanced. As reported by Fenneman (1938, p. 302–303), they are:

1. Complete obstruction of northward drainage by ice, which ponded the waters, in which sediments then accumulated to the necessary height.
2. Local dams of ice, which held back the streams and caused the necessary deposition on their upstream sides (Campbell, M. R., 1902).
3. Over-loading of streams which flowed from the ice, causing aggradation, not only of their own valleys but of north-flowing streams with which they united (Shaw, E. W., 1911). Any one of these three conditions might result in the filling of valleys to a level above that of local divides and the adoption of a new course.

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[2] "Progress report on subsurface study of the Teays River Valley sediments in Pike, Jackson, and Scioto Counties." Unpublished manuscript in the files of the Ohio Division of Water, Department of Natural Resources, Columbus, Ohio, October 1, 1954.

The first of these hypotheses, according to Fenneman, was advanced by I. C. White (1896, p. 368–379) to explain the origin of terrace deposits along the Monongahela River, but credit for the major development of this concept must go to Wilber Stout (Stout and Lamb, 1938, p. 69, 70) who described the effects of ponding of the Teays Valley system by an early glacier:

> The Teays River, however, was completely dammed in its lower course, with the result of flooding in the main valley and in those of all the larger tributaries. This was especially true of the streams in southern Ohio. Such valleys became long finger lakes. It was during this time that the Minford silts were deposited from the fine materials long held in suspension and carried into the basin from head-water areas, some far out into the Piedmont Plateau. Such silts in southern Ohio are found at elevations as high as 840 feet and are thus plastered well up on the valley walls of these old streams the relief of which was from 250 to 300 feet, the usual position below the Lexington peneplain. Eventually through continued ponding the waters broke over low divides or cols and soon established a new system of drainage bearing little resemblance in direction or pattern to the older Teays system. This second cycle of drainage is known as the Deep Stage on account of the depth of cutting of the valleys.

According to Fenneman (1938, p. 303, 304), evidence to support Stout's hypothesis in southern Ohio is strong. He says that remnants of clay have been found as high as 860 feet, and all requirements of superposition of drainage would be met by filling to a level somewhat below 900 feet. On the other hand, Fenneman states that evidence of important lacustrine deposits is weak in the Monongahela basin, for which the hypothesis was first put forward.

The second hypothesis, that of ice dams originating as jams in the larger streams, is not probable, according to Fenneman, except in the Monongahela Valley for which it was proposed. Aggradation by overloaded streams fed by the ice is the third hypothesis advanced to account for the deposition of fine-grained sediments in valleys cut in pre-Pleistocene time and for the abandonment of former drainage courses in the Pleistocene. Though Fenneman is inclined to doubt this last hypothesis as applied to the Teays Valley in southern Ohio (because it does not explain the features) he says it explains fairly well the conditions in the abandoned valleys along the Allegheny River and its tributaries.

Evidence revealed by the present investigation indicates that the Minford silt originated chiefly as lacustrine deposits in the manner described by Stout. Coarser deposits, associated with the clay in some areas, probably were contributed as outwash by glacier-fed streams.

TEAYS VALLEY AND THE MINFORD SILT IN AREA OF INVESTIGATION

GRADIENT AND CONFIGURATION OF CHANNEL

On the basis of the depths to bedrock reached in test holes 1, 3, and 6 (pl. 8) in Madison and Champaign Counties on sites where the earth-resistivity determinations indicated the deepest part of the buried channel to lie, and the depth to bedrock at the site of test hole 2 in Clark County, it is computed that the Teays Valley declines in altitude from 568 feet in south-central Madison County to 556 feet near London, in the western part of Madison County, to 548 feet east of Springfield in Clark County, and to 538 feet in southern Champaign County. The gradient of the channel is 13.4 inches per mile between test holes 3 and 6, 6 inches per mile between test holes 2 and 3, and 13.3 inches per mile between test holes 1 and 2. The overall gradient is 10.3 inches per mile over the total channel distance of about 35 miles between test holes 1 and 6. Probably the gradient does not change appreciably over the total distance, even though such a change is indicated by the depths to bedrock reached in some of the intermediate test holes. This apparent variation in gradient may be due to failure to locate the deepest part of the channel in all places. The overall gradient of about 10 inches per mile between test holes 1 and 6 agrees approximately with the known gradient of the Teays Valley of 9 inches per mile south of the glacial boundary and a postulated gradient of 1 foot per mile in the glaciated area of Ohio between Ross County and the St. Marys Reservoir in Mercer County, a distance of 133 miles (Stout, Ver Steeg, and Lamb, 1943, p. 53). This general agreement between the gradient of the Teays Valley, determined from the test holes in west-central Ohio and its gradient south of the glacial border, furnishes additional evidence for the validity of earth-resistivity methods in locating the buried channel.

The configuration of the Teays Valley is revealed by the records of 5 closely spaced test holes (4–8) in south-central Madison County, alined transverse to the axis of the buried valley. The gorgelike shape of the valley is revealed by these test holes. On the southwest side the valley wall descends more than 200 feet in a lateral distance of about 1,800 feet; on the opposite side the valley wall is nearly as steep. At the former stream level the valley in the area of test holes 4–8 is about 3,000 feet wide. The shape of the valley here was predicted from the resistivity data before the drilling was done. If the terrain and metal farm fences had permitted closely spaced depth profiles, the resistivity methods probably would have been able to determine the valley configuration.

The narrow, gorgelike character of the Teays Valley in south-central Madison County, compared to its much greater width just south of the glacial border, is to be expected from the character of the rocks through which the stream flowed. The erosional resistance of the Silurian limestones, in which the gorge is developed in west-central Ohio, is very much greater than that of the Mississippian shales and sandstones in which the stream developed its valley in southern Ohio, to a width ranging from 1 to 2 miles and averaging 1.45 miles (Stout, Ver Steeg, and Lamb, 1943, p. 53).

Somewhere between the line of test holes drilled across the buried valley in south-central Madison County and the site of test hole 3, near London, the former stream left the area of Silurian rocks and flowed onto the somewhat less resistant Ordovician shales. Probably this resulted in some undercutting of the valley walls, resulting in the widening of the valley downstream. Resistivity determinations made at close intervals at the sites of test holes 1 and 3 indicate the width of the valley to be about 3,500 feet near London in western Madison County, and nearly 4,000 feet in southern Champaign County. The valley is substantially wider both several miles above and a like distance below the transverse line of test holes in south-central Madison County, therefore the width of about 3,000 feet determined for the valley at the latter location may be the minimum in its lower reaches.

CHARACTER AND PROBABLE ORIGIN OF MINFORD SILT

Clays similar to those in the Minford silt at the type locality in southern Ohio are the principal deposits in the area of this investigation and occur extensively in the buried Teays Valley in association with scattered deposits of fine-grained sand. These clays and the associated fine-grained sand are assigned to the Minford silt. As shown by the test-hole records on plate 8, practically all the unconsolidated material found below the level of the ground moraine at the sites tested consists of clay. This clay is dull blue gray to brown, soft, and highly plastic. It so closely resembles the Minford at its type locality that it was indistinguishable from it. The clay is 264 feet thick at the London Prison Farm, where test hole 3 was drilled; at two other test-hole sites it is more than 200 feet thick. The median thickness of the clay in the 12 test holes is 100 feet, with a minimum thickness of only 18 feet in hole 4 in south-central Madison County. In 8 of the test holes the clay was found to overlie the bedrock directly, which locally in southern Ohio also is true of the Minford.

Samples of clay from several of the test holes were examined by John B. Droste, Geology Department, University of Illinois. He reported (written communication, 1954) that the clay minerals in selected samples from three of the holes consist of well-crystallized illite and chlorite, the composition being similar to that which he determined in the clay from the Minford at the type locality. Selected samples from three other test holes, according to Droste, contained some montmorillonite in addition to the illite and chlorite, and a sample from still another test hole contained illite and hydrated chlorite, tending toward vermiculite. Two of the samples containing the montmorillonite were taken near the bedrock floor of the buried valley. The possibility should not be discounted that the montmorillonite fraction may have come from the bentonite used in the drilling mud, which may have contaminated the samples. All samples, said Droste, contained quartz.

It is reported by Grim (1953, p. 355) that—

> In 26 sediments of lagoonal origin, illite was found to be the dominant clay mineral in 19, montmorillonite in 4, and attapulgite-sepiolite in 3. Chloritic mica and vermiculite were frequent minor clay-mineral components.

Grim points out also that in sediments of lacustrine origin, as distinct from those formed under lagoonal conditions—

> Where the lake is believed to have contained "aggressive" water, i. e., where there was actual leaching of alkalies and alkaline earths in the accumulating sediments because of active movement of water through them, or because of relatively low pH of the water, the dominant clay mineral is kaolinite. In such sediments the total content of illite, chloritic mica, and montmorillonite ranged from 0 to 30 percent.

Further, according to Grim—

> In sediments of lacustrine origin of the "nonaggressive" type, where salts and carbonate are likely to accumulate because of slight movement of water through the lake and/or relatively alkaline water, the dominant clay-mineral components are illite, montmorillonite, and sepiolite-attapulgite.

Droste's analyses of samples of clay from the test holes and samples of clay from the Minford from southern Ohio, which show illite to be the dominant clay mineral in each, and Grim's account of the formation of illite and other minerals in "nonaggressive" lake waters, are additional evidence to support Stout and Schaaf's conception of how the Minford silt must have been laid down in the quiet waters of a lake. Stout and Schaaf (1931, p. 669) describe the deposition thus:

> The Minford silts are distributed throughout all the large valleys and well towards the headwaters of the smaller tributaries; they spread entirely across the valleys with no breaks from stream action; they exhibit no marks of strong currents * * * they are present in such volume as to have required considerable time for deposition * * * The waters had slight motion and stood well towards the rims of the basins.

A similarity in time of origin between the clay deposits found in the test holes and clays in the Minford in southern Ohio is suggested not only by similarities in their appearance, general agreement in their clay-mineral composition, and their presence within the same valley system, but also by the close agreement of the maximum altitudes at which the respective deposits are found. The upper surface of the clay in the area of this investigation ranges in altitude from 691 feet at the sites of test-holes 9–11 in southeastern Madison County to a maximum of 850 feet in test hole 8 in south-central Madison County. Continuing northward, the top of the clay was found at altitude 820 in test-hole 3 at the London Prison Farm, at altitude 832 at test hole 2 in Clark County, and at altitude 788 in test-hole 1 in southern Champaign County. The maximum altitude, 850 feet, at which the clay was found in the test holes agrees very closely with the highest altitude, 860 feet, at which the Minford silt has been reported in southern Ohio.

The record of a well drilled for gas at St. Paris in western Champaign County in 1887 reveals the presence there of perhaps as much as 40 feet of clay underlying the ground moraine at a depth of 360 feet and whose upper surface lies at about 865 feet. From the description of this clay it appears similar to that found in the present investigation. Orton (1888, p. 277) describes the clay found in the well at St. Paris, together with deposits associated with it, as follows:

> At 360 feet a tough, brown clay, that burned terra cotta red, was found. At 400 feet a genuine surprise was encountered by the driller. Gravel, containing large pieces of wood and bark, and also fragments of mussel-shells, was struck at this depth. The shells were scattered and no scientific examination was made of them, but the fragments of wood seemed to be the red cedar that generally occurs in our forest soils. At 405 feet the well filled up 150 feet with quicksand.

The well was drilled to the depth of 530 feet before it was abandoned in favor of a new location, and no detailed record remains to describe the deposits below 405 feet except for the information that bedrock was not reached. The site of the well at St. Paris (see pl. 8), is about 2 miles west of the course postualted for the main Teays Valley, and apparently is over a tributary valley formed by a short northward-flowing preglacial stream. The clay found in this well may be correlative with the clay deposits found in the test holes drilled during the present investigation. Aside from the record of the well at St. Paris, it seems evident that the Minford silt in southern Ohio and the buried clay in the Teays Valley system in west-central Ohio represent but various portions of essentially one vast deposit that extended well to the north of the glacial boundary.

The difference most readily discernible between the occurrence of the clay at Minford and its occurrence in the area of this investigation seems to be its association in the latter place with deposits of fine-grained sand, of considerably greater thickness than the basal sand in southern Ohio. As in southern Ohio, the coarser material generally occurs beneath the clay, separating it from the bedrock, although at two places fine-grained sand also occurs at or near the top of the clay, directly beneath the ground moraine. In test-holes 9, 7, 5, and 2 the clay was separated from the bedrock surface by 5, 25, 42, and 147 feet, respectively, of fine-grained sand. In test hole 5 the sand was underlain by 4 feet of poorly sorted material which may be the original stream alluvium. In the other three holes the sand directly overlies the bedrock. Forty feet of sand was found above the clay in test-hole 7 in south-central Madison County, with the top of the sand deposit at an altitude of 856 feet. At London a considerable quantity of fine-grained sand and silt was pumped during development of a water well 3 miles southeast of test hole 3 at the edge of the buried Teays Valley. The well is about 170 feet deep and apparently the fine-grained sand and silt overlie the bedrock at the approximate elevation of 870 feet. The sand deposits penetrated in test-hole 7 and in the water well at London may be associated with the underlying clay or with the overlying ground moraine. If with the clay, it represents the highest level at which these particular water-laid sediments have been reported in this area.

Samples taken from the test holes and from the water well at London show the sand deposits to be generally uniform in appearance and mineral composition. The grains mostly range in size between about 0.125 mm and 0.25 mm; they are ragged looking and few of them are well rounded or frosted. Samples of the sand were examined microscopically by Duncan McConnell who said it was made up mostly of quartz with lesser amounts of feldspar and other minerals that commonly result from the disintegration of igneous and metamorphic rocks, chiefly granitic types, mixed with fragments of calcareous and arenaceous rocks. This heterogeneity and the generally fresh and unweathered appearance of most of the grains indicate that the sand is glacial outwash. The present scattered evidence indicates that the basal sand becomes generally thinner in a southerly direction, decreasing from a thickness of 147 feet at the site of test-hole 2 in Clark County to a thickness of 5 feet in test-hole 9 in southeastern Madison County. However, thinning is not uniform—the sand was absent in some of the intervening test holes and, more important, it is absent at the site of test-hole 1 in Champaign County, the northernmost hole drilled in the present investigation. Probably these local variations in thickness are not significant with respect to the direction of source of the sand deposits.

It is significant that fine sand similar to that found in test-holes 5 and 7 (which are about 3,000 feet apart) was not found in test-hole 6, which is about midway between holes 5 and 7; nor was fine sand found in test-holes 4 and 8, which are on opposite sides of holes 5 and 7, roughly 1,800 feet and 2,700 feet away, respectively. The presence of sand in but 2 alternate holes in a line of 5 that were drilled across the buried valley, and its absence in 8 of the 12 test holes drilled in the area of this investigation, indicate a general lack in continuity of these coarser deposits.

If the sand deposits are related in their time of origin to the more extensive body of clay that constitutes most of the fill in the buried Teays Valley, possibly these coarser materials were scattered delta deposits by sediment-laden streams flowing from the ice front, discharging into the ponded Teays Valley at various places.

It seems more probable that the sand deposits represent local variations in the load carried by the sediment-laden waters at the beginning and near the end of the aggrading cycle. The materials that make up the deposits probably originated as glacial outwash. Their general uniformity and extreme fineness of grain size indicate that they were laid down at a relatively great distance from the ice front. Perhaps they were carried into the ponded basin by glacier-fed streams and, commingling with the even finer and more extensive sediments from distant headwaters areas, were brought to their present places and concentrated at random by the vagaries of the currents in the former lake. However varied their origin, the lacustrine deposits in the Teays Valley generally lie directly on the bedrock, which somehow must have been swept clean of most of its normal accumulation of stream alluvium. Perhaps this erosion occurred just before the ice dammed the Teays at a time when its waters were reinforced by drainage diverted from another major north-flowing stream, the Pittsburgh River, whose course would have had to be blocked slightly earlier.

The Pittsburgh River, according to Stout, Ver Steeg, and Lamb (1943, p. 73–74), flowed from the vicinity of Pittsburgh northwestward and northward toward Lake Erie. The main western tributary of the Pittsburgh River, which the above authors named the Steubenville River, was separated from the Marietta River, an important Teays tributary, by a col at Sardis in the Ohio Valley (see fig. 16). The advance of an early glacier blocked the Pittsburgh River before the ice dammed the Teays. This resulted, Stout, Ver Steeg, and Lamb say (1943, p. 84), in the reduction of the divide at Sardis, cut by the overflow of waters from the ponded Pittsburgh basin, and the "pouring of the flood on southwestward into the less elevated basin of the Marietta River, a tributary of the Teays." There must have been a relatively short span of time, therefore, during the advance of the glacier when the Teays basin furnished the major outlet for the drainage from a vast area. During this stage of greatly increased flow the Teays River might be expected to have swept its channel clean of alluvium.

If, as the evidence shows, the Teays and the Pittsburgh Rivers were dammed by a glacial advance that failed to reach the area of west-central Ohio, the advance must have been pre-Illinoian in age, for both the Illinoian and the Wisconsin glaciers advanced well beyond the area of the present investigation. The antiquity of this early glacier is shown also, according to Stout (1953, p. 184), by the length of time required to produce features of post-Teays or Deep Stage drainage. Stout says—

> Thus a great new valley from Pitsburgh to Cincinnati, at least, was excavated not only deep but wide through the resistant rocks. Some 50 to 60 percent of what is now the Ohio Valley was cut during the Deep Stage time, hence of long duration.

And on page 186, Stout (1953) says further—

> * * * the Deep Stage Pomeroy-Cincinnati River was cut over 300 miles in length far below the levels of the older Teays Stage streams, and on an average over one mile wide. In places the degradation of the course had little or no help from earlier streams * * * the cutting was done through all kinds of rocks such as shales, sandstones, limestones, clays, and coals, many hard, massive, and resistant. Under any consideration the time required was long, measured at least in hundreds of thousands of years, if not in millions.

Assuming the Teays River to have been dammed in its lower reaches by an early glacier, it is interesting to conjecture, and would be important to know, where this occurred. For that would mark the limit of the lacustrine deposits in the buried Teays Valley, beyond which point the valley fill would be composed chiefly of glacial drift, possibly permeable outwash sands and gravels. Stout says (1953, p. 184)—

> From the effects on the old Teays streams in central and western Ohio this glacier evidently passed on westward across Ohio and on into Indiana, and probably to the Mississippi Valley. This glacier definitely closed the Pittsburgh River near New Castle, Pennsylvania, and most assuredly the Teays River somewhere in western Ohio.

Statements by Flint (1947, p. 277–284) and a study of two maps which he has compiled to show pre-Pleistocene lines of drainage and the margin of the Kansan drift sheet (p. 165, 281), coupled with the evidence revealed by the present investigation indicate that the Teays may have been dammed much farther downstream than suggested by Stout, possibly somewhere in the area southwest of Ft. Wayne, Ind. This hypothesis would require considerable—and it seems more reasonable—alteration of the previously conjectured shape of the Illinois lobe of the pre-Illinoian ice advances. Wherever the damming was, it must not have occurred in Illinois, where the basal deposits in the buried Mahomet Valley (the downstream continuation of the Teays) are said by Horberg (1953, p. 12, 18, 40) to consist of sand and gravel of glacial origin. According to Horberg the sand of the Mahomet Valley may be extensive in Illinois and may extend eastward into Indiana.

CONCLUSIONS

The northwesterly course of the pre-Pleistocene Teays River in Ohio, as it was postulated by Tight and Stout, and the events in the Pleistocene epoch by which the valley was dammed and lacustrine deposits were laid down in the ponded basin prior to the Illinoian stage, all graphically described by Stout, seem to be affirmed by the results of the present investigation. The altitudes and gradient of the buried valley in Madison, Clark, and Champaign Counties agree well with the assumed elevations and gradient of the Teays Valley based on the projection northward into this area of the slope of its abandoned course south of the glacial boundary. Further evidence that the buried valley in the area of this investigation is the northward continuation of the abandoned Teays Valley is found in the similarity of the deposits that rest on the bedrock floor in both areas, which shows that these separated segments were subjected to the same sequence of events during at least one stage in their history. The fine-grained lacustrine deposits, which attain a thickness of more than 250 feet at the London Prison Farm, were laid down in finger lakes produced, probably as Stout says, by the damming of the Teays River by a pre-Illinoian glacier. The presence of these lake clays beneath the glacial drift shows that the depositional stage took place prior to the advance of the Illinoian glacier, the first ice sheet known to have reached the central Ohio area. The association of the clays with considerable deposits of fine-grained sand, whose character suggests they may be glacial outwash materials, may indicate a northern origin for part of the sediments that may have found passage into the ponded Teays Valley from the Pittsburgh Basin through the col at Sardis, or were contributed by streams flowing southward directly from the ice front where it dammed the Teays Valley.

The chronology of events in the area of this investigation seem, on the basis of the present evidence, to be about as follows:

1. In pre-Pleistocene time the northerly flowing Teays River cut its channel to depths of more than 400 feet below the level of the adjacent uplands. The Teays River entered Madison County from the southeast and flowed northwestward to the area of the London Prison Farm, where it turned westward into Clark County. The stream flowed across the northeastern corner of Clark County to the vicinity of Urbana in southern Champaign County. The course of the Teays was northwestward beyond Urbana, crossing the western border of Champaign County near its northern end.
2. The Teays drainage cycle was brought to a close in early Pleistocene time by a pre-Illinoian glacier, which in the course of its advance first dammed the northward-flowing Pittsburgh River, and later the Teays. During the interval between the damming of the Pittsburgh River and the damming of the Teays the water that was ponded in the Pittsburgh Basin overflowed a divide at Sardis in the headwaters area and drained into the Teays Basin, thus greatly augmenting the flow in the Teays River. This increased flow resulted in the removal of much of the then-existing floodplain deposits in the Teays Valley.
3. Widespread ponding was produced in the Teays Valley and its tributaries, in which the water stood at least as high as the 860-foot contour, when the continued advance of the early glacier had carried the ice front southward sufficiently far for it to dam the Teays River. That the ice did not reach the area of this investigation is shown by the absence from the floor of the buried Teays Valley of ice-laid deposits and of typically coarse outwash deposits.
4. Thick and extensive deposits of clay, with lesser amounts of fine sand, were laid down in the flooded valleys, the coarser sediments originating mainly as outwash from the distant ice sheet, commingling with the finer-grained materials carried into the ponded basin chiefly by headwaters streams.
5. The lake stage was ended when the streams found new outlets and the drainage had become reestablished on different lines. After the end of the lake stage it is probable that some of the lacustrine deposits were removed by the erosion of streams of the new drainage system.
6. The area was occupied by both the Illinoian and the Wisconsin glaciers. The first of these probably scoured and removed considerable of the lake sediments. This was followed by the deposition in both the Illinoian and the Wisconsin of the materials, mostly unstratified, that make up the present ground moraine.

This investigation illustrates the value of earth-resistivity methods in locating valleys buried beneath glacial drift in a limestone region and in tracing their courses before test drilling.

The generally favorable picture of the results achieved by the electrical method in locating the buried Teays Valley was marred by the results of a few determinations that were made at sites where the apparent-resistivity curves, because of undetected interference, did not correctly reveal the buried relief. This is not astonishing because the area is crisscrossed with metal fences, buried conductors, grounded power lines, and other potential sources of interference. The very great care exercised by the operators in choosing sites and making the electrical measurements undoubtedly prevented even greater errors in the measurements. The results show the need for caution in applying the results of the method and for correlative drilling records to interpret the electrical data properly.

The main purpose of the investigation, of which this paper is an outgrowth, was to provide data on the character of the unconsolidated deposits and the depth to bedrock in the area. Questions relating to the availability and magnitude of ground-water supplies in areas underlain by the more deeply buried valleys required an answer. It was important to know something of the nature and extent of the unconsolidated deposits that comprise the bulk of the valley fill beneath the level of the ground moraine, and whether these deposits generally are important sources of water. The present evidence shows that they are not. The extensive lacustrine clays and the sand deposits in the buried Teays-stage valleys in this area are at best poor sources of ground water, even for domestic or farm use. The clay is relatively impermeable and the sand deposits are so fine grained as to preclude ordinary well development. Over most of the area the lacustrine deposits overlie Ordovician shales that also are poor sources of water. The information on ground-water conditions revealed by this investigation should reduce future economic losses caused by drilling in unfavorable buried-valley areas. One result would seem to be greater efforts to obtain water at shallow depths from the glacial deposits in those areas, or even in the substitution of cisterns for wells where necessary, rather than to incur the risk of failure in deep drilling.

This investigation shows the need for additional prospecting in the buried Teays Valley. Somewhere downstream from Urbana the lower course of the Teays River was dammed by an early glacier. In that area the lacustrine clays and sands can be expected to give way to glacial deposits that probably include buried outwash sands and gravels that would be productive of ground water. This possibility should be thoroughly explored in the hope of discovering additional ground-water supplies in the State. The advantages of earth-resistivity depth profiling, in combination with test drilling, so strikingly demonstrated in the present investigation, could be used in a similar way to define ground-water conditions in the remainder of the buried Teays Valley in Ohio.

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