Geology of the Upper East Fork Drainage Basin, Indiana

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DEPARTMENT OF NATURAL RESOURCES
GEOLOGICAL SURVEY SPECIAL REPORT 3

PRINTED BY AUTHORITY OF THE STATE OF INDIANA
BLOOMINGTON, INDIANA: 1966

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GEOLOGY OF THE UPPER EAST FORK DRAINAGE BASIN, INDIANA

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ABSTRACT

Basic geologic information is essential to planning flood-control measures in the Upper East Fork Drainage Basin, an area of about 2,300 square miles in east-central Indiana. Principal streams of the basin include the Driftwood, Big Blue, Little Blue, and Flatrock Rivers; Sugar, Clifty, and Sand Creeks; and the upper part of the East Fork of White River, from Columbus downstream to the south line of Bartholomew County. Shelbyville is nearly centrally located within the basin.

The present drainage system of the Upper East Fork basin is dominated by a pattern of southwestward-flowing streams. Many of these streams follow inherited valleys that were used by glacial meltwaters during the Wisconsin Age of the Pleistocene Epoch. Preglacial streams, however, flowed in a more westerly direction, generally following the regional slope of the bedrock surface. Although the dip of the bedrock formations is somewhat steeper than the slope of the bedrock surface, the close correspondence in direction between the two clearly indicates that the regional slope is structurally controlled.

Almost all the Upper East Fork Drainage Basin is blanketed by unconsolidated deposits of Pleistocene age, which in the southern part of the basin are thin but which thicken northward to more than 300 feet. The most extensive surficial deposit is till of the Trafalgar Formation (Wisconsin), which covers about 60 percent of the basin. Extending out from beneath the lobate form of this unit is a crescent-shaped zone a few miles wide around the southern edge of the basin in which older (Illinoian) till assigned to the Jessup Formation is at the surface. Broad belts of outwash of the Atherton Formation and narrower ribbons of alluvium mapped as the Martinsville Formation cross the basin, principally along the shallow northeast-southwest trending valleys. Isolated kame and esker gravels are scattered across the upland, mainly in the area of the Trafalgar Formation, and small areas of both dune sand and an older alluvial deposit, the Prospect Formation, occur in the southwestern part of the basin. Bedrock outcrops are numerous in the southeast where the drift is thin, but only in a narrow belt of high land at the southwestern edge of the basin are unconsolidated deposits largely absent.

Bedrock exposed or recognized immediately below the drift cover in the Upper East Fork Drainage Basin consists of bluish-gray shales and siltstones, black shales, limestones and dolomites, and interbedded shales and limestones totaling about 1,000 feet in thickness. These rocks range in age from early Mississippian along the southwestern margin of the basin to late Ordovician along the southeastern margin. Exposures are virtually limited to the southern part of the basin; in the central and northern parts these rocks are known mainly from subsurface records.

Geologic factors relevant to the construction of dams and reservoirs in the Upper East Fork Drainage Basin include topographic conditions, leakage potential, availability of materials, and foundation conditions. Supplies of suitable construction materials are adequate and foundation problems do not appear serious, but on the basis of other geologic factors the basin is much better suited to relatively small dams and reservoirs than to large structures.

Within the basin only a few areas are topographically suitable for moderate-sized to large multipurpose dams and reservoirs. In these areas, however, leakage through permeable gravels or cavernous limestones is likely to constitute a major problem. Thus an integrated plan of surface-water control should be developed for the entire basin to achieve maximum overall benefits at minimum cost.

Two types of structures should be considered for the major controlling elements in this integrated plan. First, in topographically suitable sites that have drainage areas of 50 to 250 square miles, consideration should be given to reservoirs of conventional design intended only for the temporary retention of floodwaters. Because of the relatively short use period, leakage problems would be minimized. Second, in areas of low relief that have larger watersheds, broad low structures should be considered. Shallow depths and resultant low pressures would help minimize leakage in these reservoirs.

INTRODUCTION

GEOGRAPHY OF THE BASIN

The area discussed in this report is the drainage basin of the upper part of the East Fork of White River, an area of about 2,300 square miles in east-central Indiana (fig. 1). This area, which is here designated the Upper East Fork Drainage Basin, extends from just below the confluence of the East Fork with Sand Creek in southeastern Bartholomew County upstream to the headwaters of Big Blue and Flatrock Rivers in northeastern Henry County (fig. 2), and includes all tributary drainage. This basin was designated by the Indiana Water Resources Study Committee (1956) as Indiana Watershed Area Number 11.

Politically, the area includes all of Shelby County, most of Hancock, Rush, Decatur, and Bartholomew Counties, much of Henry and Johnson Counties, and parts of Jennings, Marion, Fayette, Jackson, Brown, and Madison Counties. Principal cities are New Castle, Greenfield, Rushville, Franklin, Shelbyville, Columbus, and Greensburg (fig. 2). Several major highways and railroads cross the area.

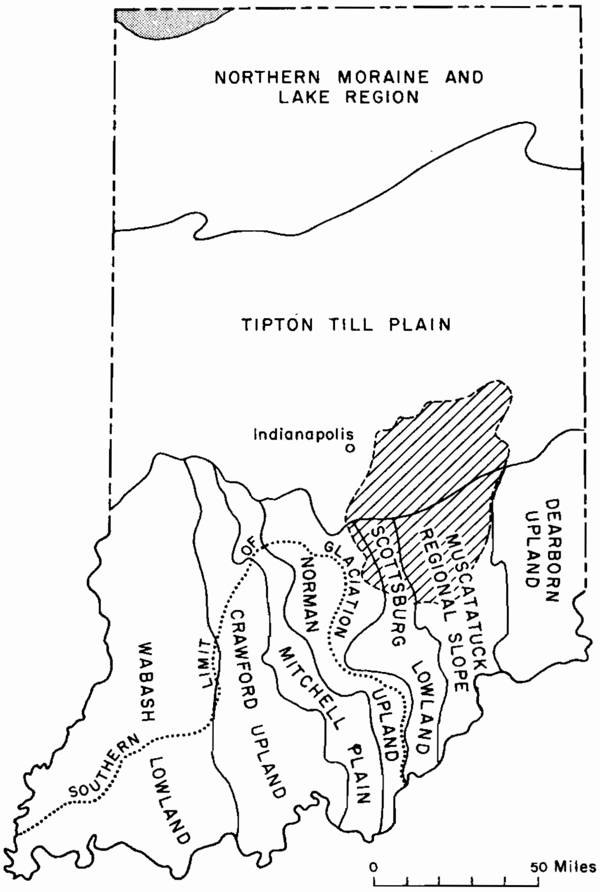


Figure 1. --Index map of Indiana showing area of the Upper East Fork Drainage Basin (shaded) and physiographic divisions of Malott (1922).

The Upper East Fork Drainage Basin is subelliptical in outline; its long axis trends northeast-southwest. Although the eastern, northern, and western rims of the basin are all fairly high, only the western divide, which is defined by the crest of a range of hills, is prominent. The floor of the basin is for the most part an undulating westward-sloping plain; the slope is so gradual, however, that one may be unaware that in crossing the basin from Greensburg to Columbus, for instance, he has descended about 350 feet. The lowest point in the basin, about 570 feet above sea level, is at the junction of Sand Creek and the East Fork; the highest points, about 1,180 feet above sea level, are around the northeastern rim of the basin. Total relief thus exceeds 600 feet; local relief is about 50 feet per mile, but the figure varies considerably from one part of the basin to another.

Most of the streams of the Upper East Fork Drainage Basin occupy shallow valleys, the bottoms of which are only 20 or 30 feet below the surface of the plain. Exceptions include the upper part of Big Blue River, which is rather deeply entrenched into glacial deposits, and the two major streams of the southeastern part of the basin, Sand Creek and Clifty Creek, both of which have excavated valleys as much as 100 feet deep, partly into bedrock.

METHOD AND SCOPE OF INVESTIGATION

Basic geologic information is essential to all aspects of water-resource studies. This report was prepared at the request of the Indiana Flood Control and Water Resources Commission to provide background data of a geologic nature for engineers making preliminary appraisals of sites for hydraulic structures. The basic geologic data and interpretations presented are not restricted in application, however, but are useful in several planning and development fields.

No new geologic fieldwork was undertaken in connection with the compilation of the text

Figure 2. --Location map of the Upper East Fork Drainage Basin showing drainage and culture.

Table 1. --Principal sources of data used in preparing this report

County	Area mapped (sq. mi.)	Data on unconsolidated deposits					Data on bedrock units		
		Previous mapping	Well records	Seismic refraction records	Recorded field observations	Total	Previous mapping	Well records	Recorded field observations
Bartholomew	320	Soil map, 1:63, 360; Ulrich and others, 1947	56	13	26	95	Geological map of Indiana, scale 1:250, 000 (Logan, 1932) Geologic map of Indiana, scale 1:1, 000, 000 (Patton and others, 1956)	11	19
Brown	10	Soil map, 1:63, 360; Rogers and others, 1946	0	0	0	0		0	0
Decatur	300	Soil map, 1:63, 360; Baldwin and others, 1922	223	54	63	340		78	27
Fayette	20		0	1	0	1		0	0
Hancock	270	Soil map, 1:63, 360; Tharp and Simmons, 1930	71	45	0	116		16	0
Henry	250	Preliminary soil map of unknown origin	243	1	0	244		29	0
Jackson	1		0	0	0	0		0	0
Jennings	70	Soil map, 1:63, 360; Kunkel and others, 1940	10	3	4	17		7	17
Johnson	200	Soil map, 1:48, 000; Ulrich and others, 1948	51	229	2	282		16	0
Madison	7	Preliminary geologic map by William J. Wayne	1	0	0	1		0	0
Marion	50	Geologic map, 1:48, 000, Harrison, 1963	28	41	0	69		1	0
Rush	380	Soil map, 1:63, 360; Simmons, Kunkel, and Ulrich, 1937	151	18	14	183		42	7
Shelby	410	Preliminary geologic map by William J. Wayne	92	30	30	152		44	8

and maps in this report. Published material and unpublished data in the files of the Indiana Geological Survey and in the library of Indiana University are the sources of all factual data presented (table 1). Compilations and interpretations, which are original unless otherwise specified, are based on these data supplemented by the study of topographic quadrangle maps and aerial photographs.

Data on drift thickness used in the compilation of the drift-thickness map (fig. 5) and the bedrock-topography map (fig. 6) were obtained from water well records, oil and gas well records, seismic refraction records, and recorded field observations. In addition to the nearly 1, 500 records of points within the basin proper (table 1), several hundred records from adjacent areas were used. Many of these were used in earlier drift-thickness studies by McGrain (1949), Wayne (1956), and Harrison (1963). Elevations of the bedrock surface were obtained by subtracting drift-thickness figures from surface elevations read from topographic quadrangle maps. In areas of thick drift, especially in Henry County, a large proportion of the water wells do not enter bedrock and therefore furnish incomplete data on drift thickness.

The map showing unconsolidated deposits (fig. 4) was compiled mainly from maps in the Survey files. Much of the basic data came from published soil maps (see table 1) that had been geologically interpreted for use in preparing a glacial materials map of Indiana (Thornbury and Wayne, in preparation). Previous bedrock mapping in the region was found generally to be accurate only in areas of thin drift in Decatur County and adjacent parts of Jennings, Bartholomew, Shelby, and Rush Counties. In the remainder of the area, where glacial drift is thicker and direct information on the bedrock is not so abundant, bedrock contacts were interpolated on the basis of indirect evidence.

PHYSIOGRAPHY AND DRAINAGE

PHYSIOGRAPHIC UNITS

General statement.–Most of the Upper East Fork Drainage Basin is in the physiographic unit designated by Fenneman (1938) as the Till Plains Section of the Central Lowland Province. A small area in the southwestern part of the basin is included in Fenneman's (1938, p. 425-426; pl. 3) Highland Rim Section of the Interior Low Plateau Province. In this report, however, the more detailed divisions outlined by Malott (1922, p. 77-124) will be used. According to Malott's terminology the Upper East Fork basin lies within four physiographic units (fig. 1): the Tipton Till Plain, the Muscatatuck Regional Slope, and the Scottsburg Lowland, all of which are part of the Till Plains Section of Fenneman, and the Norman Upland, which is part of Fenneman's Highland Rim Section.

Tipton Till Plain.–About half the area of the Upper East Fork Drainage Basin occurs within Malott's (1922, p. 104-112) Tipton Till Plain, a nearly flat to gently rolling glacial plain that covers almost one-third of the State (fig. 1). The plain is crossed by several end moraines, but most of these are so low and poorly developed that they modify only slightly the overall flatness of the topography. Furthermore, the plain has been but slightly modified by postglacial stream erosion; most modern streams have cut only shallow valleys or follow inherited glacial drainageways.

In the Upper East Fork basin the Tipton Till Plain has a total relief of about 450 feet. The plain slopes in a general southwesterly direction from an elevation of 1,180 feet above sea level at the head of the basin in northeastern Henry County to 730 feet above sea level south of Franklin in Johnson County, where it passes imperceptibly into the Scottsburg Lowland. Except for scattered kames and narrow morainic areas, the upland surface of the till plain is almost featureless; the plain is not so monotonous as elsewhere in Indiana, however, because in the Upper East Fork area it is crossed by a network of southwestward-draining glacial sluiceways, the floors of which are, on the average, about 50 feet below the upland.

The southern margin of the Tipton Till Plain across the Upper East Fork basin is probably the most poorly defined physiographic boundary in Indiana. The Shelbyville Moraine was selected by Malott as the logical southern boundary of the till plain in western Indiana, but in the eastern part of the State no natural boundary exists. There is instead a broad transitional zone, in which the topography is similar to that of the till plain, but glacial drift is sufficiently thin that the general form of bedrock physiographic units may be recognized. Thus the Scottsburg Lowland and the Muscatatuck Regional Slope are identifiable as physiographic units, but their characteristics are subdued by the northward-increasing thickness of glacial drift. This transitional zone, according to Malott (1922, p. 105), could be placed in either the Tipton Till Plain or the appropriate bedrock physiographic units.

Muscatatuck Regional Slope.–The southeastern part of the Upper East Fork basin is at the northern end of the Muscatatuck Regional Slope (Malott, 1922, p. 86-88), a gently sloping plain that descends from nearly 1,100 feet above sea level in east-central Rush County to about 675 feet in southeastern Bartholomew County. The Muscatatuck Regional Slope is commonly interpreted as a structural plain or stripped surface on bedrock, but the northeast-southwest grain of the topography clearly suggests that glaciation at least partly accounts for the general physiographic character of the area. A blanket of glacial drift, which thickens northward to a maximum of about 100 feet, covers the middle Paleozoic carbonate rocks that underlie the entire unit.

Many of the valleys of the Muscatatuck Regional Slope are steep sided and moderately deep, the streams having downcut through the thin cover of unconsolidated materials into the underlying limestones and dolomites. Upland areas between the streams are, in general, very broad and nearly flat to undulating. These features indicate that the region is still in the youthful stage of landform development.

Scottsburg Lowland.–The Muscatatuck Regional Slope passes westward with little apparent topographic break into an elongate area of low relief named the Scottsburg Lowland by Malott (1922, p. 88-90). In the Upper East Fork basin the Scottsburg Lowland has been partially filled with glacial drift that is as much as 150 feet thick; therefore, the lowland is less distinct than farther south, where the drift is thinner or absent. As a physiographic unit, the lowland is recognizable as far north as southern Johnson County, where it passes beneath the still thicker drift cover of the Tipton Till Plain. In this area the general elevation of the Scottsburg Lowland is 730 to 750 feet above sea level, but along its western edge the elevation in places approaches 800 feet. The axis of the trough in this northern area is about 700 feet above sea level and gradually drops to 600 feet at the southern end of the drainage basin.

Geomorphically, the Scottsburg Lowland is a strike valley--a linear lowland whose position is controlled by the structure and lithology of the underlying bedrock formations. The Scottsburg Lowland follows the belt of outcrop of relatively nonresistant shales of late Devonian and early Mississippian age. In cross section the trough is strongly asymmetric, the more gentle eastern slope truncating the gently westward-dipping shale beds at a low angle. (See Malott, 1922, fig. 17, p. 160.)

Norman Upland.–The Norman Upland (Malott, 1922, p. 90-94) is a dissected low plateau underlain by relatively resistant siltstones and interbedded softer shales of the Borden Group of Mississippian age. These rocks dip about 35 feet per mile to the west-southwest. The upland is an area of strong local relief characterized generally by flat-topped narrow divides, steep slopes, and deep V-shaped valleys. Most shorter tributary streams have only incipient flood plains or none at all, but the larger streams are marked by conspicuous narrow flood plains. The area is extremely well drained and virtually all of it is in slope. These features clearly indicate that the Norman Upland is in the mature stage of landform development.

The eastern boundary of this plateau is drawn at the base of the eastward-facing Knobstone Escarpment, one of the most prominent topographic features in Indiana. In western Bartholomew County the escarpment rises 250 to 350 feet above the Scottsburg Lowland to the east, and the boundary between this lowland and the Norman Upland is sharp and well defined. The escarpment is even higher and more prominent south of the Upper East Fork basin, with relief of 400 to 600 feet near the Ohio River, but farther north in southern Johnson County the ridge gradually disappears beneath glacial drift of the Tipton Till Plain.

GLACIAL MORAINES

Three morainic systems cross the Upper East Fork Drainage Basin. For the most part these moraines trend in a general northeast-southwest direction across the Tipton Till Plain and Muscatatuck Regional Slope. (See Leverett and Taylor, 1915, pl. 6; Malott, 1922, pl. 3; and Wayne, 1958b, for detail on the distribution of moraines.) The moraines were described, first by Leverett (Leverett and Taylor, 1915, p. 77-122) and then by Malott (1922, p. 107-108, 152), as the Shelbyville, Champaign, and Bloomington Morainic Systems. These names, derived from localities in Illinois, had been used by Leverett (1899a, p. 192-290) in describing moraines in Illinois and western Indiana and were simply extended eastward as Leverett's work progressed in this direction.

The outermost or Shelbyville Moraine marks the general southern limit of the continental ice sheet that invaded Indiana during the Wisconsin Age. East of the East Fork of White River the Wisconsin glacial boundary trends generally northeast-southwest as it crosses the Muscatatuck Regional Slope between northwestern Jennings County and northeastern Decatur County. The boundary is marked by the distal (outer) edge of the Shelbyville Moraine, which in this area is a belt of hummocky topography that rises only about 20 feet above the adjacent plain of silt-veneered older drift to the southeast. The boundary is readily discernible, however, because of the marked difference in materials and soils on opposite sides of the line. Leverett remarked that "for more than 40 miles in Fayette, Decatur, and Jennings counties the border is so sharp and distinct that it can be located within a few yards" (Leverett and Taylor, 1915, p. 78). West of the East Fork of White River, however, the Wisconsin glacial boundary is less distinct, in terms of both topography and soils.

The Champaign and Bloomington Moraines roughly parallel the Shelbyville. East of the drainage axis occupied by the East Fork, the Driftwood River, and lower Sugar Creek, the Champaign Moraine is about 15 to 20 miles inside (northwest of) the Wisconsin boundary and the Bloomington Moraine is about 35 to 40 miles, but in the western part of the basin the belts are closer to this boundary. In general, these moraines are not very well developed in the Upper East Fork Drainage Basin;

of the two, the Bloomington is the stronger. In some places the moraines have little or no topographic expression and are represented only by boulder belts. In places, however, they are defined by knobs or ridges of till and by prominent kames that rise above the general level of adjacent areas. The belt of gravel hills or kames that trends in a general east-west direction across northern Johnson County, for example, was considered by Leverett and Malott to be part of the Bloomington Morainic System.

DRAINAGE

The most striking aspect of the physiography of the Upper East Fork area is the subparallel pattern of southwestward-draining streams that dominates the drainage system of the basin. To express this pattern semiquantitatively, a rudimentary statistical analysis of the drainage system was made by measuring the air-line direction of alternate 5-mile segments of all principal streams. The mean direction of these segments for the entire basin is S. 27° W., and two-thirds of the segments are oriented within 28° of this mean, that is, within the sector from S. 1° E. to S. 55° W. (fig. 3). The strong parallelism of streamflow directions thus indicated is a consequence of the geologic history of the basin.

The drainage basin of the upper East Fork can be subdivided into two units, a slope that makes up the eastern two-thirds of the basin and a trough that occupies the western third. The slope exhibits a relatively uniform regional gradient of about 8 feet per mile, descending from about 1,175 feet above sea level on the northeast to perhaps 875 feet on the southwest (fig. 3). The trough, by contrast, is a strongly asymmetric southward-pitching basin, whose more gently sloping eastern limb is merely a continuation of the slope area.

The axis of the trough is best defined from the mouth of the drainage basin upstream (northwestward) to Columbus. In this segment it is followed by the East Fork of White River, the position of the axis being controlled by the belt of weak shales that underlies the Scottsburg Lowland. In the vicinity of Columbus, however, the trough appears to split. The axis of its eastern branch trends slightly east of north as it passes through northern Bartholomew County, western Shelby County,

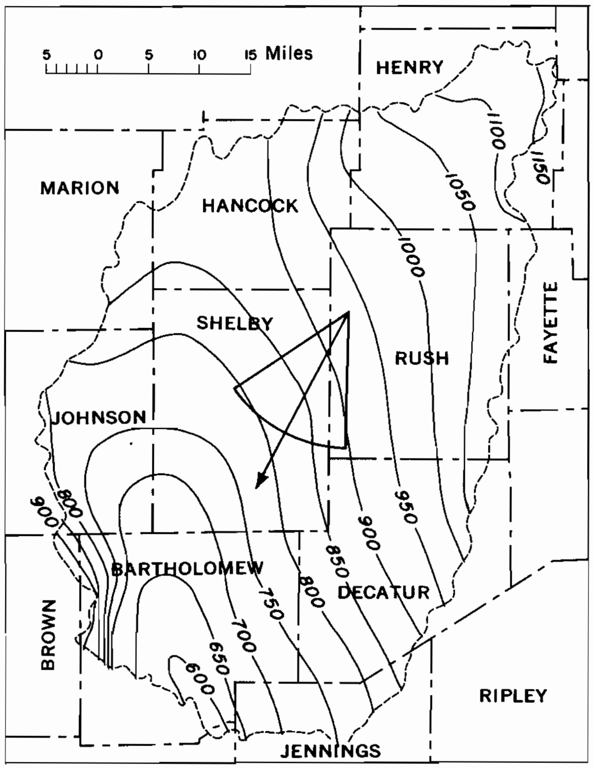


Figure 3. --Map of the Upper East Fork Drainage Basin showing regional slope of the basin (contours), mean direction of streamflow (arrow), and standard deviation of streamflow (sector). Elevations in feet above sea level.

and western Hancock County (fig. 3). The western branch continues northwestward from Columbus through Edinburg and Franklin as the drainage axis of the trough and leaves the basin southwest of Greenwood in northern Johnson County (fig. 3). From Columbus upstream to Franklin this branch is occupied by the Driftwood River, lower Sugar Creek, and Youngs Creek; it no doubt represents the northern expression of the Scottsburg Lowland.

Streams entering the drainage axis from the northeast exhibit the strong subparallel drainage pattern described above. The master stream of much of the area east of the drainage axis is the Big Blue River, which follows a well-defined trench in its southwesterly course from the head of the East Fork basin in northeastern Henry County to the head of the Driftwood River in southeastern Johnson County. North of the Big Blue River in the northwestern part of the drainage basin the northeast-southwest pattern is less

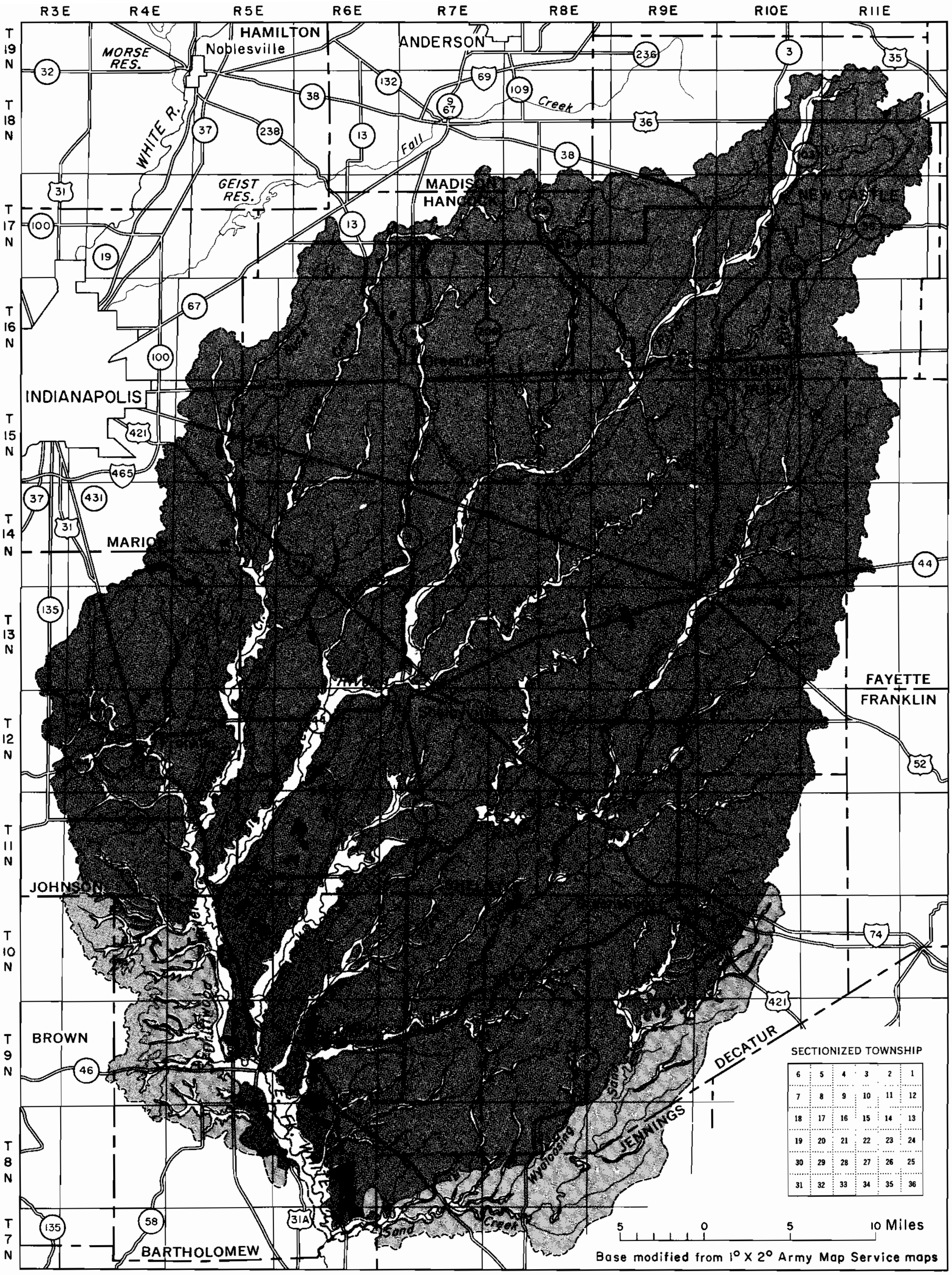
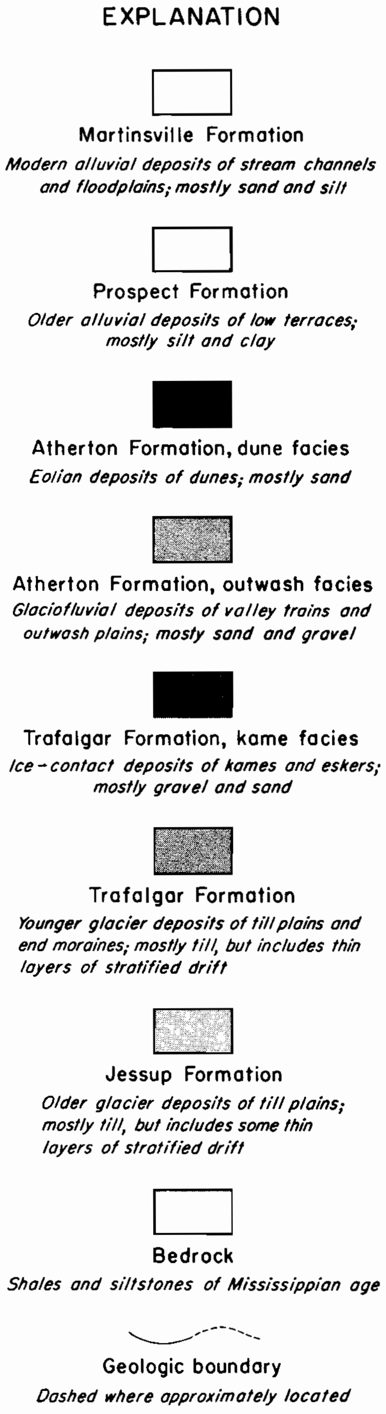


Figure 4. --Map showing unconsolidated deposits of the Upper East Fork Drainage Basin.



apparent than it is south of the river. Many of the streams, or segments thereof, flow in a more southerly direction, following the regional slope (fig. 3). Divergence from the general northeast-southwest pattern is not particularly sharp, however, and even in this part of the basin some streams have southwestward-flowing segments.

The area west of the East Fork and Driftwood River segment of the drainage axis is drained by several short eastward-flowing streams that follow the steep regional slope of this part of the basin. Most of these streams head at or near the western rim of the basin in the area underlain by rocks of the Borden Group, thence flow down the front of the Knobstone Escarpment and across an area covered by relatively thin older drift. A noticeable difference in stream development between areas underlain by older drift (Jessup Formation of Illinoian age) and younger drift (Trafalgar Formation of Wisconsin age) is apparent in figure 4.

The origin of the northeast-southwest stream lineation is not entirely clear, but it is certain that the essentials of the pattern were established during the Pleistocene Epoch, most probably during the Wisconsin Age. Many of the streams (for example, Big Blue River, Flatrock River, Clifty Creek, Sugar Creek, Buck Creek, Hurricane Creek, and Brandywine Creek) follow inherited valleys formerly occupied by glacial drainage during the Wisconsin, as both Leverett (Leverett and Taylor, 1915, p. 119) and Malott (1922, p. 109, 166, 171) recognized. Whether the drainageways represent subglacial (beneath the ice) or proglacial (beyond the ice margin) channels is not known, but there is no question as to their glacial origin.

It is not uncommon for drainage divides to cross abandoned parts of these glacial channels. The divide between the drainage basins of the East Fork and the White River north of New Castle in northeastern Henry County crosses a conspicuous dry drainageway half a mile to three-fourths mile wide and 60 to 100 feet deep that farther south is occupied by the Big Blue River. Other abandoned glacial drainageways, or segments thereof, are abundant in the Upper East Fork area. Among the many good examples that can be easily observed on the map (fig. 4) are those in north-central Hancock County between Sugar Creek and Brandywine Creek; in south-central Hancock County between Brandywine Creek and Big Blue River; in eastern Henry County from the northeastern tip of the drainage basin west-southwestward to Big Blue River and also south-southwestward into northeastern Rush County; in north-central Shelby County, where a cutoff of Big Blue River is used partly by the lower part of Brandywine Creek; in south-central Shelby County, south of Shelbyville, between Big Blue River and Flatrock River; and in southwestern Rush County, a cutoff of Flatrock River southwest of Rushville.

UNCONSOLIDATED DEPOSITS

GENERAL STATEMENT

Most of the Upper East Fork Drainage Basin is covered with unconsolidated sedimentary materials that were deposited by water, wind, or ice; only in a narrow belt about 14 miles long in northeastern Brown County and western Bartholomew County are such unconsolidated deposits absent (fig. 4). Except for alluvial and some colluvial sediments that are mostly of Recent age, these unlithified materials were laid down during the glacial ages of the Pleistocene Epoch and are therefore classified as (glacial) drift.

Two general types of unconsolidated deposits are present in the Upper East Fork area, those that are sorted and stratified and those that are virtually unsorted and nonstratified. Sorted and stratified sediments include alluvial clay, silt, sand, and gravel deposits of normal streams, sand and gravel deposits of glacial meltwaters, and eolian (wind-deposited) silts and sands. The unsorted material, called till, was deposited by glacier ice; in areal extent it is much more widespread than any of the other unconsolidated deposits in the area. Because ice, unlike water and wind, has virtually no ability to sort materials according to size, till consists of a heterogeneous admixture of rock fragments; it is perhaps best described as a conglomeratic mudstone composed of a finer grained matrix that contains granules, sand, silt, and clay, and a coarser grained fraction that consists of pebbles, cobbles, and boulders of various shapes. The material, though generally uncemented, is in most places firm and compact as a result of deposition beneath several hundred feet of ice.

Engineers refer to such unconsolidated deposits as soil, in accord with the usage that defines soil as all loose or poorly consolidated material above solid rock that can be excavated without blasting. Soil scientists, on the other hand, generally define soil as a natural dynamic body at the surface of the earth, composed of mineral and organic matter and consisting of more or less well-defined horizons. In this report the word soil is used in this latter sense: only the weathered upper part of an unconsolidated deposit is called soil. Soil is considered to be distinct from the underlying geologic parent material from which it is derived, even though the boundary between the two is commonly transitional. Some soils data that relate directly to parent materials are included in this report, but for details on the many soils that are recognized in the Upper East Fork area the reader is referred to county Soil Survey reports (Baldwin and others, 1922; Geib and Schroeder, 1912; Kunkel and others, 1940; Rogers and others, 1946; Simmons, Kunkel, and Ulrich, 1937; Tharp and Simmons, 1930; Ulrich and others, 1947; Ulrich and others, 1948).

The unconsolidated deposits of the Upper East Fork Drainage Basin are designated in this report, both in the text and in figure 4, by geographically derived formation names. These names follow the classification of Pleistocene stratigraphic and map units proposed by Wayne (1963) for use throughout the State.

THICKNESS OF DRIFT

The thickness of unconsolidated sediments in the Upper East Fork area ranges from less than a foot to more than 300 feet (fig. 5). Although some buried bedrock valleys may be partly filled with unconsolidated materials of pre-Pleistocene age, the great bulk of these valley-fill sediments are of glacial origin. The drift is thinnest in the southern part of the area and thickens in a general northerly direction. In Decatur County, for example, the average thickness is probably less than 50 feet; the bedrock surface in many places is no more than 25 or 30 feet below the upland, and numerous exposures of bedrock occur along the stream valleys. Farther north, however, in eastern Hancock County and Henry County the glacial sediments probably average about 200 feet in thickness (Appendix, well records 17 and 18), and bedrock exposures are virtually unknown; at several localities that lie along the course of a deep buried valley drift thicknesses are known to exceed 300 feet (Appendix, well record 19), and one deep well just north of New Castle

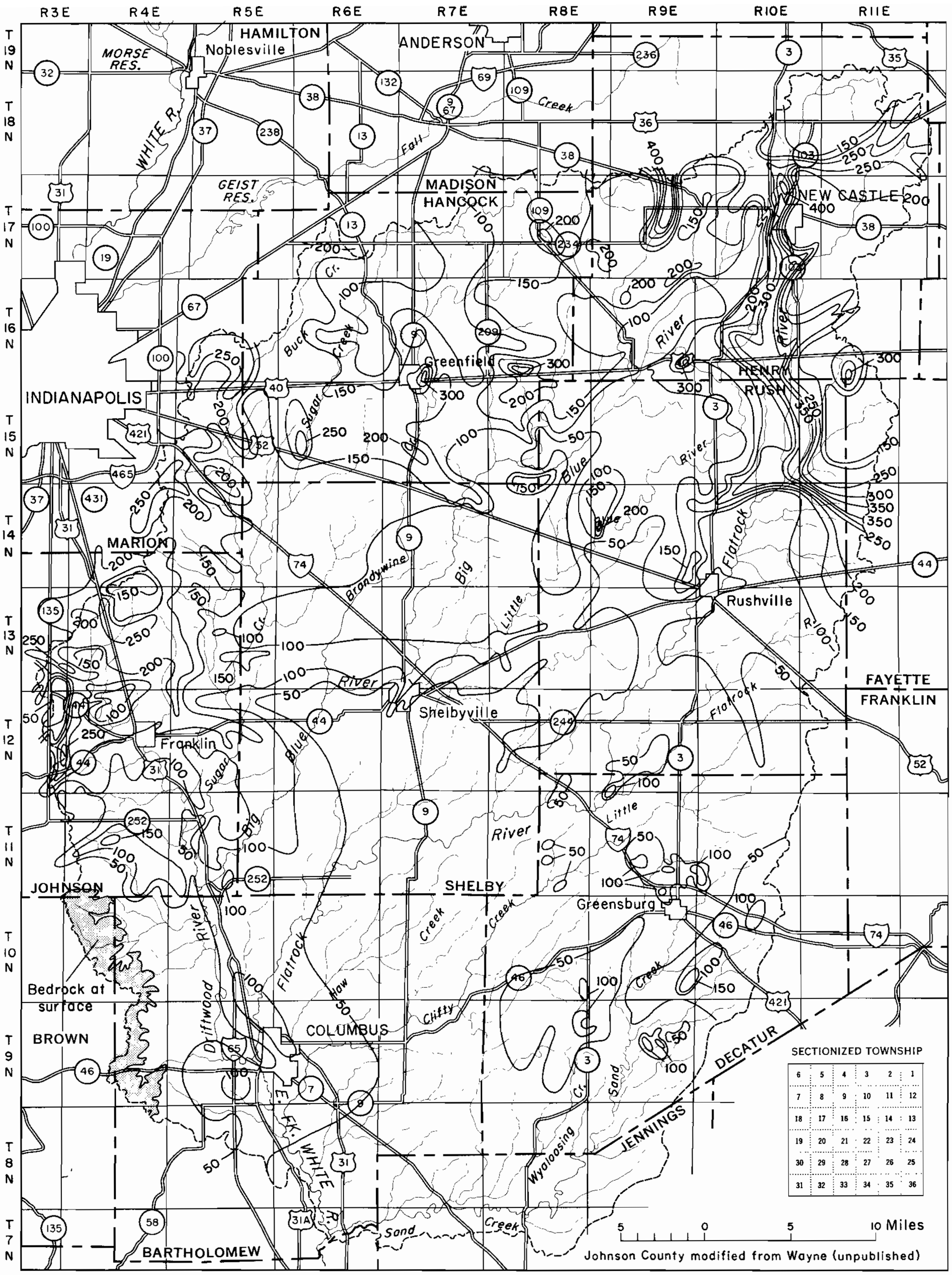


Figure 5. --Isopach map showing thickness of unconsolidated deposits in the Upper East Fork Drainage Basin. Contour interval 50 feet.

entered bedrock at a depth of 400 feet.

MARTINSVILLE FORMATION

The Martinsville Formation (Wayne, 1963) is the youngest unconsolidated unit of formation rank recognized in Indiana. It is represented in the Upper East Fork area by alluvial (and some colluvial) deposits along the channels and on the flood plains of modern streams. These sediments are geologically youthful, having been deposited during the Wisconsin and Recent Ages after the final retreat of glacier ice from the drainage basin. The sediments are therefore classed as nonglacial, although they are derived mainly from older deposits of water-laid and ice-laid drift. Because of their occurrence along stream courses, sediments of the Martinsville Formation are partly transient in nature, much of the material being subject to frequent scouring and redeposition farther downstream.

In general, the Martinsville Formation is composed of bedded silt, sand, and gravel. At some localities it consists almost entirely of sand and gravel, whereas in other places it is largely silt and clay. The upper part of the unit (about 1 to 3 feet thick) tends to be finer grained than the material below, particularly in flood-plain environments. Here also the finer materials (fine sand, silt, and clay) commonly are high in organic matter and consequently are dark brown to black. Channel deposits, on the other hand, tend to be coarser textured and yellowish brown or brownish yellow.

The Martinsville Formation is present throughout the Upper East Fork Drainage Basin (fig. 4). Although the deposits are thickest (maximum thickness about 15 or 20 feet) and the alluvial belts widest along the larger streams (East Fork of White River, Driftwood River, Flatrock River, Big Blue River, and Sugar Creek) in the southwestern part of the basin, some alluvium is present along virtually every stream. The deposits are continuous except in the southeastern part of the basin where drift is thin and several of the streams, notably Sand Creek and Clifty Creek, are partly entrenched in bedrock. In these valley segments either the Martinsville Formation is thin (2 to 5 feet thick) or, more commonly, its alluvial belt is too narrow to be mapped.

Because the Martinsville is the youngest formation of the area, it overlies all bedrock and other unconsolidated units (Appendix, well records 3 and 10). Contacts with all bedrock formations and with till of the Trafalgar and Jessup Formations are sharp. Contacts with the kame facies of the Trafalgar Formation and with the dune facies and outwash facies of the Atherton Formation are less distinct. In many places the lithology of the Martinsville is so similar to that of Atherton outwash that the contact is gradational or obscure (Appendix, well record 3). For this reason, and because there may be little or no topographic break between flood plain and outwash plain, the boundary between these two units is arbitrarily drawn.

On older soil maps of the Upper East Fork area (Baldwin and others, 1922; Tharp and Simmons, 1930; Simmons, Kunkel, and Ulrich, 1937) only two alluvial soils are shown, the Genesee series and the Eel series. But on more recent maps (Kunkel and others, 1940; Ulrich and others, 1947; Ulrich and others, 1948) several alluvial soils are recognized. These are commonly divided into two groups: (1) soils formed on neutral to slightly alkaline alluvium derived from drift of Wisconsin age and (2) soils formed on strongly acid alluvium derived from drift of Illinoian age and from clastic rocks of the Borden Group. Soil series in the first category include the Genesee and the Ross (well drained), the Eel (moderately well drained to imperfectly drained), and the Shoals (imperfectly drained). Those in the second group constitute the Pope catena and include the Pope (well drained), Philo (moderately well drained), Stendal (imperfectly drained), and Atkins (poorly drained) series. Alluvial soil profiles are shallow and poorly developed, partly because of the general youthfulness of the Martinsville Formation, but especially because of the ephemeral character of the deposits.

ATHERTON FORMATION

The Atherton Formation of Wayne (1963) includes four interrelated facies, only two of which, the outwash facies and the dune facies, are well enough expressed areally in the Upper East Fork area to be shown in figure 4 Of these, the outwash facies is the more extensive; it occurs throughout the drainage basin, mainly along stream courses in association with the younger Martinsville Formation. The dune facies is mapped only in Bartholomew County, but small dunal areas are present elsewhere within the basin.

The other two units of the Atherton Formation, the lacustrine facies and the loess facies, are not shown in figure 4. Sediments of the lacustrine facies are thin and restricted in area and so are included with the Martinsville Formation. Deposits of the loess facies are present as a thin blanket atop glacially deposited sediments of the Trafalgar and Jessup Formations and are commonly recognizable as a unit within the soil profile. Nevertheless, the facies is not sufficiently thick nor are its boundaries everywhere clear enough for the facies to be mapped as a distinct geologic unit, and it is therefore included in the Trafalgar and Jessup Formations.

Outwash facies.–The outwash facies of the Atherton Formation is composed of outwash-plain and valley-train sediments. Most of these materials were deposited by meltwater streams that drained the Upper East Fork area during the Wisconsin Age of the Pleistocene Epoch, although in the southern part of the drainage basin some of the sediments are partly Illinoian in age.

Valley-train sediments appear to be much more extensive than outwash-plain deposits, but they cannot everywhere be distinguished. Outwash plains and valley trains commonly grade into each other, as is apparently the case in north-central Bartholomew County (fig. 4). Other examples of outwash plains in the Upper East Fork area occur in northeastern Rush County and in eastern Johnson County and western Shelby County (fig. 4).

Valley-train sediments extend along the several glacial drainageways that characterize the Upper East Fork area (Appendix, well record 3, unit 2; well record 10, units 1, 2, and 3; well record 15, unit 2; well record 17, unit 2; and well record 18, unit 2). Some of these drainageways are used by modern streams that have cut down below the levels of their Pleistocene predecessors. The floors of the glacial channels are consequently preserved as terraces perched at various heights above the modern flood plains. The widest terraces are in the southwestern part of the basin along the larger streams, such as the East Fork, Flatrock River, Driftwood River, Sugar Creek, and Big Blue River. In general the terraces in this area are low, commonly being no more than 10 or 15 feet above the adjacent flood plains, and there is little topographic break between terrace and flood plain. For this reason, and because there is some similarity between the outwash facies of the Atherton Formation and the Martinsville Formation, the boundary between the two units in many places is not well defined. The most prominent terraces are those along the course of the Big Blue River between Shelbyville and New Castle, especially upstream from the confluence of the Big Blue with Sixmile Creek west of Carthage. In this part of the drainageway the valley is narrower and better defined than farther downstream; the terrace treads are higher and much more sharply separated from the flood plain than farther downstream. The Atherton-Martinsville boundary can therefore be mapped more accurately. Other terrace remnants occur along Buck Creek in southeastern Marion County, along Sixmile Creek in eastern Hancock County and northwestern Rush County, and along Clifty Creek in east-central Bartholomew County.

Many of the drainageways, on the other hand, became partly or largely abandoned as active drainage lines with the abatement of glacial meltwater, and so today are virtually dry or occupied only by underfit streams or manmade drainage ditches. Stream entrenchment in these drainageways is negligible, and the floors serve when necessary as flood plains for the modern streams or as overflow channels during flood periods. Consequently the channels are marked by a thin accumulation of fine-grained alluvial or lacustrine sediments of the Martinsville Formation on top of the outwash sediments of the Atherton Formation (Appendix, well record 10, unit 1).

In addition to its surficial distribution in outwash plains and valley trains, the outwash facies of the Atherton Formation is an important unit in the subsurface materials of the Upper East Fork Drainage Basin. Outwash deposits ranging in thickness from a few feet to several tens of feet have been recognized in well samples from virtually all parts of the basin; the sediments commonly occur as units of sand and gravel either between the Trafalgar and Jessup Formations or between the tills within these formations (Appendix, well record 3, unit 4; well record 4, unit 2; well record 7, unit 5; well record 8, units 2, 4, and 7; well record 13, units 5, 8, and 10; well record 14, units 3 and 5; well record 15, unit 6; well record 16, units 3, 5, and 8; well record 18, units 4, 5, 7, and 9; and well record 19, unit 2).

Well records suggest that the surficial outwash deposits of the Atherton Formation

Table 2.--Size analyses of samples of the outwash facies of the Atherton Formation
[Data from McGregor, 1960, fig. 13 and table 4]

Location of sampling site	Sand/gravel ratio	Percentage by weight of sizes in gravel fraction		
		$\frac{1}{4}$ to $\frac{1}{2}$ in.	$\frac{1}{2}$ to 1 in.	1 to 4 in.
South-central Henry County (SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 12, T. 17 N., R. 9 E.)	50/50	10	36	54
Southeastern Hancock County (NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 9, T. 15 N., R. 7 E.)	61/39	23	10	67
Northwestern Bartholomew County (SE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 9, T. 10 N., R. 5 E.)	66/34	50	41	9
Northeastern Jackson County (SW$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 13, T. 6 N., R. 5 E.)	84/16	75	13	12

range in thickness from 5 to 40 feet; along most of the drainageways the valley-train sediments are between 10 and 25 feet thick. The composite thickness of all outwash deposits between the surficial unit and the bedrock surface depends in part, of course, on total drift thickness; in areas of thick drift the composite thickness is commonly measured in tens of feet and may approach or even exceed 100 feet in some places (Appendix, well record 18).

The grain size of the deposits comprising the outwash facies of the Atherton Formation spans a considerable range. The unit consists mostly of sand and gravel, but in places it is dominantly silt and sand with smaller amounts of gravel and clay.

As a general principle, glacial-outwash deposits within a given drainageway become progressively finer grained downstream. This principle is well illustrated in the Upper East Fork area. In the headwater areas of the streams that unite to form the East Fork the sand/gravel ratio is about 60/40, but along the main stream below the tributary junctures the ratio is about 85/15 (Patton, 1953a). Table 2 gives the results of analytical work by McGregor (1960) on four samples of outwash collected between south-central Henry County, near the head of the Upper East Fork Drainage Basin, and northeastern Jackson County, about 10 miles downstream from the mouth of the basin; these data indicate a progressive downstream decrease in grain size that is reflected both in higher sand/gravel ratios and by increasing percentages of small pebbles ($\frac{1}{4}$ to $\frac{1}{2}$ in.) relative to total pebble content.

Notwithstanding this general downstream decrease in grain size, glacial outwash deposits, because of their stratified nature, may range from fine- or medium-grained sediments to coarse-grained materials at any particular locality. It is not uncommon for a bed of sandy silt, for example, to rest directly on a layer of mixed sand and gravel containing large pebbles. A smaller range in grain size can be expected downstream than near a former margin of the ice sheet, however, and because these deposits were laid down largely as outwash from a retreating ice front, the surficial deposits tend to be finer grained than those at some depth below the surface.

Except near the surface where they are leached, outwash sediments of the Atherton Formation are calcareous. In general, the coarser the material, the higher the carbonate content; deposits that are mostly gravel and sand have calcium carbonate equivalents of 20 to 50 percent, whereas the carbonate equivalent of outwash deposits composed mainly of sand and silt is only 10 to 20 percent (Indiana Soil Survey, 1956). Depth of leaching of gravel and sand ranges from 2 to 5 feet; the top of the calcareous zone most commonly occurs between 36 and 40 inches. In finer grained outwash (sand and silt) the upper limit of calcareous material is about a foot deeper, ranging between a depth of 3 and 6 feet and commonly being about 50 inches. (See Tharp and Simmons, 1930; Simmons, Kunkel, and Ulrich, 1937; Ulrich and others, 1947; Ulrich and others, 1948.)

Analyses of the gravel fractions ($\frac{1}{4}$ to 4 in.) of the four samples listed in table 2 indicate that pebbles of carbonate rock (limestone, dolomitic limestone, and dolomite) are much more abundant than pebbles of other rock types. The weight percentage of carbonate-rock pebbles ranged from 58 to 81 percent, averaging 68 percent of all rock types present (McGregor, 1960, table 5). Other sedimentary rocks, including chert, sandstone, siltstone, and shale, are also represented. The percentages of sandstone and particularly of chert are considerably higher in the two southern samples than in those collected at the more northern sites: whereas the samples from Henry and Hancock Counties each contain less than 1 percent chert (by weight), the Jackson County sample contains 19 percent chert (McGregor, 1960, table 5). A variety of igneous and metamorphic rock types is also present in the gravel fraction of the outwash facies; this includes, at different localities, significant amounts of vein quartz, granite, diorite, and rhyolite in the igneous class and gneiss, quartzite, and schist in the metamorphic group.

The outwash facies of the Atherton Formation is the parent material for two groups of soil series in the Upper East Fork area: (1) soils developed from strongly calcareous gravel and sand and (2) soils developed from less strongly calcareous, more deeply leached sand and silt with small amounts of gravel and clay. The first group includes the Fox and Nineveh series (both well drained to excessively drained), the Homer series (imperfectly drained), the Westland series (poorly drained), and the Abington series (very poorly drained). Three series, the Martinsville (well drained), the Whitaker (imperfectly drained), and the Mahalasville (poorly drained), constitute the second catena. (See Baldwin and others, 1922; Tharp and Simmons, 1930; Simmons, Kunkel, and Ulrich, 1937; Ulrich and others, 1947; Ulrich and others, 1948; Indiana Soil Survey, 1956.)

Dune facies.--Deposits of windblown sand in Indiana were assigned by Wayne (1963) to the dune facies of the Atherton Formation. Several small areas of eolian sand have been mapped in the Upper East Fork basin, chiefly in Bartholomew County, where they occur mainly along the east side of the valley occupied by the East Fork and its tributaries (fig. 4).

The dune facies of the Atherton Formation in this area consists of well-sorted fine-grained yellowish-brown sand. The sand is leached of its calcium carbonate content to an average depth of about $4\frac{1}{2}$ feet; below this depth it is calcareous and slightly lighter (yellowish gray) in color. Most of the soils developed on the sand belong to the Princeton series, but some are classified as Ayrshire and some as Lyles (Ulrich and others, 1947).

The exact thickness of windblown sand in Bartholomew County is unknown. The average thickness is estimated to be between 15 and 20 feet, but in some places the sand may be as much as 40 feet thick. On the upland surface north of Azalia the sand probably overlies till of the Trafalgar Formation, and the contact between the two materials is probably sharp. In places where the dune sand overlies sand and gravel of the outwash facies of the Atherton Formation, the basal contact of the sand is likely to be gradational because most of the sand was derived by eolian reworking of the outwash.

PROSPECT FORMATION

The name Prospect Formation was proposed by Wayne (1963) for a unit composed of alluvial silts, sands, and gravels that occupy terrace positions along valleys in southern Indiana. The sediments are lithologically similar to those of the Martinsville Formation but are older, as indicated by their topographic position and especially by the fact that they are more deeply weathered.

Deposits of silt and clay that underlie low terraces along certain tributaries of the Driftwood River in western Bartholomew County are provisionally assigned to the Prospect Formation (fig. 4). These deposits were interpreted by Ulrich and others (1947) as older alluvial sediments derived from Illinoian till and weathered bedrock. The material is strongly acid to a depth of 5 or 6 feet, the depth of leaching is 8 to 10 feet or greater, the calcium carbonate equivalent is less than 10 percent, and the derived soil is moderately to strongly developed (Ulrich and others, 1947; Indiana Soil Survey, 1956). In all these respects the material is typical of the Prospect Formation as defined by Wayne.

Assignment of the Bartholomew County deposits to the Prospect is provisional, however, partly because the formation has not previously been identified in this area. Its known area of distribution is farther south, chiefly in the unglaciated part of Indiana, where the unit underlies terrace remnants that are 20 to 50 feet above the modern flood plains (Gray, Jenkins, and Weidman, 1960, p. 20-21; Wayne, 1963, p. 38). The Bartholomew County deposits, in contrast, occur in terraces that are only 1 to 6 feet above the flood plains (Ulrich and others, 1947).

The maximum thickness of the Prospect Formation in Bartholomew County is estimated to be about 15 or 20 feet. Although the unit is known from localities where it is topographically higher than the Martinsville

Formation, it is older than that formation and therefore may underlie the Martinsville in valleys in western Bartholomew County. In this area it is younger than the Jessup Formation and all bedrock formations, but its exact age relationships to the Atherton and Trafalgar Formations are not entirely clear. Very probably it is older than the dune facies of the Atherton, and it may be either older than or about the same age as both the Trafalgar Formation and the outwash facies of the Atherton.

Soil series developed on the low-terrace alluvium of Bartholomew County are the Elkinsville (well drained), the Pekin (moderately well drained), the Bartle (imperfectly drained), and the Peoga (poorly drained) (Ulrich and others, 1947; Indiana Soil Survey, 1956).

TRAFALGAR FORMATION

More than half the area of the Upper East Fork Drainage Basin is underlain by glacial sediments assigned to the Trafalgar Formation of Wayne (1963). The Trafalgar Formation, which is Wisconsin in age, is the most widespread of the several unconsolidated units now recognized in Indiana. It occurs in an east-west belt from 50 to 120 miles broad that extends across the state from Ohio to Illinois. In the Upper East Fork basin the southern margin of the belt forms a V, the sides of which are approximately parallel to the southeastern and southwestern boundaries of the basin; the tip of the V is near the confluence of Sand Creek with the East Fork (fig. 4). The formation is named from the village of Trafalgar, just west of the western margin of the Upper East Fork basin; its type section is in the SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 8, T. 11 N., R. 4 E., Johnson County, at the western edge of the basin (Appendix, section 3).

The Trafalgar Formation was divided by Wayne (1963) into two principal units, the Cartersburg Till Member above and the Center Grove Till Member below. A silt bed at the top of the Center Grove member (Appendix, section 3, unit 4; section 5, unit 7; and section 6) defines the boundary between the units, but where this intertill silt is absent the Cartersburg and Center Grove tills cannot be positively identified, according to Wayne (1963, p. 48, 49), because the tills are not sufficiently distinct lithologically. This observation is confirmed by the experimental work of Harrison (1959), which indicates that there are no significant textural and mineralogical differences among various sampled till units in Marion County (including samples of the Center Grove and Cartersburg tills collected from the Upper East Fork area). The Center Grove can be identified in places by its greater quantity of included wood fragments, but this criterion is not very satisfactory.

Most of the surficial Trafalgar Formation in the Upper East Fork basin belongs to the Cartersburg member. The Center Grove member is the surface deposit in a belt about 12 miles wide that trends obliquely across the southeastern part of the basin southeast of a line between Rushville and Columbus (fig. 4). It is also the surficial unit in a small area in southern Johnson County and the northwest corner of Bartholomew County (Wayne, 1963, fig. 6).

The thickness of the Trafalgar Formation in the Upper East Fork basin ranges from 0 feet at the southern limit of the formation to about 150 feet in the northern part of the basin (Appendix, well records 17 and 19). At its type locality the formation is 25 feet thick (Appendix, section 3), but interpretations of driller's logs indicate that throughout most of the basin where both the Center Grove and Cartersburg Till Members are present the formation is somewhat thicker. Typically, it is between 30 and 50 or 60 feet thick; the Cartersburg is generally the thicker of the two members. South of the Cartersburg boundary the average thickness of the Center Grove member is about 20 feet.

Unoxidized till of the Trafalgar Formation is generally dark gray. Oxidation of finely divided iron disseminated throughout the till alters the color to various shades of grayish brown and yellowish brown. Except where it is leached, the till is strongly calcareous; it is described by soil scientists as a moderate-high or high lime till, which signifies a calcium carbonate equivalent of 20 to 50 percent (Indiana Soil Survey, 1956). Zones of secondary calcium carbonate within a few feet of the surface are not uncommon, but in general these zones are not cemented. In most places the till is firm and compact.

Till of the Trafalgar Formation is most commonly described by soil scientists as a loam to coarse clay loam till containing less than 28 percent clay (Indiana Soil Survey, 1956; Odell and others, 1960). A loam is a relatively even mixture of sand, silt, and clay that by definition (Soil Survey staff, 1951) contains less than 52 percent sand (2.0 to .05 mm), 28 to 50 percent silt (.05 to .002 mm), and 7 to 27 percent clay (finer than .002 mm). Mechanical analyses of nine samples of Trafalgar till from the Upper East Fork area, seven of which came from Rush County (Simmons, Kunkel, and Ulrich, 1937, p. 23) and two from Hancock County (Tharp and Simmons, 1930, p. 10, 16), indicate that the till averages 41.0 percent sand (2.0 to .05 mm), 37 percent silt (.05 to .005 mm), and 22 percent clay (below .005 mm). Harrison's (1959, tables 1-3) analyses of nine samples of Trafalgar till from Marion County,[1] two of which came from the Upper East Fork area (Appendix, section 6, units 1 and 7), indicate that the matrix of the till averages 4 percent granules (4 to 2 mm), 41 percent sand (2 to 1/16 mm), 35 percent silt (1/16 to 1/256 mm), and 20 percent clay (below 1/256 mm). Small pebbles (4 to 32 mm) make up about 7 percent of the total material below 32 millimeters in diameter. The grain-size distributions of the two samples from the Upper East Fork area were very similar to the average.

Microscopic analyses of the small pebble fractions of the Marion County samples show a preponderance of carbonate rocks, limestone pebbles averaging about 55 percent and dolomite pebbles about 16 percent (by weight) of the pebble assemblage (Harrison, 1959, table 3). Other sedimentary rocks present are shale (4 percent), sandstone (4 percent), chert (3 percent), and siltstone (1 percent). Acid igneous rocks (for example, granite, syenite, and monzonite) and various metamorphic rocks (including quartzites) average about 7 percent each; basic igneous rocks and miscellaneous rock types account for the remaining 3 percent of the assemblage (Harrison, 1959, table 3).

X-ray analyses of the silt and clay fractions from the Marion County samples indicate the presence of quartz, calcite, dolomite, illite, chlorite, mixed-layer clay minerals, and feldspar. Quartz and the carbonate minerals are much more abundant in the coarser fractions than in the finer, whereas the clay minerals show the reverse relationship; dolomite is more abundant than calcite in virtually all sizes (Harrison, 1959, table 1). The most abundant clay minerals in unweathered Trafalgar till are illite and chlorite (Harrison, 1959; Bhattacharya, 1962; Droste, Bhattacharya, and Sunderman, 1962). Kaolinite and montmorillonite seem to be virtually absent in unaltered till (Harrison, 1959; Bhattacharya, 1962), but they may be rather common species, along with degraded illite, degraded chlorite, and mixed-layer clay minerals, in oxidized and leached horizons of the weathering profile (Hensel and White, 1960; Bhattacharya, 1962; Droste, Bhattacharya, and Sunderman, 1962). Size fractions of 2.0 to 0.2μ from samples collected at depths of 30 to 36 inches at 15 localities in the Upper East Fork basin averaged 48 percent illite, 26 percent montmorillonite, 15 percent 14 Å mineral, and 12 percent kaolinite (Hensel and White, 1960, table 2).

In addition to till the Trafalgar Formation includes layers of gravel, sand, and silt that occur both as lenses (discontinuous layers) within the till and as relatively continuous beds that separate the formation into two or more units (Appendix, sections 3, 5, and 6). Such layers of sorted material range in thickness from an inch to about 10 feet, but commonly they are between 1 and 5 feet thick. The sand and gravel layers were deposited within the ice or near the ice margin by streams that derived both their discharge and load from melting ice. Some of the silt layers were also deposited by meltwater streams, but others are interpreted as deposits of windblown silt called loess.

One of these eolian silts was used by Wayne to divide the Trafalgar Formation into the Cartersburg and Center Grove members. The silt occurs at the top of the Center Grove member (Appendix, sections 3, 5, and 6) and was described by Wayne (1963, p. 49-50) as a thin gray to brown fossiliferous silt, commonly 4 to 12 inches thick. Except where it is leached, the silt is calcareous. Snail shells and wood fragments are generally present, especially in the upper part of the unit. A sample of the silt collected in southeastern Marion County (Appendix, section 6, units 3 and 4) was found to contain about 4 percent sand, 93 percent silt, and 3 percent clay (Harrison, 1963, table 2). The lithologic characteristics of the unit, especially grain size, strongly suggest that the silt is of eolian origin.

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[1] Of the 11 samples analyzed by Harrison, 9 are considered by Wayne (oral communication) to have come from the Trafalgar Formation. Two samples (11 and 13) were collected from the older Jessup Formation, according to Wayne.

In that part of the Upper East Fork basin where the Center Grove member of the Trafalgar Formation is at the surface, the silt cap on the Center Grove till is 18 to 40 inches thick (Odell and others, 1960). Soils are noncalcareous to a depth ranging from 42 to 70 inches (Indiana Soil Survey, 1956); they belong largely to the Russell catena and include the Russell series (well drained), the Fincastle series (imperfectly drained), and the Brookston series (poorly drained). Farther north the till and loess of the Center Grove member are buried by the Cartersburg till, which is the surface unit in a large part of the basin. This till is overlain in places by a veneer of loess that ranges in thickness from 0 to 17 inches (Indiana Soil Survey, 1956). Depth of leaching is less than in areas of the Center Grove member, ranging from 24 to 42 inches (Indiana Soil Survey, 1956). The soils developed on the Cartersburg member are mapped as the Miami, Crosby, and Brookston series, which are respectively the well-drained, imperfectly drained, and poorly drained members of the Miami catena.

Kame facies.–Within the area mapped as Trafalgar Formation there are many small isolated patches of sand and gravel (fig. 4). Most of these cover only a few acres or a few tens of acres each; several are too small in area to be shown on the map. Some are expressed topographically as crudely conical to irregularly shaped hillocks called kames, whereas others, termed eskers, occur as discontinuous low ridges that rise 10 to 50 feet above the general level of the surrounding area. These kames and eskers are composed mainly of stratified sand and gravel, which Wayne (1963) called the kame facies of the Trafalgar Formation.

The thickness of the kame facies at any given locality is roughly proportional to the height of the topographic feature in which the deposit occurs. In some kames layers of till are interbedded with the sand and gravel, but, on the other hand, the stratified materials may extend to some depth below the base of the hill. Thus the thickness of the kame facies varies considerably from place to place; in general, the kame and esker deposits of the Upper East Fork basin probably average about 20 feet thick (Appendix, well record 9, unit 1).

The lithologic character of kame and esker deposits also varies considerably, not only from place to place but even within a single deposit. Grain size is especially variable because of the stratified nature of the deposits, which, unlike till, may range from fine sand to coarse gravel within a vertical interval of a few feet. Laboratory analyses of single samples, therefore, yield results that are probably less indicative of the character of the deposit as a whole than are analyses of till samples. Nevertheless, analytical results provide information on the general nature of kame and esker deposits. Table 3 gives the results of size analyses of channel samples collected from kames in Hancock and Johnson Counties; the latter locality is about 3½ miles beyond the western boundary of the Upper East Fork basin but is within the kame belt of this general area (fig. 4).

Kame and esker gravel generally is characterized by a great variety of rock types, and so composition, as well as grain size, varies from locality to locality. In the Upper East Fork area, however, pebbles of carbonate rocks (limestone, dolomitic limestone, and dolomite) seem to constitute about three-fourths of the gravel fraction (table 4). Other sedimentary rocks--sandstone, siltstone, shale, and chert--probably range between 5 and 15 percent. The remainder consists of a variety of igneous and metamorphic rock pebbles: coarse-grained intrusive rocks, such

Table 3.--Size analyses of samples of the kame facies of the Trafalgar Formation
[Data from McGregor, 1960, fig. 13 and table 4]

Grade size	Percentage by weight in each grade size	
	North-central Hancock County (SE¼ SW¼ sec. 29, T. 17 N., R. 7 E.)	Northwestern Johnson County (SE¼ NE¼ sec. 16, T. 13 N., R. 3 E.)
Gravel:		
1 to 4 in --	32	1
½ to 1 in --	16	5
¼ to ½ in --	7	17
Sand:		
Below ¼ in -	45	77

Table 4.--Lithologic composition of gravel fractions from samples of the kame facies of the Trafalgar Formation [Data from McGregor, 1960, table 5]

Rock type	Percentage by weight	
	North-central Hancock County ($SE\frac{1}{4}$ $SW\frac{1}{4}$ sec. 29, T. 17 N., R. 7 E.)	Northwestern Johnson County ($SE\frac{1}{4}$ $NE\frac{1}{4}$ sec. 16, T. 13 N., R. 3 E.)
Limestone ------	20	23
Dolomitic limestone	22	15
Dolomite -------	32	46
Other sedimentary rocks --------	9	4
Igneous rocks ----	10	6
Metamorphic rocks-	6	6

as granite, syenite, granodiorite, diorite, and gabbro; fine-grained igneous rocks, such as rhyolite, andesite, and basalt; vein quartz; and the metamorphic rocks quartzite, gneiss, and schist. The percentage of each of these rock types is commonly less than 5 percent but in places may be much higher. (See McGregor, 1960, table 5, for greater detail on percentages of rock types in gravel samples.)

Soils developed on kame and esker deposits in the Upper East Fork Drainage Basin are mapped as the Bellefontaine series (Baldwin and others, 1922; Tharp and Simmons, 1930; Simmons, Kunkel, and Ulrich, 1937; Ulrich and others, 1948). The depth to fresh gravel commonly ranges between $2\frac{1}{2}$ and 4 feet.

JESSUP FORMATION

The Trafalgar Formation is underlain by the Jessup Formation (Wayne, 1963), which in general is the oldest unconsolidated unit of Pleistocene age now recognized in Indiana. In most places the Jessup rests directly on bedrock (Appendix, sections 1 and 2), but in a few localities it is underlain by a tongue of the Atherton Formation called the Cagle Loess Member (Wayne, 1958a; 1963, p. 35). Lithologically, the Jessup Formation is similar to the Trafalgar; it consists mostly of till but also includes thin beds or lenses of gravel, sand, silt, clay, peat, and marl (Appendix, sections 4 and 5).

Where it is at or near the surface in the southeastern and southwestern parts of the Upper East Fork Drainage Basin, the Jessup Formation is generally about 30 feet thick (Appendix, section 1; well records 3, 5, and 7). In many places, however, it is thinner (Appendix, section 2; well records 2 and 4) or even absent, whereas elsewhere it is thicker (Appendix, well record 1). The formation appears to reach a maximum thickness of nearly 100 feet (Appendix, well records 8 and 19), but typically it is only a few tens of feet thick (Appendix, well records 9, 16, and 17) throughout most of the basin.

The Jessup Formation was divided by Wayne into two members, the Butlerville Till Member of Illinoian age and the underlying Cloverdale Till Member of Kansan age. According to Wayne (1963, p. 54), the Cloverdale is marked by slightly wider oxidized zones along joint planes and by an apparent higher pebble content than the Butlerville, but in general the tills are not lithologically distinct. Where the two members are in contact they may be identified by reference to a well-developed paleosol at the top of the Cloverdale member (Appendix, section 1, unit 12).

The surficial Jessup Formation in the Upper East Fork basin (fig. 4) belongs entirely to the Butlerville member. Only one exposure of the Cloverdale member is known to be present within the Upper East Fork area, and at this locality the Cloverdale is buried, as elsewhere in the basin, by younger material. The unit is also exposed at several localities in adjacent areas, however, in northeastern Jennings County (Appendix, section 1), northern Brown County, and northwestern Marion County. Possibly, therefore, the Cloverdale till is present beneath the Butlerville throughout much of the Upper East Fork Drainage Basin.

Unweathered till of the Butlerville member is gray and strongly calcareous; the acid-neutralizing value or calcium carbonate equivalent is given as moderate to high (20 to 50 percent) in the Key to Indiana Soils (Indiana Soil Survey, 1956), but it probably ranges only from 20 to 30 percent (Ulrich and others, 1947, p. 78). The till is rather deeply weathered, however, and this characteristic distinguishes it from till of the Trafalgar Formation. Butlerville till is leached of its carbonate content to a depth of about 10 feet (Ulrich and others, 1947), in contrast to the much shallower depth of leaching on the Trafalgar tills. The color of Butlerville till in the unleached but oxidized zone is yellowish brown to brownish yellow.

The surficial till of the Jessup Formation is a moderately compact heterogeneous mixture of mineral and rock fragments that range in size from boulders to clay. The matrix of the till is commonly described as a loam to coarse clay loam (Indiana Soil Survey, 1956; Odell and others, 1960). Laboratory analyses of till considered by Wayne (oral communication) to belong to the Butlerville member were performed by Harrison (1959) on two samples from northwestern Marion County. The results show that the grain-size distribution of the till at this locality is very similar to that of the Trafalgar Formation: 4 percent granules (4 to 2 mm), 39 percent sand (2 to 1/16 mm), 39 percent silt (1/16 to 1/256 mm), and 18 percent clay (finer than 1/256 mm). Small pebbles (32 to 4 mm) constitute about 8 percent (by weight) of all material below 32 millimeters in diameter. It is probable that the texture of the Jessup and Trafalgar Formations is similar throughout a large area.

The pebble content of Jessup till is probably similar to that of Trafalgar till, at least in general aspect. In the two samples of Butlerville till from northwestern Marion County analyzed by Harrison (1959), pebbles of carbonate rock are dominant; limestone pebbles average about 58 percent and dolomite pebbles about 15 percent of all pebbles not more than 32 millimeters in diameter. Other rock types represented are sandstone (5 percent), siltstone (3 percent), shale (4 percent), chert (5 percent), acid igneous rocks (4 percent), basic igneous rocks (1 percent), and metamorphic rocks (5 percent).

Studies of the mineralogy of Jessup till have related mainly to changes in clay mineral content induced by weathering. For the most part, these studies have involved samples of Butlerville till collected in southwestern Indiana, and the degree to which the results would apply to the Butlerville and Cloverdale tills of the Upper East Fork area is not known. Furthermore, because of differences in sampling and analytical techniques, these studies have yielded results that are not directly comparable.

Silt and clay fractions of unweathered Butlerville till contain quartz, calcite, dolomite, feldspar, and various clay minerals that have been identified as chlorite, kaolinite, illite, montmorillonite, a 14 Å clay mineral, and mixed-layer clay minerals (Murray, Leininger, and Neumann, 1954; Gravenor, 1954; Harrison, 1959; Hensel and White, 1960; Droste, Bhattacharya, and Sunderman, 1962; Bhattacharya, 1962). Illite or degraded illite is the dominant clay mineral in both weathered and unweathered till (Gravenor, 1954; Hensel and White, 1960; Bhattacharya, 1962). Kaolinite is much less abundant than illite, although it is probably more common in both Jessup tills than in Trafalgar till (Bhattacharya, 1962). Montmorillonite was found by Murray, Leininger, and Neumann (1954) to be much more abundant in the upper part of the weathering profile than in unaltered Butlerville till, but other workers (Hensel and White, 1960; Bhattacharya, 1962; Droste, Bhattacharya, and Sunderman, 1962) have found the reverse relationship. Primary calcite and dolomite are, of course, absent from leached horizons.

The upland surface of the area mapped as Jessup Formation is veneered with wind-deposited silt (loess) similar to but for the most part older than that at the top of the Center Grove member of the Trafalgar Formation. In some places this loess blanket is apparently absent (see Gravenor, 1954), whereas elsewhere it may be as much as 7 or 8 feet thick. The principal lithologic characteristic of the loess is its uniformity of texture. According to Odell and others (1960), the loess is a silt loam; by definition a silt loam contains 50 percent or more silt (.05 to .002 mm) and 12 to 27 percent clay (below .002 mm), or 50 to 80 percent silt and less than 12 percent clay (Soil Survey staff, 1951, p. 210).

The soils of the area underlain by the Jessup Formation are mapped as the Cincinnati series (well drained), the Gibson series (moderately well drained), the Avonburg series (imperfectly drained), and the Clermont series (poorly drained). On the Decatur County soil map upland soils developed on 6 to 10 feet of loess overlying till are mapped as Clermont, whereas those soils derived largely from till are mapped as Cincinnati (Baldwin and others, 1922, p. 8). Apparently this distinction has been abandoned because both series, and also the Gibson and Avonburg, are now thought of as being developed

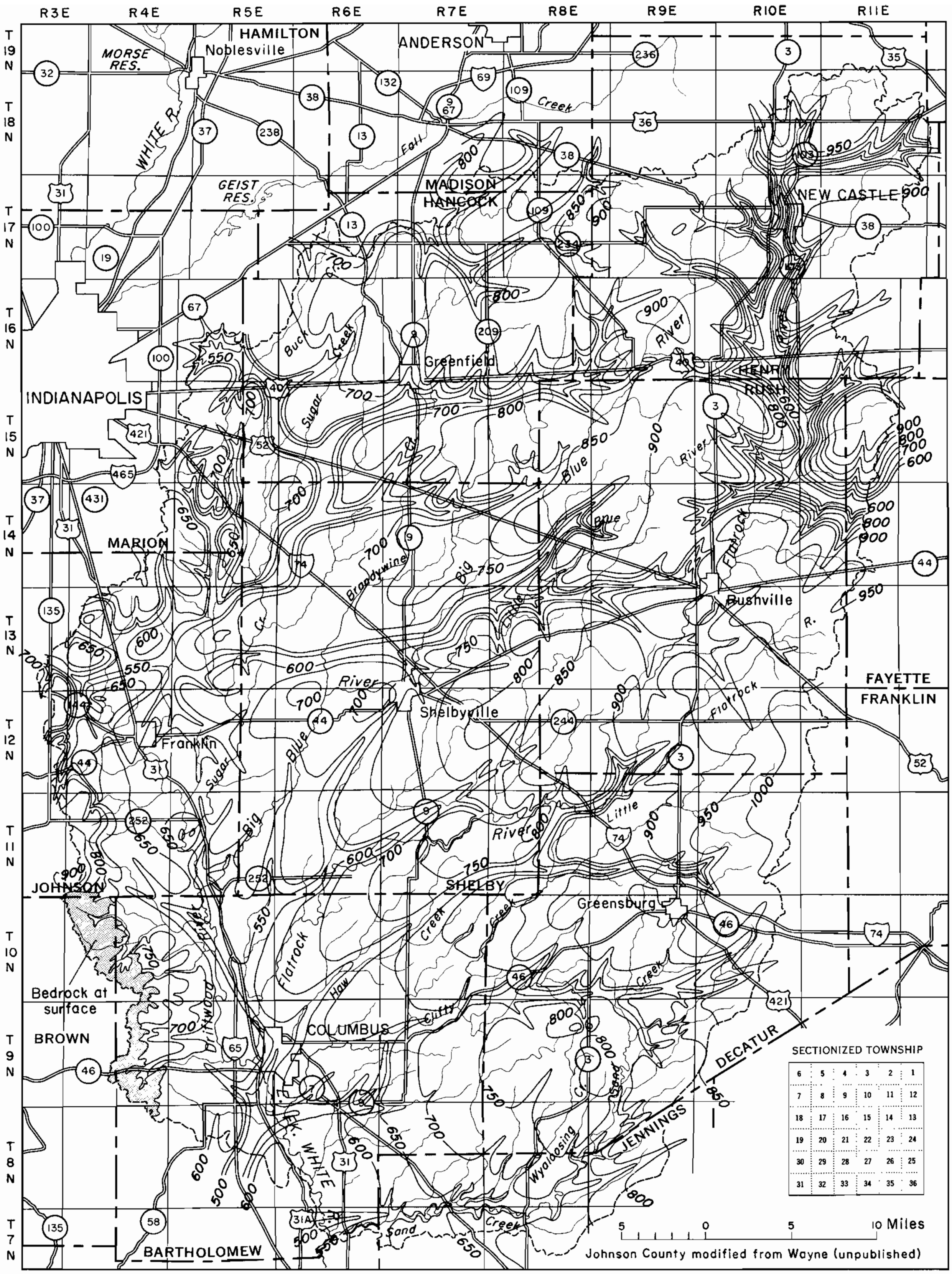

Figure 6. --Map of the Upper East Fork Drainage Basin showing topography on the bedrock surface. Contour interval 50 feet.

on loess of variable thickness (10 to 80 inches, according to Indiana Soil Survey, 1956; 0 to 36 inches, according to Odell and others, 1960) over Illinoian till.

TOPOGRAPHY AND DRAINAGE OF THE BEDROCK SURFACE

The bedrock topography and preglacial drainage of that part of Indiana north of the Wisconsin glacial boundary were discussed in some detail by Wayne (1956). Inasmuch as only the southeastern and southwestern parts of the Upper East Fork Drainage Basin lie beyond (south of) this boundary, much of the basin was considered in Wayne's study. Wayne and also McGrain (1949), in his Henry County study, outlined the probable courses of larger preglacial streams by drift-thickness contours, but they were unable to prepare bedrock-topography maps because accurate elevation data on the present topographic surface were not available at the time of their studies.

Prior to Pleistocene glaciation the Upper East Fork area was, for the most part, a maturely dissected westward- to southwestward-sloping plain with maximum relief of about 500 feet (fig. 6). Local relief was probably highest in the northeastern part of the area, where a valley that is now completely filled with glacial drift was cut some 300 feet below the adjoining preglacial upland. The highest part of this buried bedrock surface is in southeastern Rush County and northeastern Decatur County, where some points probably reach an elevation of 1,025 feet above sea level. Farther north, in northern Rush County and Henry County, the top of the bedrock seems to be about a hundred feet lower. The upland surface descends westward and southwestward to an elevation of about 625 feet in western Shelby County. The regional slope, therefore, averages nearly 12 feet per mile; its direction corresponds so closely with the direction of regional dip (see fig. 10) that one may be certain that the regional slope of the bedrock surface is structurally controlled.

In general, the preglacial drainage lines follow the regional slope as they cross the Upper East Fork area from east to west. Their courses seem to have been effectively blocked, however, in the western part of the area by a ridge or highland area underlain by the resistant rocks of the Borden Group. Consequently, the drainage in the southern

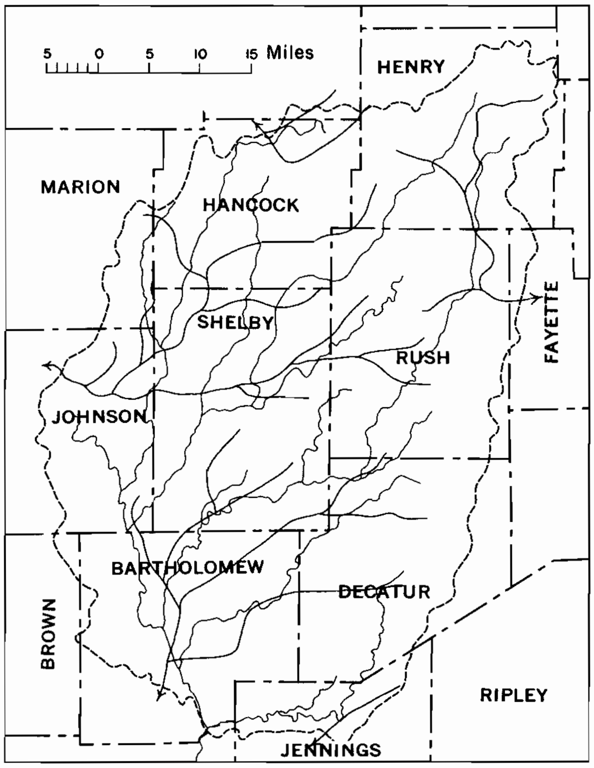

Figure 7. --Map showing present drainage (blue) and inferred preglacial drainage (red) in the Upper East Fork Drainage Basin.

part of the basin was deflected southwestward toward a master stream that developed along the strike of the less resistant Devonian and Mississippian shales. Drainage in the central part of the basin appears, however, to have left the area by a gap through the ridge, and that in the north seems to have flowed northwestward to either the Montclair or Anderson Valleys of Wayne (1956), which respectively emptied into the Wabash and Teays Valleys.

Most of the buried valleys that follow the regional slope originate near a divide that appears to trend nearly north-south through eastern Decatur County and southeastern Rush County, whence it extends northwestward to central Rush County (fig. 6). From here it continues northward to west-central or northwestern Henry County. A major divide with approximately this course was recognized by Wayne (1956, p. 18; fig. 7, p. 26) as a northerly continuation of what Malott (1922, p. 85) called the Laughery Escarpment. East of this divide the drainage entered the Whitewater drainage basin, according to Wayne

(1956, p. 45); the deep buried valley in the northeastern part of the area (fig. 6) almost certainly was part of the preglacial Whitewater system.

In summary, there are two significant differences between the present and preglacial drainage patterns of the Upper East Fork area (fig. 7). (1) Whereas the present drainage system is dominated by streams that flow in a south-southwesterly direction, several of the preglacial streams seem to have flowed more nearly westward. (2) Whereas the area is now drained entirely by the East Fork of White River, in preglacial time it contributed runoff to at least three, or perhaps four, different drainage basins. The alteration of the drainage is a direct result of Pleistocene glaciation, which not only destroyed the earlier pattern but also was the principal controlling factor in the development of the present pattern.

BEDROCK UNITS

The following descriptions of thickness and lithology of the various bedrock units are summarized principally from Dawson (1941), Murray (1955), Patton (1953b), and Shaver and others (1961), supplemented and modified by data collected in the preparation of this report. Principal sources of additional data used are well records on file in the Petroleum Section, Indiana Geological Survey, and published field observations from annual reports of predecessors of the Indiana Geological Survey (Borden, 1876; Collett, 1882; Elrod, 1882, 1883, 1884; Foerste, 1897, 1898; Kindle, 1901; and Price, 1900).

For purposes of illustration and discussion the bedrock formations of the Upper East Fork Drainage Basin are grouped into informally designated units, each of which is identified by a letter symbol that signifies its geologic age. The units are described in descending order, from youngest to oldest.

Rocks of unit M are Mississippian in age. The Borden Group, which makes up the larger part of unit M, is exposed at the surface or directly underlies unconsolidated deposits along the southwestern margin of the Upper East Fork Drainage Basin (fig. 8). A maximum thickness of approximately 500 feet of Borden rocks is present in this area, and most of the group is represented, only the upper part being absent. The component formations of the group are not, however, generally recognizable, and only the lowermost formation can readily be distinguished (fig. 9). The major part of the Borden Group consists principally of alternating beds of gray siltstone and gray soft shale. The siltstones are relatively resistant to erosion; they cap the hills of the Norman Upland and uphold the steep slopes of the Knobstone Escarpment. The New Providence Shale, the basal formation of the Borden Group, is about 175 feet thick and consists of gray, greenish-gray, and reddish-brown soft shale that weathers rapidly to a sticky, smooth clay. The Rockford Limestone, a brownish-gray dolomitic limestone about 5 to 10 feet thick, underlies the New Providence Shale and is here included as the basal member of unit M. The New Providence and the Rockford are not well exposed because they underlie glacial deposits along the western part of the Scottsburg Lowland.

The New Albany Shale (unit DM, fig. 8), which underlies the rocks of unit M, consists of gray and brown carbonaceous shale that weathers rapidly into small platy fragments. This formation, which is about 120 feet thick (fig. 9), underlies unconsolidated deposits in the eastern part of the Scottsburg Lowland in central Bartholomew County, southwestern Shelby County, and eastern Johnson County. Outcrops are found in northwestern Jennings County and southeastern Bartholomew County, where thin shale outliers lap up onto the limestones that underlie the Muscatatuck Regional Slope. The major part of the New Albany Shale is of Devonian age, but the upper few feet of the formation are of earliest Mississippian age.

Beneath the New Albany Shale is a group of limestones and dolomites of Devonian age. The contact between these rocks and the New Albany is apparently one of very slight disconformity, but because of the extensive cover of unconsolidated deposits in the Upper East Fork Drainage Basin, few exposures of the contact are available and these are inadequate to confirm the suggested relationship.

Limestones and dolomites of Devonian age (unit D, fig. 8) aggregate about 80 feet thick and consist of three formations (fig. 9). The uppermost of these is the North Vernon Limestone, a gray coarsely crystalline crinoidal limestone 1 to 3 feet thick, which in the Upper East Fork basin is recognizable only in Bartholomew County and northern Jennings County. Beneath this formation is the Jeffersonville Limestone, which consists of light-gray

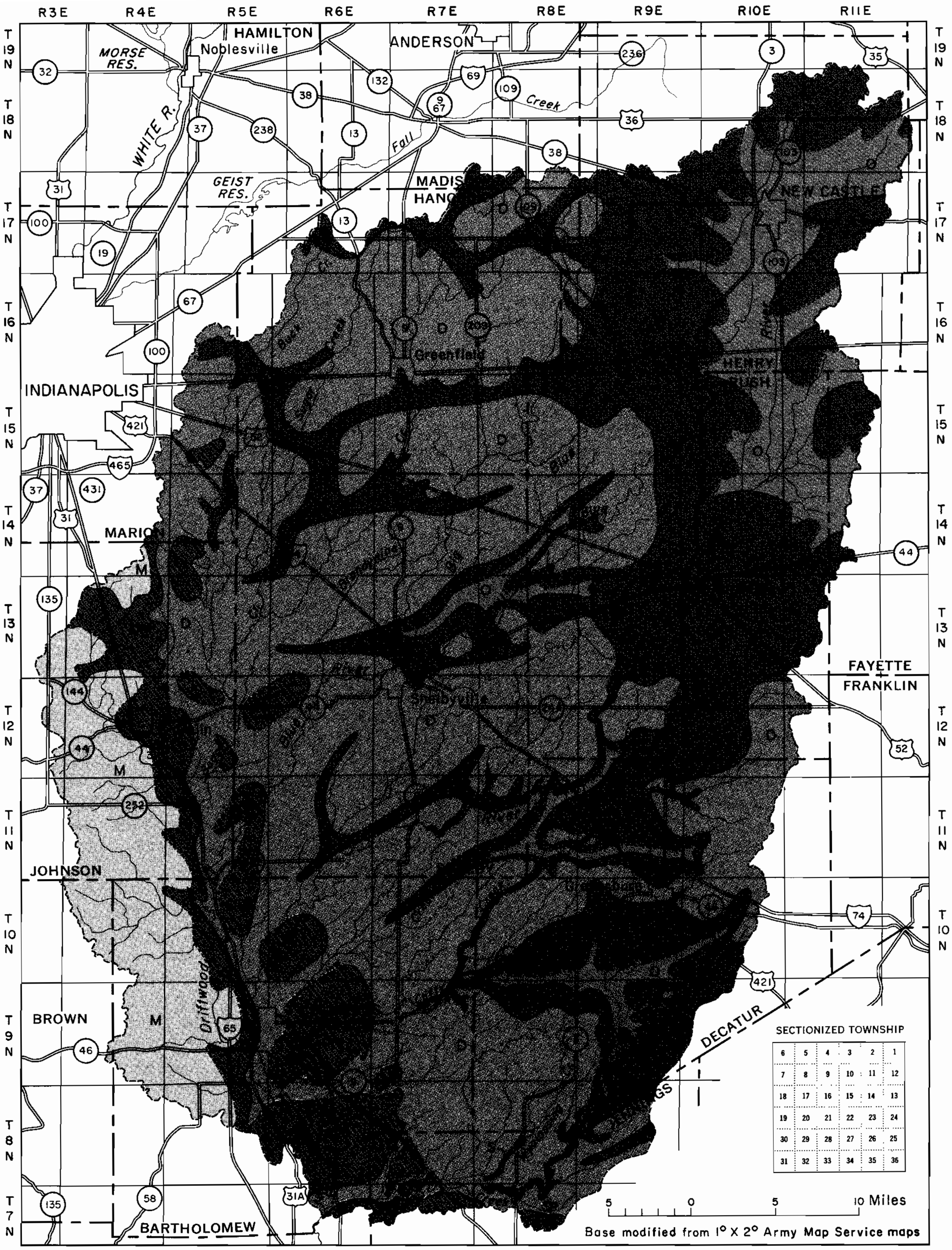

Figure 8. --Map showing bedrock geology of the Upper East Fork Drainage Basin.

EXPLANATION

M

Shales and siltstones of Mississippian age

DM

Black and gray shales of late Devonian and early Mississippian age

D

Limestones and dolomites of Devonian age

Limestones, dolomites, and shales of Silurian age

O

Shales and limestones of Ordovician age

Geologic boundary at or near surface

Geologic boundary inferred beneath thick unconsolidated deposits

thickly stratified fossiliferous limestone underlain by tan to brown dolomitic limestone and dolomite, altogether 35 to 80 feet thick. At the base of unit D is the Geneva Dolomite, a brown crystalline dolomite generally 30 to 40 feet thick but in a few places much thicker or much thinner. All these Devonian formations are best displayed along the valleys of Flatrock, Clifty, and Sand Creeks; elsewhere they are mostly drift covered.

The limestones and dolomites of Devonian age are separated from rocks of Silurian age by an uneven surface of disconformity that truncates several Silurian formations. The basal Devonian formation, the Geneva Dolomite, is of variable thickness and within the Upper East Fork area directly overlies at least four different formations with a combined thickness of more than 100 feet. At any single outcrop, however, the basal contact of the Geneva appears only slightly uneven.

Rocks of Silurian age (unit S, fig. 8) total 80 to 180 feet thick and consist of six formations (fig. 9). The uppermost of these is the Wabash Formation (Pinsak and Shaver, 1964, p. 34 ff.), gray dolomitic siltstone and shale about 50 feet in maximum thickness and present only along the north edge of the Upper East Fork Drainage Basin beneath unconsolidated deposits. The stratigraphic position and lithologic character of these rocks identify them as the Mississinewa Shale Member of this formation. Next below is the Louisville Limestone, a gray crystalline thinly stratified limestone 45 feet thick in the northern part of the area, thinner to the south, and absent in a few places in Decatur and Bartholomew Counties. Below this is the Waldron Shale, a gray calcareous shale with a maximum thickness of 15 feet, also thin and in places absent in Decatur County.

Thickness variations and local absence of the above three formations are the result of pre-Devonian erosion. The Laurel Limestone (fig. 9) was in a few places reached by this erosion, but it was not much reduced in thickness and is rather uniformly 50 feet thick throughout the mapped area. The Laurel consists of light-gray to light yellowish-brown very finely crystalline thinly stratified dolomitic limestone with much chert in the upper part. Beneath this is the Osgood Formation, gray argillaceous limestone and calcareous shale 10 to 20 feet thick. At the base of unit S is the Brassfield Limestone, a stratum of coarsely crystalline ledge-forming limestone usually called "cream" or "salmon"

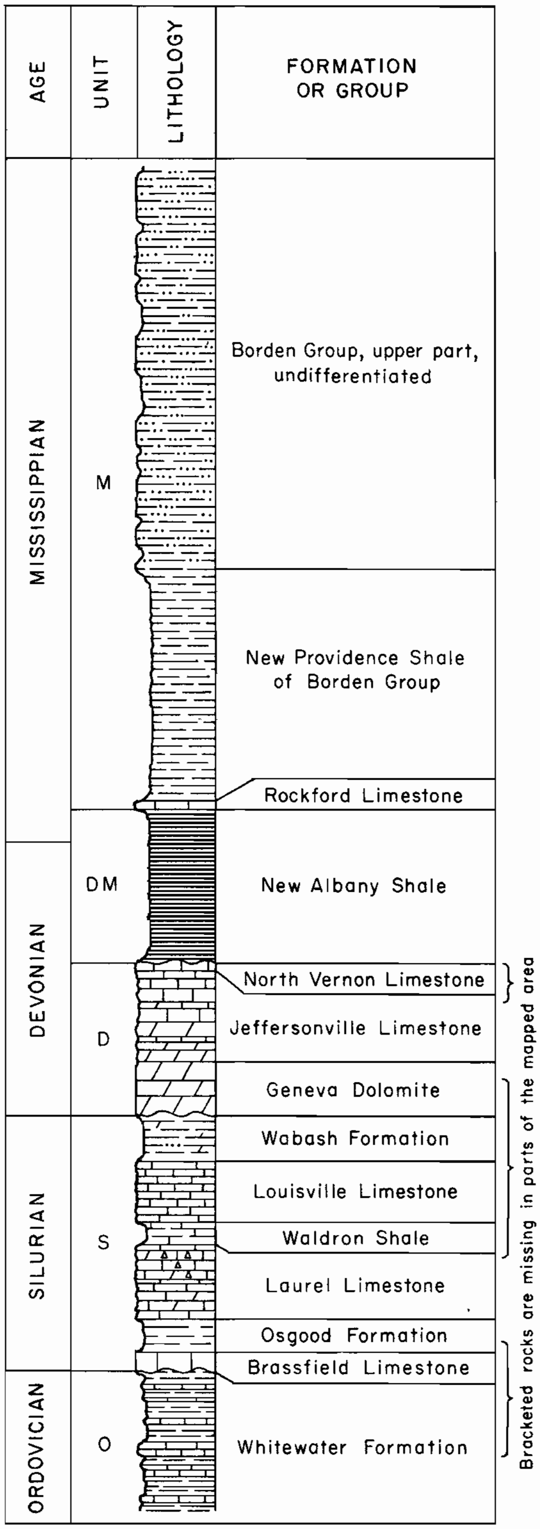

Figure 9.--Columnar section showing bedrock units of the Upper East Fork Drainage Basin. Vertical scale approximately 1 inch to 100 feet.

in color. Throughout its area of outcrop the Brassfield is normally 5 to 12 feet thick, but in a few places in Decatur and Jennings Counties the Brassfield is absent and the Osgood is the basal Silurian formation. Traced northwestward beneath the drift, however, the Brassfield thickens to about 30 feet in Hancock County. The contact of the Brassfield with underlying rocks of Ordovician age is an uneven surface of disconformity, and variations in thickness of the Brassfield are therefore probably the result of unequal deposition rather than erosion.

All the Silurian formations except the Wabash Formation are exposed along stream valleys in the southeastern part of the Upper East Fork Drainage Basin; along with the Wabash they also underlie at variable depths the unconsolidated deposits in the northeastern part of the area. Silurian and Devonian formations together support the Muscatatuck Regional Slope, and the resistant nature of several of these formations, particularly the Geneva Dolomite and the Laurel Limestone, is a factor in prominent stripped-surface development in this physiographic unit.

Rocks of late Ordovician age (unit O, fig. 8) are the oldest rocks exposed in the area studied. In accordance with the suggestion of Utgaard and Perry (1964, p. 17), these rocks are all placed in the Whitewater Formation of the Richmond Group. The Whitewater consists of about 100 feet of abundantly fossiliferous bluish-gray argillaceous limestones and calcareous shales (fig. 9). It comes to the surface only in the valley of Sand Creek; in other areas along the eastern margin of the basin it directly underlies the unconsolidated deposits.

Rocks older than late Ordovician do not reach the bedrock surface in the Upper East Fork Drainage Basin and are therefore not discussed here. Bedrock units are further described in the Appendix (sections 1 and 2; well records 1 and 6).

SUMMARY OF GEOLOGIC HISTORY

EARLIER DEPOSITIONAL HISTORY

The span of geologic history pertinent to the Upper East Fork Drainage Basin begins in late Ordovician time with deposition of the shales and limestones of the Whitewater Formation (fig. 9). These rocks record the presence of broad, shallow, warm, mud-bottomed seas in which life was abundant. Toward the end of Ordovician time the area was raised above sea level. The rocks were slightly tilted as part of the region was uplifted somewhat more than other parts, and erosion shaped these rocks into a land surface of gentle relief. Thus the Whitewater Formation was reduced in thickness, in places perhaps as much as 50 feet.

We know that this lost page of geologic history extends into Silurian time because the rocks that rest directly upon the unconformity that marks the old land surface are not of earliest Silurian age. The events of much of Silurian time are recorded, however, by a series of limestones and dolomites which indicate that the area was again covered by broad, shallow, probably warm seas. Terrigenous muds that later were compacted into shales form only a small part of the sediments, and from this fact it is inferred that land areas were far away and topographically low. In parts of the area mapped several of the Silurian formations are thin or missing as a result of a second episode of uplift, tilting, and erosion of the rock strata that began as Silurian time came to an end.

Deposition did not begin again until about a third of Devonian time had passed. The limestones and dolomites that were then deposited indicate open, shallow, warm seas that were even clearer than before. Late in Devonian time, however, the dominant mode of deposition changed. The area was invaded by a flood of fine-grained sediment, an indication perhaps of a sudden increase in the rate of erosion in the distant source regions. The sea was not deep, but wave-stirring of the bottom was prevented by a floating mat of marine plants from which a steady rain of fine-grained organic fragments fell, to be incorporated in the sediment accumulating on the sea floor. Thus the black New Albany Shale was formed (Lineback, in preparation). Few organisms lived on the dimly lit. muddy bottom, and most of the fossils in the New Albany represent floating or swimming organisms. Abundant plant debris and a few large trunks of trees rafted from the distant source regions are found among the fossil remains.

Black shale deposition continued without interruption into earliest Mississippian time but soon thereafter was succeeded by the deposition of bluish-gray muds that became the shales and siltstones of the Borden Group. These rocks apparently were laid down in shallowing water, perhaps on a large delta front. Sedimentation was rapid and waters were murky; sea life apparently was not abundant as the fossil record is very scanty. This evidence indicates that the distant landmass from which these sediments were derived was being more actively eroded than before.

With this depositional episode the earlier phase of geologic history of the Upper East Fork Drainage Basin fades into obscurity. Probably the seas continued to cover the area and deposition continued for some time, but rocks younger than those of the Borden Group are not present in the area, and one can only infer that if younger rocks were present, they have been removed by erosion. Finally the seas withdrew, and the rocks were uplifted and tilted to their present structural attitude.

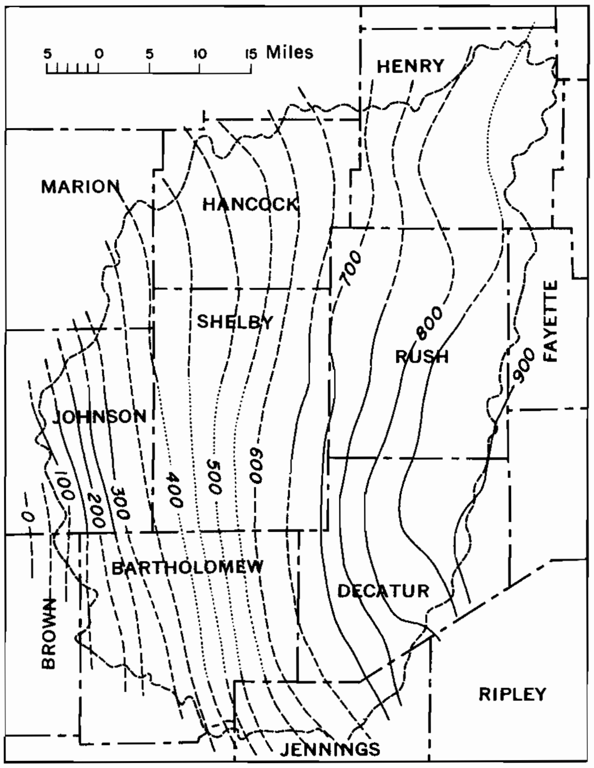

Figure 10.--Map of the Upper East Fork Drainage Basin showing generalized geologic structure. Contoured horizon is top of unit O (rocks of Ordovician age); other horizons show similar structural configuration. Contours dashed in areas of little information, dotted where surmised. Elevations in feet above sea level.

The westerly dip of approximately 20 feet per mile (fig. 10) was not the result of a single movement; rather, it represents the cumulation of many minor movements, dating back perhaps to Ordovician time and indicated in part by westward thickening of several of the bedrock formations.

EROSIONAL INTERVAL

Few details are known about the geologic history of the Upper East Fork area during the time interval between the emergence of the bedrock units and the deposition of the oldest unconsolidated deposits. The area probably underwent several cycles of uplift and erosion during this period, but there is no direct evidence of most of the events. The earliest cycle for which any evidence now remains probably terminated with the production of a gently rolling surface that Malott (1922) considered to be part of the Lexington or Highland Rim Peneplain. According to Malott (1922, p. 129-131), this erosion surface was formed during the early part of the Tertiary Period, but later workers (Wayne and Thornbury, 1951, p. 25; Thornbury and Deane, 1955, p. 32; Wayne, 1956, p. 46-47) believe that the age of the peneplain was middle to late Tertiary.

The formation of the Lexington Peneplain was followed, probably near the close of the Tertiary Period, by an episode of uplift that inaugurated a new cycle of erosion. Streams were rejuvenated and entrenched themselves some 200 to 300 feet below the uplifted Lexington surface; the surface is represented now, according to Malott (1922, p. 130-131), by flat-topped ridges at nearly accordant elevations between 900 and 1,000 feet in the Norman Upland (fig. 1) and by much of the upland surface of the Dearborn Upland just east of the Upper East Fork basin. The highest areas of the buried bedrock surface, at 900 to 1,000 feet elevation, in the east-central and northeastern parts of the basin (fig. 6) may also be part of this Tertiary erosion surface.

After most of the stream entrenchment had occurred, broad flood plains were formed along the major streams, particularly in areas of outcrop of the less resistant bedrock formations. Malott (1922, p. 166-170) believed that the Scottsburg Lowland was formed at this time as the streams downcut through the more resistant rocks in the upper part of the Borden Group into the softer New Providence and New Albany Shales below. The drainage pattern of the Upper East Fork basin at this time probably did not differ significantly from the bedrock drainage pattern postulated in figures 6 and 7.

PLEISTOCENE HISTORY

The final chapter in the geologic history of the Upper East Fork Drainage Basin begins with the advance of a huge continental ice sheet, which overspread much of North America during the Pleistocene Epoch. With the possible exception of a narrow strip of the Norman Upland in Brown and Bartholomew Counties, all the Upper East Fork basin was covered by ice sometime during the Pleistocene. In most places the ice probably eroded the preglacial terrain, but in some places little or no erosion of the preglacial surface seems to have occurred, as indicated by well records which show that the oldest glacial deposits present rest on disintegrated bedrock (Appendix, well record 7, unit 6; well record 14, unit 6) and on decomposed bedrock and residual soil (Appendix, well record 4, unit 4; well record 5, unit 5; and well record 19, units 7 and 8). Preglacial drainage lines were largely obliterated as the bedrock valleys became choked with ice and filled with glacier deposits and ice-derived meltwater sediments. (See Wayne, 1956, p. 49-57, for a discussion of major drainage changes in Indiana.)

Four distinct periods of cold climate or glacial ages, each followed by a warm postglacial period, affected the Upper East Fork area. During the time of the earliest glaciation, called the Nebraskan Age, continental ice extended as far south as the latitude of southern Indiana elsewhere in the Midwest (see Flint and others, 1959), but it is not known whether any part of Indiana was glaciated. The Upper East Fork area, if not actually covered by glacier ice, was probably subjected to intensive frost action, strong wind activity, and other processes that characterize periglacial regions. The Nebraskan Age was followed by the interglacial Aftonian Age, during which the climate of the Upper East Fork area was probably not unlike that of today.

During the second or Kansan episode of glaciation the ice sheet almost certainly covered most of the Upper East Fork Drainage

Basin, as indicated by the distribution of glacial sediments identified as Kansan in age by Wayne (1958a). In the southwestern part of the basin the western limit of the ice was probably controlled by the Knobstone Escarpment, which served as an effective barrier to further westward movement of the glacier. The ice eroded the subglacial surface in some places and dropped its load elsewhere as the Cloverdale till. Although only one exposure of the Cloverdale is known from the Upper East Fork area, it is presumed to underlie younger glacial sediments throughout much of the basin.

The retreat of the Kansan ice was initiated by a climatic amelioration that culminated in the Yarmouth Age. During this warm interglacial period the fresh Cloverdale till was weathered, and a new drainage pattern began to form on its surface. Flood-plain deposits were probably laid down along some of the new drainage lines, for Yarmouth flood-plain sediments have been identified by Wayne (1958a) at localities in Monroe County some 20 miles west of the Upper East Fork area and elsewhere in Indiana.

During the third major period of Pleistocene glaciation, known as the Illinoian Age, glacier ice again covered nearly all the Upper East Fork area. The Illinoian ice advanced beyond the Kansan drift border (see Wayne, 1958b), depositing the Butlerville till and destroying the still youthful drainage pattern that had formed on the surface of the Kansan drift. The Knobstone Escarpment again served as a barrier to westward movement of the ice in the southwestern part of the basin, so the Illinoian glacial boundary in that area lies only a few miles beyond the Kansan border. Warm periods within the Illinoian Age, during which times the ice sheet temporarily retreated, are suggested by thin fossiliferous silt beds within the Butlerville member elsewhere in Indiana (Wayne, 1963, p. 53-54, 55); at least one such bed may be present in the Upper East Fork area (Appendix, section 4, unit 1). The southeastern and southwestern parts of the Upper East Fork basin were not again glaciated after the final recession of the Illinoian ice sheet, as indicated by the fact that in these areas the Butlerville member is at the surface, whereas farther north it is buried by younger drift.

The interglacial Sangamon Age that followed the retreat of the Illinoian ice resulted in the formation of well-developed soil and weathering profiles on the Illinoian till (Appendix, section 2, unit 22; section 5, unit 5). Except in places where it has been eroded, the Sangamon soil is buried and preserved beneath younger deposits of Wisconsin age, as in the vicinity of Greensburg, where exposures showing fresh till overlying a deeply weathered older till were described more than 80 years ago by T. C. Chamberlin (1883, p. 333). A new drainage pattern also developed during the Sangamon interval, and the older alluvial sediments (Prospect Formation, fig. 4) that underlie low terraces along tributaries of the Driftwood River in western Bartholomew County may have been deposited at that time.

The warm Sangamon interval was followed by the Wisconsin Age, the fourth and last major cold period of the Pleistocene Epoch. The southern margin of the Wisconsin ice sheet was strongly lobate all across the eastern United States, as indicated by the distribution of Wisconsin till and by the concentric pattern of arcuate end moraines that mark significant stillstands of the ice front. One of the many tongues of ice that protruded from the southern part of the glacier was the East White Sublobe of the Ontario-Erie Lobe (Horberg and Anderson, 1956).

The East White Sublobe entered the Upper East Fork area from the northeast. As it advanced, a discontinuous thin layer of proglacial windblown silt (loess) was deposited on the Sangamon soil at the top of the Illinoian till, but the loess was soon buried in much of the area as the Center Grove till was plastered down by the advancing Wisconsin ice. In many places the basal part of the Center Grove till bears inclusions of weathered Butlerville till and Sangamon soil and wood fragments, which were scraped up by the Wisconsin ice and incorporated into its load (Appendix, section 2, unit 23; section 3, unit 2; section 4, unit 4; and section 5, unit 6).

Most of the Upper East Fork Drainage Basin was glaciated during the Wisconsin Age, although here, as elsewhere in Indiana and the southern Great Lakes region, the ice sheet did not extend so far south during the Wisconsin as during the Kansan and Illinoian Ages. The snout of the East White Sublobe pushed southward to the mouth of the basin in southeastern Bartholomew County and northwestern Jennings County, but the ice did not cover the southeastern and southwestern parts of the basin. At its maximum extent the edge of the ice stood along the distal (outer) margin of Leverett's (Leverett and Taylor, 1915,

p. 77-86) Shelbyville Morainic System. The margin of the East White Sublobe and also the lobate form of the ice are indicated by the boundary between the Jessup and Trafalgar Formations (fig. 4), along which the Illinoian drift sheet (Butlerville Till Member of the Jessup Formation) emerges as the surficial unit from beneath the thicker Wisconsin drift (Trafalgar Formation) to the north.

Not long after it had reached its maximum position, however, the East White Sublobe began to recede. Much meltwater from the shrinking ice was probably carried off by a large ice-marginal stream along the western edge of the sublobe. Great quantities of sand and gravel that constitute part of the outwash facies of the Atherton Formation were deposited by this stream between north-central and southeastern Bartholomew County (fig. 4), and also downstream below the mouth of the present Upper East Fork Drainage Basin.

The Wisconsin episode of glaciation was not a single event but was instead punctuated by several advances, stillstands, and recessions of the ice. The East White Sublobe readvanced at least once after retreating from its maximum or so-called Shelbyville position. In Malott's interpretation two such readvances took place, the first during his Champaign Substage and the second during his Bloomington Substage (Malott, 1922, p. 152; pl. 3), at which times the ice deposited the Champaign and Bloomington Morainic Systems of Leverett (Leverett and Taylor, 1915, p. 87-122). According to Wayne (1956, p. 56; 1963), however, stratigraphic evidence indicates that the ice readvanced only once during Wisconsin time.

In its second advance the East White Sublobe again entered the Upper East Fork area from the northeast, probably flowing about S. 35° -40° W. Proglacial outwash sediments deposited adjacent to and beyond the edge of the advancing ice were reworked by the wind, which scooped up and redistributed the finer grained particles over a much larger area. Thus the Center Grove till was blanketed with a veneer of loess. Cartersburg till was then deposited atop the loess by the readvancing ice sheet, and so the silt is now found sandwiched between the two main till units of the Trafalgar Formation. The East White Sublobe did not advance so far south as in its earlier movement, however. The edge of the ice during this second advance followed in a general way the distal boundary of the Champaign Moraine, as indicated by the general southern limit of the Cartersburg till sheet. In the southeastern part of the basin the Cartersburg till boundary follows a line that trends generally northeast-southwest between Rushville and Columbus (fig. 4). Southeast of this line loess deposition was probably continuous, as suggested by the greater thickness of loess in this area, where it is at the surface, than to the northwest, where it is overlain by Cartersburg till.

Many of the streams that constitute the strong subparallel drainage pattern of the eastern or slope portion of the Upper East Fork basin follow inherited glacial channels of probable Wisconsin age. If one assumes that the basin was actively glaciated only twice during Wisconsin time, as suggested by the stratigraphic evidence, then the elements of the present drainage pattern probably came into existence during the latter part of this second stade. The drainageways may have originated as channels beneath the ice, their courses being controlled mainly by the subglacial gradient and direction of movement of the ice (northeast to southwest). Alternatively, the drainageways may have originated as proglacial channels formed as the East White Sublobe receded to the northeast. If, on the other hand, the eastern margin of the glacier withdrew to the northwest, as may be indicated by the northeast-southwest trend of the Champaign and Bloomington Moraines of Leverett and Malott, then the channels probably originated as ice-marginal streams along the southeastern edge of the retreating ice.

Regardless of the exact origin of the glacial channels, sand and gravel deposits of the Atherton Formation were laid down as outwash-plain and valley-train deposits by meltwater streams that derived both their discharge and their load from the melting ice. Most of the silty and clayey materials were carried farther downstream and deposited beyond the mouth of the Upper East Fork Drainage Basin. Some of the finer grained materials in the outwash, however, were picked up by the wind and redistributed over the upland, as indicated by the thin blanket of loess that in places overlies the Cartersburg till.

Later in Wisconsin time the Upper East Fork Drainage Basin was not reglaciated, although the lobate southern margin of the ice sheet was very active farther north in Indiana. The Big Blue River drainageway and one or two other glacial channels may have carried meltwater drainage southwestward to the East Fork, but the evidence is obscure.

The modern drainage pattern of the Upper East Fork basin evolved during late Wisconsin and Recent time as some of the glacial drainageways were largely abandoned and other channels became established as permanent drainage lines. In these latter watercourses modern flood plains developed, upon which streams deposited alluvial sediments of the Martinsville Formation. Glacial outwash terraces were formed along some of the channels as the streams incised their courses below the surface of the older meltwater deposits. Wind erosion and deposition were still active processes, as evidenced by the formation of sand dunes along the valley of the East Fork at about this time. As the climate became warmer chemical weathering processes were intensified, and modern soils began to form on the various surficial materials.

APPLIED GEOLOGY

This report was prepared at the request of the Indiana Flood Control and Water Resources Commission to aid in the planning of dams and reservoirs in the Upper East Fork Drainage Basin, and it is therefore appropriate to summarize briefly that part of the data that applies directly to this planning. Among the factors considered in the selection of dam and reservoir sites are many that to some extent are controlled by elements of geologic nature, including topographic suitability, leakage potential, bearing strength of foundation materials, slope stability in the reservoir area, and availability of construction materials. Nongeologic factors that influence site selection are not considered here.

TOPOGRAPHIC SUITABILITY

Ideally, the surface area of a reservoir should not be excessive in relation to the volume of water stored, and the area should not fluctuate widely with changes in pool level. On the basis of both considerations, a reservoir basin with moderate topographic relief is required. The Upper East Fork Drainage Basin is deficient in such areas.

To obtain a rough quantitative estimate of variations in topographic relief within the Upper East Fork Drainage Basin, a brief statistical study was made. For each quarter congressional township of 9 square miles, a predetermined square-mile section served as a sample. The relief in each of these sampled sections was found by inspection of the $7\frac{1}{2}$-minute quadrangle maps. The average relief per square mile was computed for each group of four adjacent samples; local variation within each group was determined by subtracting the smaller relief value from the larger. Shaded areas in figure 11 are those in which average relief, as thus calculated, is in excess of 50 feet per square mile, and local variation is less than half the average relief. Such areas could be described as having fairly uniformly moderate relief and would generally be topographically suited to multipurpose reservoirs of moderate size.[2] Within the Upper East Fork basin there are 220 miles of major watercourses having a drainage area of 100 square miles or more. Less than 60 miles of these are in areas of fairly uniformly moderate relief; the remainder are in areas of low relief less well suited to moderate-sized multipurpose reservoirs.

LEAKAGE POTENTIAL

Leakage problems result when water is stored over highly permeable materials. In the Upper East Fork Drainage Basin serious leakage problems may be encountered in glacial sands and gravels and in fractured or cavernous limestones.

Two general areas of leakage must be considered, leakage around and under the dam itself and leakage from the reservoir into adjacent watersheds at lower elevations. The occurrence of highly permeable materials at all potential damsites must be carefully investigated, but their presence farther upstream generally will not present a serious problem unless there are short direct leakage paths into adjacent watersheds or unless long-term water storage is a major consideration.

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[2] Reservoirs of moderate size are here considered to be those with drainage areas of about 50 to 250 square miles and surface areas that range from perhaps 200 to 2,000 acres. Examples of moderate-sized reservoirs are Lake Lemon (Monroe County), Versailles Lake (Ripley County), Geist Reservoir (Marion County), Mansfield Reservoir (Parke County), and Morse Reservoir (Hamilton County).

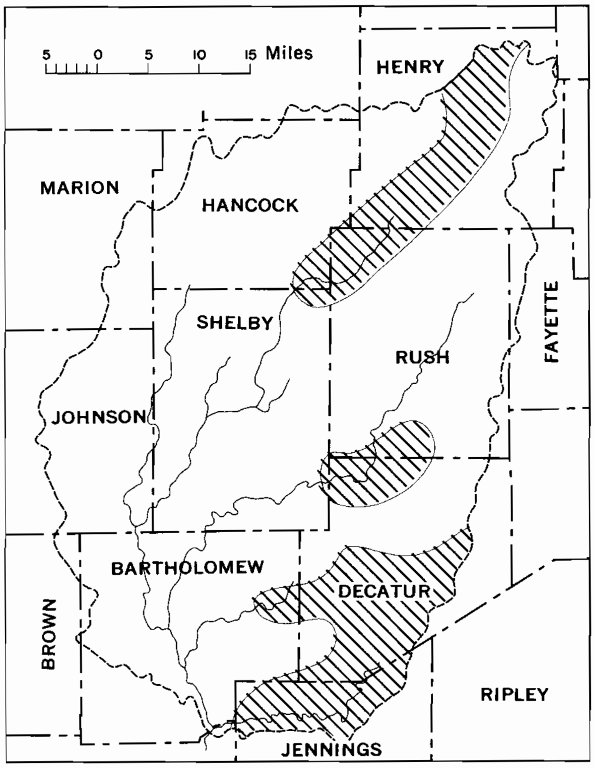

Figure 11.--Map of the Upper East Fork Drainage Basin showing streams that drain areas of at least 100 square miles and areas that have relatively uniform relief of at least 50 feet per square mile (shaded).

Deposits of the kame facies of the Trafalgar Formation are coarse grained (p. 22) and extremely permeable, and serious leakage problems undoubtedly would result should reservoir water come into contact with them. But since most of these deposits cover only relatively small areas on the uplands (fig. 4), the kame facies will present a problem only in those few places where individual kames and eskers are broken by valleys.

Locations in which coarse-grained sediments of the Atherton Formation occur at the surface are also unfavorable for dam and reservoir sites. Sand and gravel deposits of the outwash facies of the Atherton, because of their grain-size distribution (p. 17-18), stratified character, and high permeability, will present leakage problems similar to those of the kame facies of the Trafalgar Formation. The Atherton gravels are much more extensive, however, and because of their distribution along drainage lines (fig. 4) require careful consideration. Finer grained outwash materials (sand and silt) and dune sands are generally less permeable, and leakage can be expected to take place at a slower rate than through the coarser outwash. On the basis of purely geologic considerations, the selection of damsites in areas underlain directly by thick deposits of either the dune or outwash facies of the Atherton Formation is not recommended.

Alluvial deposits of the Martinsville and Prospect Formations are, for the most part, finer grained and less permeable than the outwash deposits of the Atherton Formation. In some places, however, the Martinsville consists mainly of sand and gravel and would be unfavorable for water retention, but where the formation is composed largely of silt and clay, leakage through the unit should not be a serious problem, particularly if the unit is thin and overlies till or relatively impermeable bedrock.

The till deposits of the Upper East Fork Drainage Basin should, in general, make excellent dam foundations and reservoir floors. The tills of both the Trafalgar and Jessup Formations are relatively dense, compact sediments with a moderately high content of silt and clay that appears to average about 55 or 60 percent (p. 20-21, 24). These tills are virtually impermeable and should present no leakage problem. Careful examination of any proposed damsite in areas underlain by the Trafalgar and Jessup Formations is recommended, nevertheless, to insure that the tills do not contain thick or extensive interbeds of sand, gravel, or silt.

Nearly all the limestone and dolomite formations of the Upper East Fork Drainage Basin are of Devonian, Silurian, or Ordovician age (fig. 9). The more soluble of these rocks, those that present the greater hazard in dam and reservoir construction, are in the North Vernon and Jeffersonville Limestones at or near the top of unit D. The North Vernon Limestone is nowhere more than 3 feet thick in the Upper East Fork area, but it is highly calcitic (Murray, 1955, p. 64) and is therefore quite soluble. Solution features are extensive in this formation in the limited areas in which it crops out, principally along the lower part of Sand Creek in Jennings County. The underlying and more extensive Jeffersonville Limestone is variable in composition (Murray, 1955, p. 64). In the upper part of this limestone, which typically is fairly calcitic and light gray, solution cavities are common. The lower part of the formation

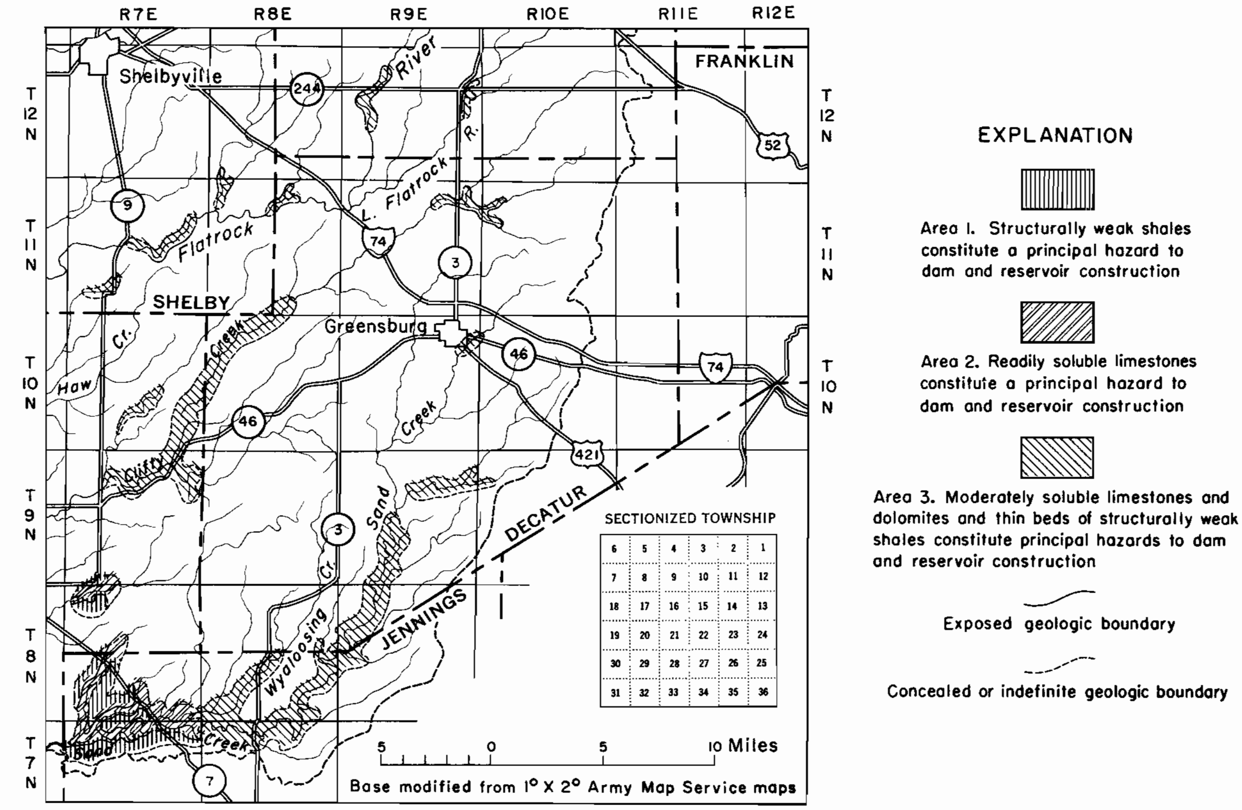

Figure 12.--Map of southeastern part of the Upper East Fork Drainage Basin showing areas of potentially cavernous and structurally weak bedrock.

is darker and dolomitic (Appendix, well records 1 and 6), and consequently is less cavernous. Winslow (1960, p. 15-16) emphasized this color relationship as an indicator of solubility of these rocks. The area of outcrop of the North Vernon and Jeffersonville Limestones is shown as area 2 on figure 12.

Beneath the zone of readily soluble limestones is a zone consisting principally of moderately soluble impure limestones, dolomites, and interspersed thin beds of shale (area 3, fig. 12). This zone includes all bedrock formations from the Geneva Dolomite down to the oldest rocks exposed within the area mapped, the Whitewater Formation (fig. 9). These rocks crop out principally along Sand, Clifty, and Flatrock Creeks (fig. 12), but solution features are not common in these areas except along Sand Creek. It seems probable that the thinner and older drift cover in the Sand Creek area allows bedrock topographic features, including sinkholes and other solution phenomena, to be better expressed at the present surface than they are in the younger drift area to the north and west. Buried solution features in the younger drift area probably are plugged with glacial deposits and in general constitute no major hazard, but investigation is warranted wherever the drift will be stripped from the bedrock, as at dam abutments and along spillways.

The Geneva Dolomite, the lowermost Devonian formation of the area (fig. 9), is a relatively pure dolomite and therefore is not commonly cavernous. Solution-widened joints are present in the Geneva, however, at several localities where it disconformably overlies the Louisville Limestone. These openings apparently have worked upward from similar solution-widened joints in the Louisville, a dolomitic limestone that is only moderately soluble. These conditions prevail principally along Sand and Wyaloosing Creeks in north-central Jennings County; to the north the Louisville becomes more dolomitic and less cavernous, and the Geneva rests on other less soluble Silurian formations. The cherty and dolomitic Laurel Limestone is variable in composition (Patton, 1953b, p. 27); solution features are common in the Laurel only along Sand Creek, where numerous caves, sinkholes, and solution-widened joints mark its outcrop. Older limestones in the area are too thin or too impure to contain extensive solution features.

BEARING STRENGTH OF FOUNDATION MATERIALS

The strength of the various earth materials upon which or against which the dam and appurtenant structures will rest is an important consideration in damsite planning. In the Upper East Fork Drainage Basin valley walls and valley floors typically are composed of different materials. Valley walls are commonly bedrock, till, or sand and gravel; valley floors are generally outwash or alluvial deposits. Sound unweathered material must be found in valley walls for the placing of abutments. Stable, relatively impermeable material must be found in valley floors to carry the load of the structure.

Bearing strengths of most of the unconsolidated sediments of the basin should be adequate to support earth-fill dams and associated structures. Alluvial sediments of the Martinsville and Prospect Formations and layers of silt and sand within the Trafalgar and Jessup Formations will probably present some problems, however, because of their relatively high water content. Sands and gravels of the Atherton Formation and of the kame facies of the Trafalgar Formation probably have adequate bearing values, but in many places they are loosely packed and may settle or slide under strong pressures; these sediments should therefore be carefully examined and tested. The Trafalgar and Jessup tills, where uniform and unweathered, should form good to excellent foundations; the deposits generally are dense and compact, most of the till having been subject to strong preconsolidation pressures at the time of deposition. The principal drawback of till is the possibility that mineralogic composition, grain size, density, consolidation, and permeability may change significantly within short distances.

Aside from the problem of leakage already discussed, most of the bedrock formations of the area are, where unweathered, suitably strong for abutments and foundations of earth-fill dams. One or more joint sets cross most of the limestone and dolomite beds, but except where they are enlarged by solution these joints probably will not present major structural problems.

Shales and shaly limestones weather rapidly on exposure, and where structures are to be founded upon such rocks it is generally necessary to take precautions to prevent the development of a weak and potentially plastic layer at the base of the structure. The New Providence Shale (fig. 9) weathers rapidly to a soft plastic clay, but this formation does not crop out extensively in the Upper East Fork Drainage Basin. The New Albany Shale, which crops out along the lower course of Sand Creek and on Little Sand Creek (fig. 8 and area 1, fig. 12), weathers less rapidly, but here the possibility of slippage along bedding surfaces must be investigated because the formation crops out in an area in which the westerly dip is steeper than average for the region (fig. 10). There are several beds of potentially weak shale in area 3 of figure 12; these shales will present minor problems in many places, but generally they are sufficiently thin that precautionary measures may be undertaken.

SLOPE STABILITY IN THE RESERVOIR AREA

When a new reservoir is filled with water for the first time, the drastically changed hydrologic conditions in earth materials that form the reservoir walls may cause formerly stable slopes to slump. This process may continue for several years, especially in areas between high and low pool levels. Most seriously affected are poorly sorted clay- and silt-rich unconsolidated sediments, such as tills. Many sands and gravels are not significantly less stable when wet than when dry. Sound bedrock walls are least likely to be affected except where held up in part by shales, which become plastic and slippery when wet and are likely to permit sliding of otherwise sound overlying material.

Slumping is not likely to be more than a minor problem at most potential reservoir sites in the Upper East Fork Drainage Basin. Probably the most serious result of slumping will be slight reductions in permanent pool capacity and useful reservoir life.

AVAILABILITY OF CONSTRUCTION MATERIALS

Construction materials suitable for earth-fill dams are available in ample supply in most parts of the Upper East Fork Drainage Basin. Most of the necessary materials are available from the unconsolidated deposits. Unweathered tills of both the Trafalgar and Jessup Formations, because of their dense, compact character and moderately high content of silt and clay (p. 20-21, 24), are virtually impermeable and should make excellent rolled-earth fill. Beds or lenses of sand and gravel that occur as interlayers within these formations should cause no serious problem except in the few places where these more permeable layers constitute a large part of the deposit.

Sand and gravel for use as concrete aggregate, subgrade material, road metal, or other purposes is present in nearly all parts of the area (fig. 4). Coarse sand and gravel is available from kames and eskers (kame facies of the Trafalgar Formation), from valley trains and outwash plains (outwash facies of the Atherton Formation), and in some places from flood-plain deposits (Martinsville Formation). In general, material from the Martinsville Formation is less desirable than that from the Trafalgar and Atherton Formations because of its higher content of silt and clay and also organic matter. The windblown sands (dune facies) of the Atherton Formation are too fine grained for aggregate and road metal, and deposits of the Prospect Formation in western Bartholomew County are unsuitable for the same reason.

Deleterious rock types are present in nearly all gravel deposits. Available data indicate that the gravel deposits in the Upper East Fork area contain pebbles or chips of chert, hard sandstone and siltstone, shale, and some soft igneous and metamorphic rocks, such as schist (p. 18-19, 22-23). The percentages of these deleterious rock types are generally low, but because they vary from place to place lithologic analyses should be made to determine if the gravel at any particular site is satisfactory for the intended use.

Limestone and dolomite suitable for riprap and, if necessary, for crushed-stone aggregate are available in and adjacent to Decatur County, principally along the valleys of Sand Creek, Clifty Creek, and Flatrock River.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

1. Within the Upper East Fork Drainage Basin only limited areas are topographically suitable for moderate-sized to large multipurpose reservoirs, and these areas present moderate to severe leakage problems that probably would be expensive to overcome. Geologically, the basin is much better suited to small dams and reservoirs than to large ones.

2. In view of the above factors, we recommend that an integrated plan of watershed control be formulated for the entire drainage basin. This plan should take into account the geologic conditions and limitations in each part of the area.

3. At least two types of control structures, both designed primarily for temporary retention of floodwaters, should be considered:

(a) Conventional-type structures at topographically suitable sites, with drainage areas of 50 to 250 square miles. Because of the short periods during which these structures would be used, leakage problems could probably be satisfactorily resolved.

(b) Low, wide structures in areas of low relief with larger drainage areas. Leakage problems would be minimized, partly because the reservoirs would be shallow.

4. Several areas, mostly in the slope part of the basin, merit further investigation as possible sites for conventional-type structures designed for temporary retention of floodwaters. Sand Creek above Brewersville, Clifty Creek in the vicinity of Hartsville, Flatrock River near St. Paul, Big Blue River above Morristown, Sugar Creek above Boggstown, and numerous other sites on smaller streams should be studied if this type of reservoir is desired.

5. Areas of low relief possibly suitable for broad shallow reservoirs for the temporary retention of floodwaters occur in the southwestern or trough part of the basin. Driftwood River, Flatrock River, Big Blue River, and Sugar Creek in the area between Columbus, Franklin, and Shelbyville should be studied if this type of reservoir is suitable for flood-control requirements.

6. Adequate supplies of suitable construction materials are available nearly everywhere throughout the Upper East Fork Drainage Basin, and foundation problems appear to be minor in most parts of the area.

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APPENDIX

MEASURED SECTIONS

Section 1. NW$\frac{1}{4}$ NE$\frac{1}{4}$ and NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 16, T. 7 N., R. 9 E., Jennings County; road cut and spillway cut at mouth of Brush Creek Reservoir about 1$\frac{1}{2}$ miles northwest of Butlerville. Description modified from Murray, 1955, p. 31-33, and Wayne, 1963, p. 69-70.

	Thickness (ft)
Illinoian Stage:	
Jessup Formation:	
Butlerville Till Member:	
16. Clay: silty, sandy, light yellowish-gray, mottled, noncalcareous	5.0
15. Till: sandy, clayey, brown, noncalcareous	2.0
14. Till: conglomeratic, gray, noncalcareous; brown along joint planes	5.0
13. Till: conglomeratic, gray, calcareous; material is oxidized to brown along joint planes; basal part of unit less strongly calcareous than remainder; unit contains inclusions of dark yellowish-brown noncalcareous till. This unit thickens considerably on east side of bridge, where it contains an abundance of fossil wood	15.0
Kansan Stage:	
Jessup Formation:	
Cloverdale Till Member:	
12. Till: clayey, dark yellowish-brown, noncalcareous; contains abundant chert pebbles and some quartzite pebbles; interpreted as part of a truncated paleosol	1.0
Total thickness of Pleistocene section	28.0
Devonian System:	
Geneva Dolomite:	
11. Sand: yellowish-white, fine-grained; composed largely of authigenic quartz; loosely consolidated; contains a few fossils	1.0
10. Sand: yellowish-gray, thick-bedded; composed largely of authigenic quartz and interstitial calcite; basal contact smooth	1.8
Total thickness of Geneva Dolomite	2.8
Silurian System:	
Laurel Limestone:	
9. Limestone: medium bluish-gray, brownish-yellow in upper few beds, thick-bedded, dolomitic; contains beds of light-gray chert	9.2
8. Limestone: light bluish-gray, thick-bedded; contains a few zones of dark bluish-gray siliceous nodules	12.0
7. Limestone: light bluish-gray, medium-grained, medium-bedded, moderately fossiliferous, glauconitic. The upper part is the spillway floor	5.2
6. Limestone: pale yellowish-gray, fossiliferous with fine-grained matrix; cherty	5.6

Silurian System--Continued	Thickness (ft)
Laurel Limestone--Continued	
5. Limestone: gray to orange-brown; thin- to thick-bedded; lower part fossiliferous; cliff forming	5.3
4. Limestone: brownish-gray, thin-bedded, argillaceous	1.4
3. Limestone: pale yellowish-gray, mottled with yellowish-brown, medium-bedded, moderately fossiliferous	1.4
2. Siltstone: medium bluish-gray, thin-bedded, calcareous, clayey; contains a few limestone nodules and scattered fossils	1.6
1. Limestone: yellowish-brown to gray, mottled, medium-bedded; bedding surface irregular; in places fossiliferous; base not exposed	2.5
Total exposed thickness of Laurel Limestone	44.2

Section 2. $S\frac{1}{2}NE\frac{1}{4}$ sec. 6, T. 8 N., R. 7 E., Bartholomew County; Meshberger Stone Co. quarry about $2\frac{1}{2}$ miles northeast of Elizabethtown. Description modified from Murray, 1955, p. 29-31.

Wisconsin Stage:	Thickness (ft)
Trafalgar Formation:	
Center Grove Till Member:	
24. Till: sandy, clayey, brown, noncalcareous; upper part of unit severely weathered	5.0
23. Till: very sandy, silty, yellowish-brown, calcareous; contains wood fragments in some places	15.0
Illinoian Stage:	
Jessup Formation:	
Butlerville Till Member:	
22. Till: clayey, brown, noncalcareous; represents lower part of buried soil profile	3.0
21. Till: clayey, medium-gray, calcareous	7.0
Total thickness of Pleistocene section	30.0
Devonian System:	
New Albany Shale:	
20. Shale: dark brownish-gray, mottled, weathered	2.7
19. Shale: gray, platy, finely micaceous, hard	0.3
Total thickness of New Albany Shale	3.0
North Vernon Limestone:	
18. Limestone: upper 1.1 ft dark gray, dense, fossiliferous; lower 1.5 ft gray to tan, coarsely crystalline, fossiliferous	2.6
Total thickness of North Vernon Limestone	2.6
Jeffersonville Limestone:	
17. Limestone: upper 3.0 ft tan, crystalline, medium bedded, fossiliferous; lower 4.4 ft tan, fine grained, mottled; contains fossil detritus. A zone of lenticular and nodular chert, 0.4 ft in average thickness, occurs 1.0 ft from base	7.4
16. Limestone: tan, fine-grained, dolomitic; black shale partings occur at base and top	1.3

Devonian System--Continued	Thickness (ft)
Jeffersonville Limestone--Continued	
15. Limestone: gray, dense, dolomitic	3.6
14. Limestone: tan, dense, chalky, dolomitic	1.0
13. Limestone: brown, dense, crystalline; laminated in upper part	1.8
12. Limestone: tan, granular, porous, dolomitic; shows scattered calcite faces; contains breccia in upper part	1.1
11. Limestone: tan, dense, dolomitic; laminated in upper part	3.5
10. Dolomite: light-tan, nearly white when dry, chalky, soft, slightly banded	6.4
9. Dolomite: brown, chalky, banded	1.3
8. Limestone: tan, dense, laminated, dolomitic; fractures cemented with calcite	2.2
7. Dolomite: gray, chalky, argillaceous, banded	1.3
6. Limestone: upper 1.0 ft gray, finely granular, chalky; contains scattered calcite crystals. Lower 1.7 ft gray to dark gray brown, massive, dolomitic, granular to dense	2.7
5. Limestone: light-gray, granular, clastic, dolomitic, soft; contains fossils and fossil fragments	8.9
4. Limestone: light-gray to light-brown, dense to fine-grained, dolomitic, fossiliferous	3.3
Total thickness of Jeffersonville Limestone	45.8
Geneva Dolomite:	
3. Dolomite: brownish-gray to chocolate-brown, finely granular to saccharoidal, massive	3.8
2. Dolomite: medium-brown to chocolate-brown, granular to saccharoidal, massive; contains large masses of white to yellow coarsely crystalline calcite	26.1
Total thickness of Geneva Dolomite	29.9
Louisville Limestone:	
1. Limestone: dark medium-gray, fine-grained, crystalline, massive, dolomitic. Measured to water level	4.2
Total thickness of Louisville Limestone	4.2

Section 3. SW¼ SE¼ NW¼ sec. 8, T. 11 N., R. 4 E., Johnson County; stream cut along Buckhart Creek 500 feet north of Indiana Highway 252 about 2 miles southeast of Trafalgar. Section measured by William J. Wayne; description modified from Wayne, 1963, p. 73-74.

Wisconsin Stage:	Thickness (ft)
Trafalgar Formation:	
Cartersburg Till Member:	
11. Silt loam: light-gray; leaf litter at top	1.3
10. Till: pale-brown, dark-brown along fractures, noncalcareous	1.6
9. Till: silty, pebbly, pale-brown, calcareous	2.6
8. Silt: light olive-gray, noncalcareous, porous	1.0
7. Sand: clayey, dark-brown, noncalcareous	1.6
6. Silt: yellowish-brown, calcareous, laminated	1.6

	Thickness (ft)
Wisconsin Stage--Continued	
Trafalgar Formation--Continued	
Cartersburg Till Member--Continued	
5. Till: silty, conglomeratic, dark grayish-brown in upper part, dark-gray in lower part, calcareous, compact	6.9
Center Grove Till Member:	
4. Silt: dark-gray to dark-brown, calcareous except in upper 5 cm, fossiliferous; upper 15 cm of unit contains both mollusk shells and plant remains; interpreted as loess	1.0
3. Gravel: sandy, silty, dark-brown, calcareous	1.0
2. Till: stony, dark-gray, calcareous; oxidized surface is dark yellowish brown; lower part of unit contains contorted lenses of strong-brown noncalcareous till and fragments of wood	6.6
Illinoian Stage:	
Jessup Formation:	
Butlerville Till Member:	
1. Till: stony, strong-brown, noncalcareous	1.8
Total thickness of section	27.0

Section 4. $SE\frac{1}{4}$ $NE\frac{1}{4}$ $NE\frac{1}{4}$ sec. 31, T. 11 N., R. 6 E., Shelby County; stream cut about $3\frac{1}{2}$ miles east of Edinburg. Section measured by William J. Wayne in August 1950.

	Thickness (ft)
Wisconsin Stage:	
Atherton Formation:	
Outwash facies:	
5. Sand: yellowish-brown; thin gravel layer at base	6.0
Trafalgar Formation:	
Center Grove Till Member:	
4. Till: dark grayish-brown, calcareous; contains stringers and inclusions of wood and of gray noncalcareous materials interpreted as paleosol fragments; base very uneven; maximum thickness	4.0
Illinoian Stage:	
Jessup Formation:	
Butlerville Till Member:	
3. Till: sandy, pebbly, yellowish-red, calcareous, very compact	3.0
2. Till: sandy, pebbly, gray to brown, calcareous, compact; contains wood fragments at base	2.0
1. Silt: dark-gray, calcareous, compact; contains wood fragments at top; base concealed	1.5
Total thickness of section	16.5

Section 5. Center $NW\frac{1}{4}$ sec. 4, T. 12 N., R. 9 E., Rush County; stream cut along Flatrock River about $3\frac{1}{2}$ miles northwest of Milroy. Section measured by William J. Wayne; description modified from Wayne and Thornbury, 1955, p. 25-26.

	Thickness (ft)
Wisconsin Stage:	
Trafalgar Formation:	
Cartersburg Till Member:	
10. Till: silty, sandy, yellowish-brown, calcareous	8.0

Wisconsin Stage--Continued	Thickness (ft)
Trafalgar Formation--Continued	
Cartersburg Till Member--Continued	
9. Till: silty, sandy, stony, brownish-gray, calcareous	6.0
8. Gravel and sand: silty, brown, calcareous; unit is lenticular	2.5
Center Grove Till Member:	
7. Silt: massive, gray to brownish-gray, calcareous, fossiliferous; contains scattered gastropod shells; interpreted as loess	1.5
6. Till: pebbly, sandy, dark olive-gray, calcareous; contains inclusions of noncalcareous clay and till	4.0
Illinoian Stage:	
Jessup Formation:	
Butlerville Till Member:	
5. Clay: silty, sandy, medium-gray mottled with dark reddish-brown, noncalcareous; blocky structure; upper part of unit contains minor amounts of peaty material; interpreted as a paleosol	2.4
4. Till: gray to brown, noncalcareous; secondary limonite in upper part	1.0
3. Till: medium-gray, calcareous	1.0
2. Gravel: silty, grayish-brown, calcareous	2.0
1. Till: very silty, medium-gray, calcareous; base concealed	3.0
Total thickness of section	31.4

Section 6. SW¼ NE¼ SE¼ sec. 33, T. 15 N., R. 5 E., Marion County; stream cut along Big Run about 3 miles north of Acton. Section measured by W. Harrison; description modified from Harrison, 1959, p. 27.

Wisconsin Stage:	Thickness (ft)
Trafalgar Formation:	
Cartersburg Till Member:	
7. Till: upper half of unit is oxidized; Harrison sample 18	28.0
Center Grove Till Member:	
6. Silt: dark-gray, humus-rich	0.1
5. Sand: coarse; oxidized in places	1.0
4. Silt: unoxidized, unfossiliferous, contorted; Harrison sample 20	0.5
3. Silt: slightly fossiliferous, contorted; contains wood fragments; Harrison sample 20	2.0
2. Pebble gravel	0.5
1. Till: gray, dense; Harrison sample 22; base concealed	3.0
Total thickness of section	35.1

WELL RECORDS

Well record 1. NW$\frac{1}{4}$ NE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 24, T. 8 N., R. 5 E., Bartholomew County. Waterbury No. 1 Lee; permit no. 5373. Surface elevation 641 ft; total depth 1,608 ft. Descriptions of unconsolidated deposits from driller's log on file in the Petroleum Section, Indiana Geological Survey (geologic interpretations in parentheses); descriptions of bedrock units summarized from sample study by Andrew J. Hreha, Petroleum Section, Indiana Geological Survey.

	Thickness (ft)	Depth (ft)
Unconsolidated deposits, 69 ft:		
1. Clay (till; Butlerville Till Member, Jessup Formation)	16	16
2. Sand, soupy	6	22
3. Clay, yellow (probably till; probably Cloverdale Till Member, Jessup Formation)	31	53
4. Sand, black	4	57
5. Clay	7	64
6. Sand, black	5	69
New Albany Shale, 71 ft:		
7. Shale, dark-gray	19	88
8. Shale, greenish-gray	22	110
9. Shale, brownish-gray	14	124
10. Shale, black	16	140
Jeffersonville Limestone, 58 ft:		
11. Limestone, light-gray, finely crystalline	34	174
12. Dolomite, yellowish-brown, medium crystalline	24	198
Geneva Dolomite, 16 ft:		
13. Dolomite, brown, finely crystalline	16	214
Waldron Shale?, 25 ft:		
14. Dolomite, light-gray, argillaceous	25	239
Laurel Limestone? and Osgood Formation?, 70 ft:		
15. Limestone, light-gray, medium crystalline	24	263
16. Dolomite, gray to yellowish-brown, finely crystalline	46	309
Brassfield Limestone, 22 ft:		
17. Dolomite, yellowish-brown, finely crystalline, cherty	18	327
18. Limestone, light yellowish-brown, fossiliferous	4	331
Richmond, Maysville, and Eden Groups, undifferentiated, 689 ft:		
19. Limestone, gray to yellowish-brown, in part argillaceous, fossiliferous	194	525
20. Shale, gray to greenish-gray, calcareous; some gray limestone	495	1,020
Trenton Limestone, 94 ft:		
21. Limestone, white to light yellowish-brown, in part cherty, medium crystalline	94	1,114
Black River Limestone, 430 ft:		
22. Limestone, white to light yellowish-brown, very finely crystalline	430	1,544
Joachim Dolomite, 56 ft:		
23. Dolomite, yellowish-brown, very finely crystalline; thin gray calcareous shale at base	56	1,600
St. Peter Sandstone, 8 ft drilled:		
24. Sandstone, white, coarse, unconsolidated	8	1,608

Well record 2. $SE\frac{1}{4}$ $SE\frac{1}{4}$ sec. 36, T. 9 N., R. 4 E., Bartholomew County. Surface elevation 675 ft; total depth 222 ft. Driller's log on file in the Petroleum Section, Indiana Geological Survey (geologic interpretations in parentheses).

	Thickness (ft)	Depth (ft)
1. Soil	2	2
2. Hardpan, yellow (oxidized till; Butlerville Till Member, Jessup Formation)	10	12
3. Clay, yellow, soft	6	18
4. Clay, yellow, wet	7	25
5. Clay, brown	2	27
6. Shale, black and brown		

Well record 3. Columbus, Ind.; $NE\frac{1}{4}$ $SW\frac{1}{4}$ sec. 25, T. 9 N., R. 5 E., Bartholomew County. City of Columbus test well no. 3, drilled by Layne-Northern Co. Surface elevation 611 ft; total depth 69 ft. Driller's log on file in the Geology Section, Indiana Geological Survey (geologic interpretations in parentheses).

	Thickness (ft)	Depth (ft)
1. Soil, sand (Martinsville Formation, alluvial facies)	8	8
2. Gravel (mainly Atherton Formation, outwash facies; upper part is probably Martinsville Formation, alluvial facies)	29	37
3. Clay (till; probably Butlerville Till Member, Jessup Formation)	23	60
4. Sand, coarse (Atherton Formation, outwash facies)	4	64
5. Clay (till; probably Cloverdale Till Member, Jessup Formation)	5	69
6. Shale		

Well record 4. $SE\frac{1}{4}$ $NE\frac{1}{4}$ sec. 12, T. 9 N., R. 8 E., Decatur County. Surface elevation 895 ft; total depth 959 ft. Driller's log of gas well on file in the Petroleum Section, Indiana Geological Survey (geologic interpretations in parentheses).

	Thickness (ft)	Depth (ft)
1. Clay, yellow (oxidized till; Center Grove Till Member, Trafalgar Formation)	77	77
2. Sand and gravel (Atherton Formation, outwash facies)	17	94
3. Hardpan, gray, clayey (unoxidized till; Butlerville Till Member, Jessup Formation)	17	111
4. Clay, red, hard (weathered limestone, at least in part)	30	141
5. Limestone		

Well record 5. SE$\frac{1}{4}$ SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 13, T. 9 N., R. 9 E., Decatur County. Surface elevation 886 ft; total depth 909 ft. Driller's log of gas well on file in the Petroleum Section, Indiana Geological Survey (geologic interpretations in parentheses).

	Thickness (ft)	Depth (ft)
1. Topsoil	3	3
2. Clay, yellow (till; Butlerville Till Member, Jessup Formation)	21	24
3. Gravel, sandy	1	25
4. Clay, brown (till, probably Cloverdale Till Member, Jessup Formation)	9	34
5. Gumbo, red (weathered limestone)	12	46
6. Limestone		

Well record 6. NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 2, T. 10 N., R. 3 E., Brown County. Blackwell No. 1 Moore; permit no. 11574. Surface elevation 965 ft; total depth 875 ft. Descriptions summarized from sample study by Andrew J. Hreha, Petroleum Section, Indiana Geological Survey.

	Thickness (ft)	Depth (ft)
Unconsolidated deposits, 15 ft:		
1. Silt, light yellowish-brown	15	15
Borden Group, undifferentiated upper formations, 335 ft:		
2. Siltstone, gray to brownish-gray, and some gray shale	335	350
New Providence Shale, 178 ft:		
3. Shale, greenish-gray	160	510
4. Shale, reddish-brown and greenish-gray	18	528
Rockford Limestone, 7 ft:		
5. Dolomite, greenish-brown, finely crystalline	7	535
New Albany Shale, 96 ft:		
6. Shale, black and greenish-gray	96	631
Jeffersonville Limestone, 83 ft:		
7. Limestone, light yellowish-brown, finely crystalline, cherty	47	678
8. Limestone, yellowish-brown, dolomitic, very finely crystalline	9	687
9. Dolomite, light yellowish-brown, arenaceous, very finely crystalline	27	714
Geneva Dolomite, 41 ft:		
10. Dolomite, brown, finely crystalline	41	755
Laurel Limestone? and Osgood Formation?, 65 ft:		
11. Dolomite and limestone, light-gray, very finely crystalline, cherty	25	780
12. Limestone, dolomitic and argillaceous, light-gray to light yellowish-brown, finely crystalline	40	820
Brassfield Limestone, 30 ft:		
13. Limestone, light yellowish-brown to light pinkish-brown, medium crystalline	30	850
14. No record	25	875

Well record 7. Greensburg, Ind.; $W\frac{1}{2}SW\frac{1}{4}NE\frac{1}{4}$ sec. 2, T. 10 N., R. 9 E., Decatur County. Surface elevation 945 ft; total depth 939 ft. Driller's log on file in the Petroleum Section, Indiana Geological Survey (geologic interpretations in parentheses).

	Thickness (ft)	Depth (ft)
1. Clay (till; Center Grove Till Member, Trafalgar Formation)	18	18
2. Clay, sandy (till; probably Center Grove Till Member, Trafalgar Formation)	5	23
3. Clay, rocky (till; possibly Butlerville Till Member, Jessup Formation)	22	45
4. Clay, blue (unoxidized till; probably Butlerville Till Member, Jessup Formation)	15	60
5. Sand and gravel (Atherton Formation, outwash facies)	4	64
6. Broken stone and gravel	5	69
7. Limestone		

Well record 8. Adams, Ind.; sec. 19?, T. 11 N., R. 9 E., Decatur County. Surface elevation about 890 ft. Log of gas well from Leverett, 1899b, p. 50 (current geologic interpretations in parentheses).

	Thickness (ft)	Depth (ft)
1. Till (Center Grove Till Member, Trafalgar Formation)	19	19
2. Sand (Atherton Formation, outwash facies)	4	23
3. Till, blue (probably Butlerville Till Member, Jessup Formation)	52	75
4. Gravel and sand (Atherton Formation, outwash facies)	15	90
5. Till, yellow (oxidized till; probably Cloverdale Till Member, Jessup Formation)	5	95
6. Clay, blue, oily, with few pebbles (unoxidized till; probably Cloverdale Till Member, Jessup Formation)	16	111
7. Gravel, coarse (Atherton Formation, outwash facies)	15	126
8. Till, blue, hard (Jessup Formation)	20	146

Well record 9. Franklin, Ind.; SE cor. sec. 14 or NE cor. sec. 23, T. 12 N., R. 4 E., Johnson County. Surface elevation 735 ft; total depth 114 ft. Log of water well reported to Leverett (1899b, p. 41; Leverett and Taylor, 1915, p. 92) by D. A. Owen (current geologic interpretations in parentheses).

	Thickness (ft)	Depth (ft)
1. Sand and gravel (Trafalgar Formation, kame facies)	18	18
2. Till, blue (Trafalgar Formation)	40	58
3. Sand, fine	3	61
4. Till, blue; probably pre-Wisconsin, according to Leverett. (Jessup Formation)	50	111
5. Gravel	3	114

Well record 10. Shelbyville, Ind.; $SE\frac{1}{4}$ sec. 6, T. 12 N., R. 7 E., Shelby County. Surface elevation 755 ft; total depth 53 ft. Driller's log from Collett, 1882, p. 65 (geologic interpretations in parentheses).

	Thickness (ft)	Depth (ft)
1. Alluvial soil (upper part is probably Martinsville Formation, alluvial facies; lower part is probably Atherton Formation, outwash facies)	8	8
2. Gravel (Atherton Formation, outwash facies)	2	10
3. Fluvatile silt (Atherton Formation, outwash facies)	1	11
4. Boulder clay (till; Trafalgar Formation)	40	51
5. Sand and fine gravel	1	52
6. Limestone	1	53

Well record 11. $NW\frac{1}{4}$ $NW\frac{1}{4}$ $SE\frac{1}{4}$ sec. 5, T. 12 N., R. 9 E., Rush County. Surface elevation 946 ft; total depth 904 ft. Driller's log of gas well on file in the Petroleum Section, Indiana Geological Survey.

	Thickness (ft)	Depth (ft)
1. Topsoil and clay	11	11
2. Sand	1	12
3. Gravel and clay	6	18
4. Clay	23	41
5. Gravel	5	46
6. Clay	3	49
7. Gravel	1	50
8. Limestone		

Well record 12. Bargersville, Ind.; $SW\frac{1}{4}$ $SW\frac{1}{4}$ $NE\frac{1}{4}$ sec. 35, T. 13 N., R. 3 E., Johnson County. Surface elevation 810 ft; total depth 130 ft. Driller's log of water well on file in the Geology Section, Indiana Geological Survey (geologic interpretations in parentheses).

	Thickness (ft)	Depth (ft)
1. Topsoil	3	3
2. Hardpan, yellow (oxidized till; Cartersburg Till Member, Trafalgar Formation)	8	11
3. Clay, blue, gravelly (unoxidized till; Cartersburg Till Member, Trafalgar Formation)	4	15
4. Gravel, dry, dirty	2	17
5. Clay, blue, gravelly (unoxidized till; probably Center Grove Till Member, Trafalgar Formation)	16	33
6. Gravel, yellow, dry	4	37
7. Clay, gray, sandy (till; probably Butlerville Till Member, Jessup Formation)	10	47
8. Sand, yellow, fine-grained	7	54
9. Sand, muddy, packy	7	61
10. Sand, gray, fine-grained	9	70
11. Clay, blue, gravelly (unoxidized till; Jessup Formation)	13	83
12. Shale, brown		

Well record 13. SW¼ SW¼ NE¼ sec. 15, T. 13 N., R. 5 E., Johnson County. Weddel No. 1 Stillebower; permit no. 6636. Surface elevation 751 ft; total depth 1,057 ft. Driller's log on file in the Petroleum Section, Indiana Geological Survey.

	Thickness (ft)	Depth (ft)
1. Soil	1	1
2. Clay, sandy	5	6
3. Sand, soupy	2	8
4. Clay, sandy	14	22
5. Sand and gravel (Atherton Formation, outwash facies)	35	57
6. Sand	5	62
7. Clay, sandy	22	84
8. Gravel and sand (Atherton Formation, outwash facies)	15	99
9. Clay, sandy	10	109
10. Sand and gravel (Atherton Formation, outwash facies)	17	126
11. Clay	3	129
12. Limestone		

Well record 14. NW¼ SE¼ NE¼ sec. 29, T. 13 N., R. 8 E., Shelby County. Surface elevation 880 ft; total depth 900 ft. Driller's log on file in the Petroleum Section, Indiana Geological Survey (geologic interpretations in parentheses).

	Thickness (ft)	Depth (ft)
1. Clay, yellow (oxidized till; Cartersburg Till Member, Trafalgar Formation)	18	18
2. Clay, blue, gravelly (unoxidized till; Cartersburg Till Member, Trafalgar Formation)	31	49
3. Gravel (Atherton Formation, outwash facies)	5	54
4. Clay, blue (unoxidized till; probably Center Grove Till Member, Trafalgar Formation, but possibly Jessup Formation)	6	60
5. Sand, yellow, fine-grained (Atherton Formation, outwash facies)	25	85
6. Broken stone	5	90
7. Stone		

Well record 15. Morristown, Ind.; SW¼ SW¼ sec. 12, T. 14 N., R. 7 E., Shelby County. Surface elevation 826 ft; total depth 864 ft. Driller's log on file in the Petroleum Section, Indiana Geological Survey (geologic interpretations in parentheses).

	Thickness (ft)	Depth (ft)
1. Topsoil	1	1
2. Gravel (Atherton Formation, outwash facies)	10	11
3. Clay, blue (unoxidized till; Cartersburg Till Member, Trafalgar Formation)	16	27
4. Gravel	4	31

		Thickness (ft)	Depth (ft)
5.	Clay, yellow (till; possibly Butlerville Till Member, Jessup Formation)	9	40
6.	Gravel (Atherton Formation, outwash facies)	16	56
7.	Clay, brown, sticky	25	81
8.	Limestone		

Well record 16. NW¼ NW¼ NE¼ sec. 33, T. 15 N., R. 10 E., Rush County. Surface elevation 1,020 ft; total depth 1,258 ft. Driller's log on file in the Petroleum Section, Indiana Geological Survey (geologic interpretations in parentheses).

		Thickness (ft)	Depth (ft)
1.	Topsoil	2	2
2.	Clay (till; Cartersburg Till Member, Trafalgar Formation)	17	19
3.	Sand (Atherton Formation, outwash facies)	4	23
4.	Clay and gravel (mostly till; probably Center Grove Till Member, Trafalgar Formation)	10	33
5.	Gravel (Atherton Formation, outwash facies)	4	37
6.	Gravel and clay (mostly till; probably Butlerville Till Member, Jessup Formation)	13	50
7.	Sand and clay (mostly till; probably Butlerville Till Member, Jessup Formation)	10	60
8.	Sand (Atherton Formation, outwash facies)	38	98
9.	Clay, blue (unoxidized till; probably Cloverdale Till Member, Jessup Formation)	16	114
10.	Gravel	2	116
11.	Stone, shelly		

Well record 17. NW¼ NE¼ SE¼ sec. 19, T. 17 N., R. 7 E., Hancock County. Surface elevation about 880 ft; total depth 218 ft. Driller's log of water well from Steen, 1961, p. 17 (geologic interpretations in parentheses).

		Thickness (ft)	Depth (ft)
1.	Clay, yellow, and fill	10	10
2.	Sand (Atherton Formation, outwash facies)	29	39
3.	Hardpan, yellow (oxidized till; Cartersburg Till Member, Trafalgar Formation)	6	45
4.	Hardpan, gray (unoxidized till; Cartersburg Till Member, Trafalgar Formation)	60	105
5.	Clay, blue (unoxidized till; probably Center Grove Till Member, Trafalgar Formation)	60	165
6.	Clay, red (till; probably Jessup Formation)	37	202
7.	Sand	2	204
8.	Limestone, white, soft		

Well record 18. New Castle, Ind.; $SW\frac{1}{4} NW\frac{1}{4}$ sec. 15, T. 17 N., R. 10 E., Henry County. Surface elevation about 1,020 ft; total depth 160 ft. Driller's log of water well on file in the Geology Section, Indiana Geological Survey (geologic interpretations in parentheses).

		Thickness (ft)	Depth (ft)
1.	Fill	15	15
2.	Gravel, coarse (Atherton Formation, outwash facies)	20	35
3.	Clay, gravelly (till; Cartersburg Till Member, Trafalgar Formation)	34	69
4.	Sand, soupy (Atherton Formation, outwash facies)	25	94
5.	Gravel, coarse (Atherton Formation, outwash facies)	21	115
6.	Clay, blue (till, unoxidized; probably Center Grove Till Member, Trafalgar Formation)	4	119
7.	Gravel, muddy (Atherton Formation, outwash facies)	13	132
8.	Clay, blue, sticky (till, unoxidized; probably Center Grove Till Member, Trafalgar Formation)	10	142
9.	Sand, fine-grained, soupy (Atherton Formation, outwash facies)	12	154
10.	Clay, sticky (till; possibly Butlerville Till Member, Jessup Formation)	6	160

Well record 19. New Castle, Ind.; $SW\frac{1}{4} SE\frac{1}{4}$ sec. 15, T. 17 N., R. 10 E., Henry County. Charles E. Jackson No. 1 well (gas). Surface elevation 1,040 ft; total depth 923 ft. Driller's log from Indiana Division of Geology, 1941, p. 3 (geologic interpretations in parentheses).

		Thickness (ft)	Depth (ft)
1.	Clay, yellow (till; Cartersburg Till Member, Trafalgar Formation)	80	80
2.	Gravel, sandy, gray (Atherton Formation, outwash facies)	80	160
3.	Clay, brown, sticky (till; probably Center Grove Till Member, Trafalgar Formation)	80	240
4.	Clay, red, muddy (till; probably Butlerville Till Member, Jessup Formation)	75	315
5.	Quicksand, dark-gray	1	316
6.	Mud, varicolored, with streaks of peat (till; possibly Cloverdale Till Member, Jessup Formation)	9	325
7.	Clay, red, muddy (limestone soil)	15	340
8.	Lime, blue, soft, rotten (weathered limestone)	4	344