GEOLOGY OF THE UPPER PATOKA DRAINAGE BASIN

by Henry H. Gray

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GEOLOGY OF THE UPPER PATOKA DRAINAGE BASIN

By Henry H. Gray

ABSTRACT

This report summarizes regional geologic data pertinent to construction of a dam and reservoir on the Patoka River near Ellsworth, eastern Dubois County, Ind. The river occupies a valley that in its lower (western) reaches is broad by comparison with most valleys in the dissected upland area through which the river flows. The broad valley is underlain by alluvial and lacustrine deposits that in the vicinity of the damsite are 50 to 80 feet thick. This stage of valley filling was caused by blocking of the mouth of the old upper Patoka valley by glacial and glaciofluvial deposits.

Bedrock in the area includes one group of formations of Pennsylvanian age and four groups of Mississippian age. The Pennsylvanian rocks are principally sandstones and shales; Mississippian rocks include approximately equal amounts of sandstones, shales, and limestones. A disconformity separates Pennsylvanian from Mississippian rocks, and all of these formations dip almost due west at about 25 feet per mile.

The only serious geologic problems involved in construction of a dam and reservoir at Ellsworth are centered around the damsite. Two beds of cavernous limestone, 14 feet and 30 feet thick, occur in the valley walls at the damsite and in adjacent parts of the reservoir area. Detailed engineering studies must be made to determine the extent and nature of the treatment that will be necessary to prevent serious leakage through these limestones. Other engineering studies will be needed to determine the bearing capacities of the thick valley fill and the suitability of available unconsolidated deposits for earthfill in the dam. Limestone for rockfill and concrete aggregate is in adequate supply. The flood pool should not be raised above the proposed 550-foot altitude to avoid seriously increasing leakage and bearing problems.

INTRODUCTION

The Indiana Flood Control and Water Resources Commission is studying the possibility of building a dam on the Patoka River in the vicinity of Ellsworth. This report was prepared at the request of the Commission to summarize geologic knowledge requisite to effective planning of the reservoir to be impounded behind this dam. Data outlined in this report include (1) content, extent, and structural attitude of bedrock formations and (2) content, extent, and depositional history of unconsolidated deposits. These topics are discussed from a regional point of view and contribute primarily to general planning and reservoir design. A reconnaissance report by Garrison (1960) discusses the proposed damsite.

This report is based on the study of aerial photographs, topographic maps, field information secured primarily for other projects, published and unpublished geologic and soils reports (Hutchison, in preparation; Gray, 1962; Gray, Jenkins, and Weidman, 1960; Perry and Smith, 1958; Simmons and others, 1937), and subsurface data on file in the Petroleum Section, Indiana Geological Survey. Several series of refraction seismic studies, two core holes, and four auger holes constitute the new primary data that were obtained.

The area studied, here called the Upper Patoka Drainage Basin (fig. 1), includes those parts of Orange, Crawford, Martin, and Dubois Counties that drain into the Patoka River above the bedrock-floored narrows at Jasper. For 60 years it has been recognized (Leverett, 1899, p. 99) that this area once drained directly into East Fork of White River through a narrow, deep, now-buried valley about 2 miles north of Jasper. Diversion of the stream across the bedrock ridge at Jasper, an indirect result of extensive glaciation in central and northern Indiana, is the most significant single event in the history of the upper Patoka River.

The Upper Patoka Drainage Basin, as defined above, is approximately 30 miles long and 6 to 12 miles wide and encompasses an area of 260 square miles. The long dimension of the basin trends practically east-west. Principal tributaries to the upper Patoka River are Youngs, Painter, Dillon, and Davis Creeks from the north and Little Patoka River, Lick Fork, and Polson Creek from the south (fig. 1). Named settlements in the area include the town of Jasper, the villages of Dubois, Birdseye, Eckerty, and Taswell, and other smaller settlements.

The Patoka River heads in a group of high hills about 3 miles southeast of Chambersburg, Orange County. The airline distance from this point to Jasper is 33 miles, but the distance along the river channel is 81 miles. The excess distance traversed by the river is taken up by several large deflections of its valley and by many small-scale meanders of the stream within its valley. From the headwaters to Jasper the river falls more than 450 feet, and the hills through which it passes are correspondingly rugged. Average relief per square mile is approximately 200 feet; local relief is somewhat more than average in the central and eastern parts of the area and considerably less than average in the western part.

The rocks in the Upper Patoka Drainage Basin are entirely of sedimentary origin and consist, in approximately equal amounts, of sandstone, shale, and limestone. These occur in alternating layers or beds that dip gently westward, so that, for example, beds found near the valley bottoms in the western part of the area lie on the hilltops in the central part and have been completely removed by erosion in the eastern part (fig. 2). Unconsolidated deposits that are very much younger than the bedrock formations partially fill most of the larger valleys.

DRAINAGE PATTERN AND TOPOGRAPHY OF BASIN

The Upper Patoka Drainage Basin lies entirely within and extends practically across the north-south belt of hill county that was named the Crawford Upland by Malott (1922, p. 98-102). Just east of the headwaters of the Patoka River the hills fall off abruptly to the limestone-floored Mitchell Plain. West of the Crawford Upland is the Wabash Lowland, an area characterized by low hills and broad flat valleys. The boundary between this lowland and the Crawford Upland is not clear cut but is probably best placed at Jasper or just a little to the west.

The Crawford Upland is a region of high relief and steep slope angles. In a previously studied area which adjoins the Upper Patoka Drainage Basin on the north, "a little over two-fifths of the area is in relatively level upland surfaces whose slopes average considerably less than 20 percent; approximately a fifth of the area is in valley bottoms of similar low slope; the remaining two-fifths is in steep slopes generally in excess of 20 percent and averaging approximately 30 percent" (Gray, Jenkins, and Weidman, 1960, p. 14). Similar values probably apply to the area of this report.

Hills typical of the Upper Patoka Drainage Basin, and of the Crawford Upland in general, have broad, gently rolling upland surfaces and rounded steplike slopes. These features are the result of erosion of horizontally layered sedimentary rocks of varying degrees of resistance. Shales are soft and easily eroded under any climatic conditions; limestones are rather rapidly dissolved by weathering processes in humid climates. In this area prominent upland surfaces and benches along valley walls are generally underlain by sandstone.

The most common direction of streamflow in the Crawford Upland is west-southwest. The Patoka River above its junction with the Little Patoka flows in this direction, as do also all major tributaries from the north. These streams probably are consequent upon an original slope; whether this slope was related primarily to the westward dip of the rock beds, or whether it was an ancient erosional surface of which no trace now remains, is not clear.

Sharp changes in direction characterize the course of the upper Patoka below its junction with the Little Patoka. The main stream is deflected generally northwestward to the mouth of Davis Creek and thence southwest, northwest, south, and west in a series of large zigzags (fig. 1). Most of the tributaries entering the upper Patoka from the south flow north or northwest, nearly at right angles to the more common west-southwest direction noted above.

The several deflections of the Patoka and the north-northwest trend of tributaries from the south may in part have been influenced by tongues of erosion-resistant sandstone that extend into the Upper Patoka Drainage Basin from large sandstone bodies in rocks of Pennsylvanian age along the south and northwest margins of the basin. The streams have now cut far below the level of most of these sandstone tongues, but hilltop-capping remnants support this hypothesis. Thus the upper Patoka from the mouth of the Little Patoka to Jasper and the north-northwestward flowing tributaries probably should be classed as subsequent streams developed along belts of weaker rock.

The valley of the Patoka River is narrow from its headwaters to its confluence with the Little Patoka; thence to the mouth of Dillon Creek it is considerably wider. From Dillon Creek to Polson Creek the river flows again in a narrow, deep trench, and below Polson Creek it again opens into a wide valley that continues to the narrows at Jasper. The character of the bedrock in the walls of the valley appears to be an important factor in valley width. In narrow reaches of the valley, sandstones are the dominant rocks along the valley walls; conversely, sandstone makes up less than one-third of the rocks where the valley is wide.

Here and there within the main valley of the Patoka River in Ranges 1, 2, and 3 West are low, isolated bedrock knobs completely surrounded by alluvial deposits. Some of these are sufficiently large to be shown on the map (fig. 2), and several smaller ones are also known. These hills are the cores of ancient entrenched meanders that have long since been cut off by the wanderings of the river's channel and are now all but buried by the river's deposits.

UNCONSOLIDATED DEPOSITS[1]

MARTINSVILLE FORMATION

Recent deposits of present streams are known as the Martinsville Formation, the youngest formation in the area mapped. The thickness of this alluvial formation along the Patoka River is 10 to 15 feet (fig. 3). In tributaries it is thinner, and in the valleys of smaller streams it is very thin and difficult to recognize.

The Martinsville Formation is restricted to low-lying areas along streams (fig. 2). Most of the formation consists of yellowish-brown silty clays and clayey silts, but some silty sands are included (Appendix, Log 1). The upper 3 feet or so includes some silt of probable windblown origin. Coarse rock-weathering debris is incorporated into the formation where it is adjacent to steep and rocky valley walls.

At one place or another within the area the Martinsville Formation overlies nearly all other mapped units, but in the larger valleys the sparse available data indicate that the formation most commonly overlies gray silty clayey sands of the lacustrine facies of the Atherton Formation. The contact between the two formations, as revealed in auger-hole samples, appears gradational. The change from lacustrine to alluvial conditions probably took place within the last few thousand years.

ATHERTON FORMATION

Only one of the several known facies of the Atherton Formation is recognized in this area, the lacustrine silt facies. On the surface this facies is found in sharply defined terraces that are restricted to the westernmost part of the area mapped. The upper surface of this terrace is just below 500 feet altitude, approximately 40 feet above the level of the river. These are the deposits associated with the blocking of the mouth of the old upper Patoka that diverted the river into its present course across the bedrock ridge at Jasper.

Beneath the Martinsville Formation along the Patoka River near Ellsworth is a deposit of gray silty clayey sand as much as 60 feet thick (Appendix, Log 1). This material is apparently lacustrine and is here considered a part of the lacustrine silt facies of the Atherton Formation. At Ellsworth the sand is mostly of local derivation and thus differs from typical Atherton glaciolacustrine silts, but it is included with them because of its environmental affinities. The locally derived phase of this deposit probably grades imperceptibly westward into the glacially derived phase at some point between Dubois and Jasper. These Atherton deposits are younger than the Prospect Formation and probably in places overlie the Prospect as well as older bedrock units, but the lower contact of the Atherton has not been observed directly.

PROSPECT FORMATION

An older alluvial deposit similar in content to the Martinsville, the Prospect Formation is distinguished by deeper weathering, but the most apparent aid to its identification is its occurrence as rounded terraces 20 to 50 feet above stream level (fig. 3). These are best recognized on aerial photographs, where they appear conspicuous, not only be-

[1] The unconsolidated deposits are classified as formations following the usage proposed by Wayne (1963).

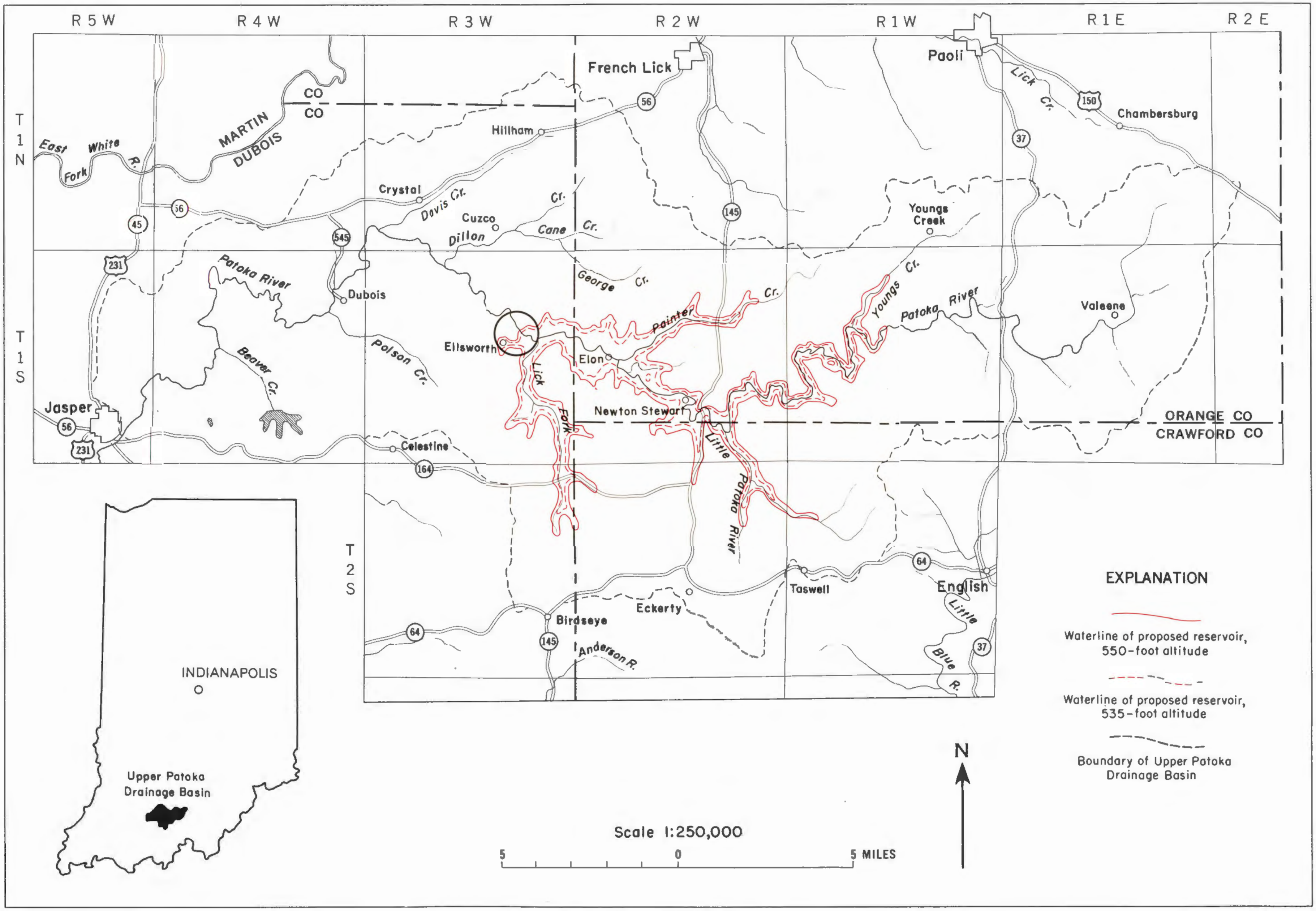

Figure 1.--Location map of the Upper Patoka Drainage Basin showing Ellsworth damsite (circled) and outlines of proposed reservoir.

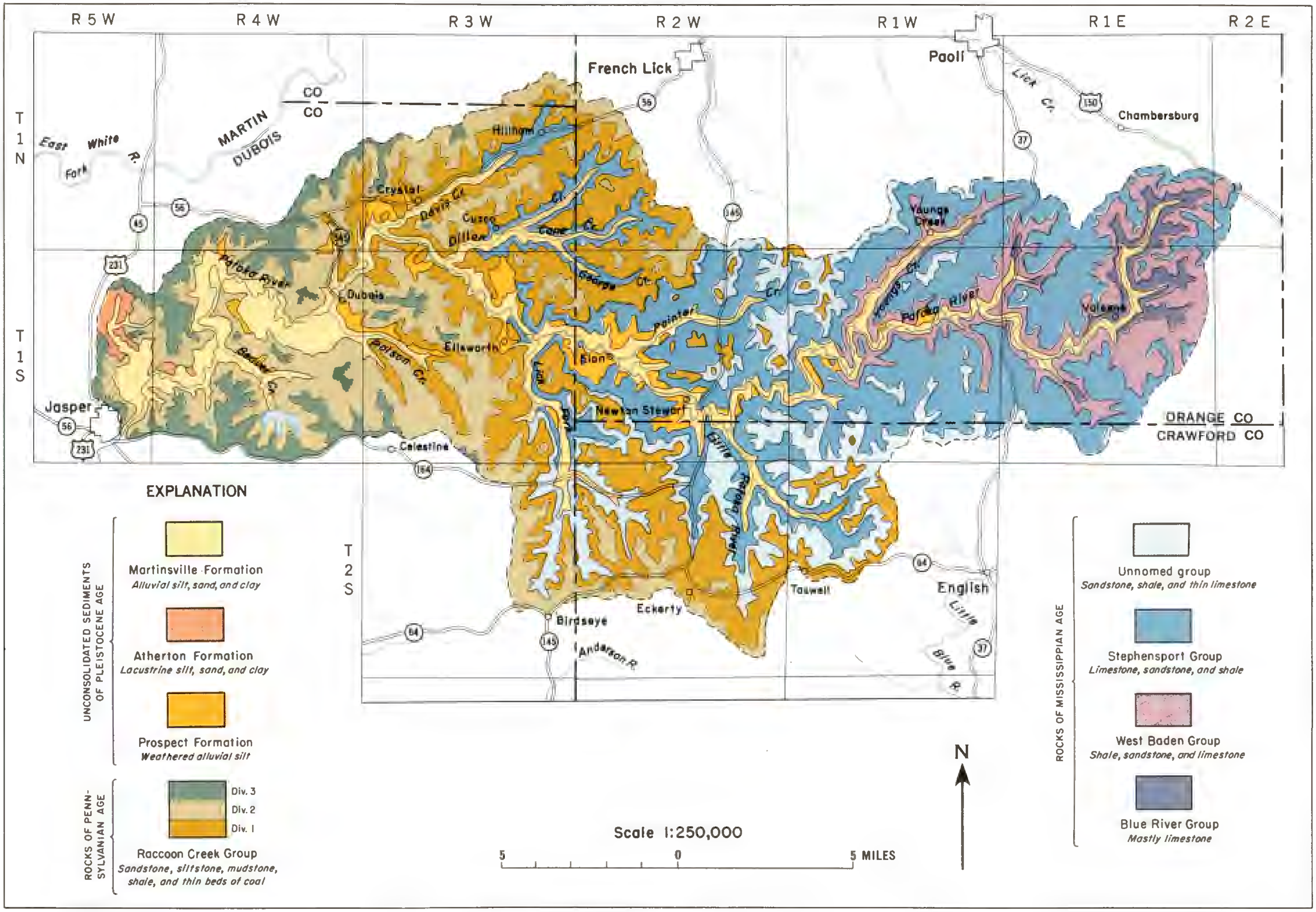

Figure 2.--Geologic map of the Upper Patoka Drainage Basin.

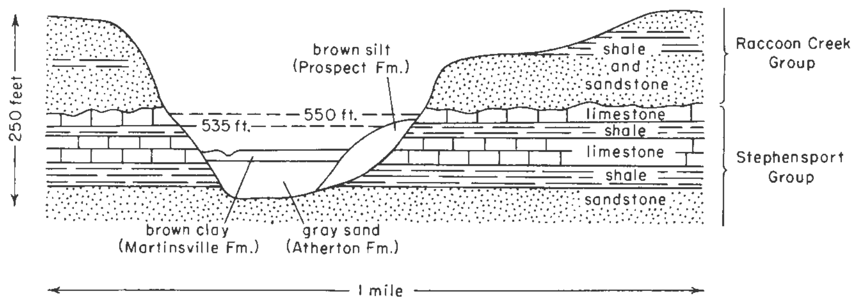

Figure 3.--Idealized cross section of Patoka River valley at proposed Ellsworth damsite. Not precisely to scale.

cause they stand in relief, but because the well-drained silty soils of the Prospect show a mottled pattern that is distinct both from the lighter colored sandy soils of the bedrock areas and from the darker colored poorly drained soils of the alluvial bottoms.

The Prospect Formation includes silty clays, clayey silts, and sandy silts and is in places at least 35 feet thick (Appendix, Log 2). The deposits are various shades of yellowish brown from top to bottom, and the thorough oxidation thus indicated denotes an age of mid-Pleistocene or earlier. The upper 12 to 15 feet of the formation includes much silt of probable windblown origin. The thickness of this windblown silt mantle is sufficient to substantiate the age suggested above and also was apparently a prime factor in developing the characteristic topographic form, drainage pattern, and soil texture by means of which areas underlain by the Prospect Formation are recognized. The Prospect Formation overlies various bedrock units within the area mapped, and weathered debris from the bedrock is incorporated in the base of the Prospect.

The Prospect Formation is most prominent along the valley of the Patoka River in Ranges 2 and 3 West (fig. 2), where the formation is readily recognized and mapped, partly because the associated terraces here are most conspicuous. Prospect deposits in the easternmost and westernmost parts of the area mapped are small, their terrace forms are low and less distinct, and they are therefore difficult to recognize.

EXPOSED SEDIMENTARY ROCKS

Sedimentary rocks exposed in the Upper Patoka Drainage Basin consist, in descending order, of five mapped groups (figs. 2 and 4): the Raccoon Creek Group, which is Pennsylvanian in age, and an unnamed group (four formations), the Stephensport Group (five formations), the West Baden Group (five formations), and the Blue River Group (three formations), all of which are Mississippian in age.[2] The contact between rocks of Pennsylvanian age and rocks of Mississippian age is an uneven surface, a disconformity that represents a long interval of erosion between the two major episodes of deposition that these rocks represent. Because of the irregularity of this surface, Pennsylvanian rocks within the area mapped rest upon several formations of Mississippian age. To some extent this variation is unpredictable, as a result of local irregularities in the surface, but there is also a fairly regular trend that brings Pennsylvanian rocks into contact with progressively older rocks toward the north. Thus Pennsylvanian rocks rest on formations of the upper part of the unnamed group along the south edge of the area but directly overlie formations of the upper part of the Stephensport Group along the north edge (fig. 2).

RACCOON CREEK GROUP

In the western half of the area mapped, exposed sedimentary rocks are mostly those

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[2] These group names are relatively new in Indiana geologic nomenclature. For a discussion of their naming, rock content, age, and distribution, see Wier (in preparation) for information on the Raccoon Creek Group and Gray, Jenkins, and Weidman (1960) for information on the Stephensport, West Baden, and Blue River Groups.

of the Raccoon Creek Group (fig. 2). The group is approximately 400 feet thick, of which the uppermost 75 to 100 feet is not exposed within the mapped area but is known from exposures just west of Jasper.

The Raccoon Creek Group is properly divisible into its formal component parts, the Staunton, Brazil, and Mansfield Formations. In this area, however, the coal beds that mark the boundaries between these formations either cannot be identified with reasonable certainty or are not sufficiently continuous and extensive to serve as useful boundaries. For purposes of this report, therefore, the Raccoon Creek Group is arbitrarily and informally subdivided into three numbered divisions (fig. 4). The boundaries between these divisions are the tops of the more widely traceable coal beds or the approximate position of the coal bed where the coal is absent. The top of Division 2 is the top of the Mariah Hill Coal, and the top of Division 1 is the top of the Pinnick Coal. Neither of these boundaries is entirely satisfactory, but they represent the best that can be done with available data.

Division 3 consists of sandstone, shale, and thin beds of coal, chert, limestone, and clay. The total thickness of this division is approximately 200 feet, but only the lower 100 to 125 feet is present in the mapped area. Sandstone beds in this division cap most of the ridges in Ranges 3 and 4 West and form the upper walls of the narrow valley at Jasper. Division 3 is approximately equivalent to the combined Brazil and Staunton Formations.

Division 2 consists of mudstone, shale, sandstone, and thin beds of coal, clay, and sedimentary iron ore. The division ranges in thickness from 80 to 130 feet and averages approximately 110 feet. Sandstone beds within this unit cap ridges at Eckerty and Birdseye, but elsewhere the division consists mostly of shale and mudstone. Where this division forms the walls of the valley of the Patoka River, the valley is relatively wide. Division 2 is essentially the upper part of the Mansfield Formation of Gray, Jenkins, and Weidman (1960).

Division 1 consists of sandstone, siltstone, shale, and a few thin beds of coal. The bottom of this division is at the irregular disconformable contact between rocks of Mississippian and Pennsylvanian ages, and the thickness of Division 1 therefore has a wide range--from 20 feet or less just north of Birdseye to 130 feet near Ellsworth. Aver-

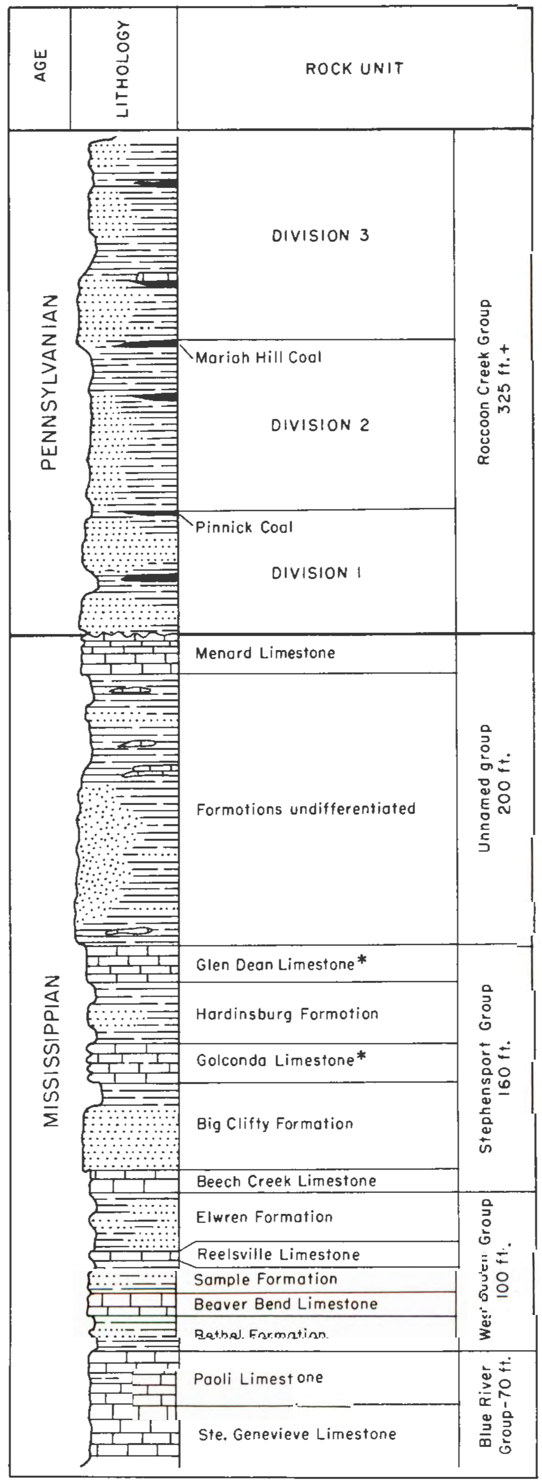

Figure 4.--Generalized columnar section of outcropping bedrock units. Asterisks indicate cavernous limestones that present design problems within area of proposed reservoir.

age thickness of Division 1 is about 80 feet. Sandstones dominate this unit, which forms the walls of the narrow valley of the Patoka just above Dubois and caps many ridges in Range 2 West. Division 1 is the lower part of the Mansfield Formation in the usage of Gray, Jenkins, and Weidman (1960).

UNNAMED GROUP

Rocks belonging to an as yet unnamed group of late Mississippian age are present in the south-central part of the area mapped and extend in reduced thickness northward across the central part of the area (fig. 2). This group attains a maximum thickness of approximately 200 feet (fig. 4) in the vicinity of Birdseye. The present study indicates that some existing formational names in this group are inappropriate in this area, but revised terminology is not proposed here.

The Menard Limestone is the uppermost formation in the unnamed group and within the area mapped is known only in the vicinity of Birdseye, where it crops out in the valleys of Lick Fork and its tributaries. This formation is incompletely exposed but appears to consist of approximately 25 feet of fossiliferous light-gray limestone and limy shale. Elsewhere in the area the Menard has been removed by erosion that preceded deposition of the rocks of the Raccoon Creek Group.

The remainder of the unnamed group includes three formations that cannot be discriminated in this area. Thus it is necessary to treat these as a unit comprising the larger part of the unnamed group and consisting principally of gray to greenish-gray to reddish-brown shale and mudstone and thinly stratified fine-grained sandstone that weathers into angular blocks. Cross-stratified sandstone that attains a maximum thickness of 90 feet near Taswell is present in many places in the lower half of the unit. Thin and discontinuous beds of limestone are found, especially in the lower half of the unit in places where the cross-stratified sandstone is absent. This undifferentiated unit is 175 feet thick near Birdseye. It thins northward and is present along the north boundary of the mapped area only in scattered small areas and in reduced thickness.

STEPHENSPORT GROUP

The Stephensport Group underlies the unnamed group and crops out in much of the central and eastern parts of the area mapped (fig. 2). The average thickness of the group is 160 feet; the range in thickness is 145 to 185 feet (fig. 4). There is some evidence that the thickness of the group increases southwestward. The five formations that make up the group are described in descending order.

The Glen Dean Limestone, the youngest extensive limestone formation in the area, ranges from 10 to 40 feet in thickness. In some places the limestone has been reduced in thickness by erosion that preceded deposition of the Raccoon Creek Group, but it also appears to have been of irregular thickness as originally deposited. The average thickness of the formation is about 25 feet. Most of the formation is gray oolitic silty limestone, but a few thin lenses of shale are included. The Glen Dean generally is not cavernous and is not an important water-bearing formation, but in the vicinity of Ellsworth the limestone, though thin, is cavernous and is the source of many springs.

The Hardinsburg Formation consists predominantly of gray, greenish-gray, and reddish-brown shale and mudstone. White thinly stratified calcareous sandstones are found in extensive thin beds and in places make up an important part of the formation. The Hardinsburg ranges in thickness from 12 to 60 feet and averages about 35 feet.

The Golconda Limestone is a gray sparingly fossiliferous silty limestone that in places contains many small nodules of chert. The formation ranges in thickness from 15 to 40 feet and averages about 25 feet. In the vicinity of Ellsworth the formation is thicker, less silty, and more cavernous than it is in most other places (Appendix, Log 3). This part of the formation appears to have been deposited in the form of a bank or reef.

The Big Clifty Formation is 45 to 65 feet thick. Its most common thickness is about 55 feet. The upper third is gray, greenish-gray, and reddish-brown calcareous fossiliferous shale, and the lower two-thirds is white thinly stratified sandstone. This sandstone is a prominent and extensive cliff-former and is readily recognized in Ranges 1 West and 1 East, where it forms steep valley walls and caps many ridges. Much of the east rim of the Upper Patoka Drainage Basin is defined by ridges held up by this sandstone.

The Beech Creek Limestone is the lowest formation in the Stephensport Group. This persistent unit varies little from its average thickness of 15 feet. Gray compact limestone that is sparingly fossiliferous makes up the entire formation. Large crinoid columns as much as 15 mm in diameter are among the most characteristic fossils. An extensive network of caverns and solution-enlarged fractures has been developed in the limestone, partly because the stone is relatively pure and partly because the permeable sandstone that almost everywhere directly overlies it forms an efficient infiltration system for the dissolving water. The Beech Creek Limestone is one of the most extensive water-bearing formations in this part of the State, and many major springs of the area come from this limestone.

WEST BADEN GROUP

Beneath the Stephensport Group is the West Baden Group, the thickness of which ranges from 70 to 150 feet and most commonly is about 100 feet (fig. 4). A fairly regular east-to-west increase in thickness was noted. The Stephensport Group crops out only in the eastern third of the mapped area (fig. 2) and consists of five formations which are described below in descending order.

The Elwren Formation, which consists largely of gray, greenish-gray, and reddish-brown shales, mudstones, and siltstones, ranges in thickness from 35 to 50 feet and averages about 40 feet. Beds of white sandstone 10 to 20 feet thick appear in various positions within the formation, and thin beds of yellowish-brown limestone have also been seen. The sandstones and limestones weather to various shades of reddish and yellowish brown. Where the underlying Reelsville Limestone is not present it is generally impossible to distinguish the Elwren from the Sample Formation.

The Reelsville Limestone is a yellowish-brown fossiliferous sandy limestone that in few places exceeds 6 feet in thickness and most commonly is about 3 feet thick. Fossiliferous or limy shale or sandstone marks the place of the Reelsville at some outcrops, and in many places the Reelsville is absent, probably because of nondeposition. The distribution of the limestone seems not to have a readily predictable pattern, and because it is thin, discontinuous, and impure, it is not an important water-bearing formation.

The Sample Formation consists of gray calcareous sandstone that weathers reddish to yellowish brown, and gray, greenish-gray, and reddish-brown shale, mudstone, and siltstone. The formation ranges from 10 to 40 feet and averages 20 feet in thickness. It is very similar in constitution to the Elwren Formation and cannot usually be distinguished from it in places where the Reelsville Limestone cannot be identified.

The Beaver Bend Limestone is 5 to 30 feet thick, but its most common thickness is about 15 feet. This formation consists entirely of limestone that is yellowish brown, oolitic, and sparingly fossiliferous. In general, it is thicker where the underlying Bethel Formation is thinner, and vice versa. The Beaver Bend does not have an extensive network of solution cavities in this area, probably because the impermeable nature of the overlying rock prevents much seepage of water into fractures in the limestone.

The Bethel Formation is at the bottom of the West Baden Group and ranges in thickness from 10 to 40 feet. Its average thickness is about 25 feet. Gray shale and yellowish-brown calcareous sandstone make up most of the formation. Very thin beds of coal are found in some places on outcrop but are rarely noted in well records.

BLUE RIVER GROUP

Rocks of the Blue River Group are dominantly limestone. Well records show that the group ranges from 400 to 700 feet in thickness; the greater figures were obtained from the western part of the area. Only the upper 70 feet of the group is exposed along the Patoka River near its headwaters (figs. 2 and 4). The remainder may be seen just east of the area, on the Mitchell Plain and along the valley of Blue River. Three formations, here described in descending order, make up the group.

The Paoli Limestone is about 25 feet thick where it crops out along the Patoka River and consists mainly of limestone that is light gray and oolitic to very finely crystalline. In some outcrops beds of calcareous siltstone are found near the middle and at the base of the formation, but these are rarely noted in well records. Many large caverns are known in the Paoli Limestone, and large springs, such as Bluff Springs, near Valeene, are common along the Paoli outcrop. There is no evidence, however, that any of the springs along the Patoka serve as important storm-water rises for subterranean drainage from the sinkhole plain region that lies to the east of the mapped area.

The Ste. Genevieve Limestone consists mainly of very finely crystalline and oolitic light-gray limestone. Nodular chert is abundant throughout the formation, and a thin bed of calcareous sandstone or sandy limestone is found near the middle. Only the upper 35 feet of the formation is exposed in the area; total thickness of the unit is about 150 feet. Solution cavities are extensively developed in the formation, especially in its upper part.

The St. Louis Limestone, the lowest in the Blue River Group, consists of yellowish-brown dolomitic limestone and light-brown dolomitic limestone and light-brown dolomitic shaly limestone. Beds of gypsum and anhydrite are found in the lower part of the formation. The St. Louis Limestone is at least 200 feet thick in the area, but it does not crop out and is known only from well records and from outcrops east of the mapped area.

REGIONAL STRUCTURE OF THE SEDIMENTARY ROCKS

Following their deposition and consolidation into rock, the sedimentary formations of this area have been raised and tilted slightly so that they now trend gently downward to the southwest (fig. 5). The general direction of dip on the formations of Mississippian age is S. 65° W. There is a slight variation in dip direction from one formation to another. The rate of dip is about 25 feet per mile, the lower beds being, in general, somewhat steeper and the higher beds somewhat less steep. Small local irregularities interrupt this general trend. Data on rocks of Pennsylvanian age are not sufficient to permit drawing a structure-contour map, but in general Pennsylvanian rocks dip more nearly westward and at a somewhat lower angle than Mississippian rocks.

Most beds of consolidated rock in the area have a network of nearly vertical fractures, or joints. It is not certain whether these fractures were induced by volume shrinkage, as on drying, or by stresses that resulted from tilting and uplift, but the latter is considered the more general cause. Some consistency in compass directions of the joint systems might therefore be expected, but joint patterns were not investigated in this study. Limestones, being the most brittle rocks of the area, exhibit the most conspicuous sets of joints. Sandstones are less brittle and have less perfect joint systems, and shales have only irregularly and poorly developed joints. Joints allow fluid to pass through otherwise rather impermeable rocks, and in rocks such as limestones that are soluble in mildly acid ground water, the joints are likely to be greatly enlarged and the flow of fluids greatly increased.

GEOLOGIC FACTORS INFLUENCING RESERVOIR DESIGN

A reservoir makes use of a natural site and impounds a natural resource behind a dam made of materials derived ultimately from the earth; thus almost every aspect of reservoir design is influenced to some extent by geologic factors. The elements of reservoir design most directly related to geologic factors are leakage potential and strength and availability of earth materials for foundations, fill, and natural banks.

The earth's surface and the rock materials beneath the surface are not inert and unresponsive but are constantly reacting to natural changes in physical and chemical conditions. The various rock materials in the proposed reservoir area are at present in approximate equilibrium with their environment, and geologic processes are acting upon them relatively slowly. A radical change in environment, however, such as clearing the land, constructing the dam, or filling the reservoir with water, will result in changes in the behavior of the rock materials. Some of these changes will be slow and minor, but others will be of sufficient consequence to warrant testing and development of precautionary steps in reservoir and structure design.

LEAKAGE PROBLEMS

Fluid flow through inclined beds of permeable consolidated rocks tends to be down dip. Movement of fluid in other directions is slower because the gradient is less. Water entering solution-widened joint systems in limestone beds in the proposed reservoir area will not move rapidly into the adjacent drainage basins of Lost River, Anderson River, or Little Blue River because it could emerge at only a little lower altitude. The possibility of short-range leakage in the immediate vicinity of the reservoir will, however, present some problems in design. The leakage path from limestone exposures along the north shoreline of the proposed reservoir (fig. 6) northward into George Creek is about 1 mile, and some leakage may be expected here although the gradient is not steep. In part of this critical area the limestone outcrop is covered by deposits of the Prospect Formation, and additional blanketing of some of the more obvious exposures of limestone along the north bank of the reservoir may help to minimize this problem.

A more serious leakage problem exists at the proposed damsite where potential leakage paths are short and down-dip gradients are fairly steep (fig. 6). Solution-widened fractures are common in limestone outcrops near the damsite. In a drill hole just north of the damsite (Appendix, Log 3), a crevice was encountered in the Golconda Limestone at a depth of about 90 feet; circulation was lost and could not be regained. This hole was therefore abandoned and the drill rig was moved about 10 feet north, where a second hole, in which no crevice was found, was drilled.

These data indicate that limestones near the damsite will require thorough testing and that it may be necessary to grout extensively. Pool levels should be no higher than the proposed 535-foot low pool and 550-foot flood pool in order to keep pressures on the permeable limestone beds as low as possible. The natural blanket of the Prospect Formation should be left undisturbed where it is present, and additional blanketing may be advisable.

The only other permeable material that may prove troublesome is the coarse stony talus and colluvial material that has been incorporated into the valley-fill deposits where these deposits are adjacent to steep bedrock slopes. It may be necessary to take precautionary measures to prevent seepage through this material under the dam and possible high uplift pressures at the toe of the dam.

STRENGTH AND AVAILABILITY OF MATERIALS

The strength of the earth materials at the damsite and in the reservoir area must be evaluated in terms of the several uses to which the materials are to be put. Materials upon which structures are to be built must have their bearing capacity determined; those that will form the walls of the reservoir must have their stability on slopes investigated; and a suitable source for each of the various materials needed in construction, such as rockfill, earthfill, and aggregate, must be found.

Present plans call for a dam 60 feet or more high in the NE$\frac{1}{4}$ sec. 14, T. 1 S., R. 3 W.; a spillway a few hundred yards northeast of the dam; and a dike in the SE$\frac{1}{4}$ sec. 15 of the same township (fig. 6). The dam is to rest mainly on unconsolidated deposits 60 feet thick, of which the upper 15 feet or so consists of silty clays of the Martinsville Formation and the remainder mostly clayey sands of the Atherton. Silts of the Prospect Formation possibly underlie the Martinsville near the northeast abutment of the dam. Martinsville and Prospect materials may be relatively stable where undisturbed, but the bearing capacities of all the unconsolidated formations are subject to question and must be tested before fundamental design features of the dam may be established. The valley walls against which the abutments will rest are of limestone, shale, and sandstone. Unless these are excessively fractured or cavernous they can be expected to support the structure satisfactorily.

The dike (fig. 6) will be 30 feet or more high and will rest on a thin veneer of silt of the Prospect Formation over bedrock. The bearing properties of these materials should be satisfactory for this smaller structure. The spillway as proposed cuts across the narrow hilltop just northeast of the damsite (fig. 6), at a place where the top of the cavernous Glen Dean Limestone lies near the altitude of the proposed spillway floor. If the spillway site is moved northeastward to a location where the limestone is higher, more satisfactory floor conditions may be obtained; this location may be impractical, however, because of the increased length and depth of excavation. An alternate site just east of the dike might also be considered. Here the limestone is 10 to 15 feet below spillway level. At any of these localities the bedrock formations through which the spillway is to be cut are amply strong to support the spillway walls.

The hills surrounding the proposed reservoir consist mainly of limestone, shale, and sandstone; in many places, however, deposits of the Prospect Formation rest against the lower part of the bedrock walls at about the level of the shoreline. Limestone and

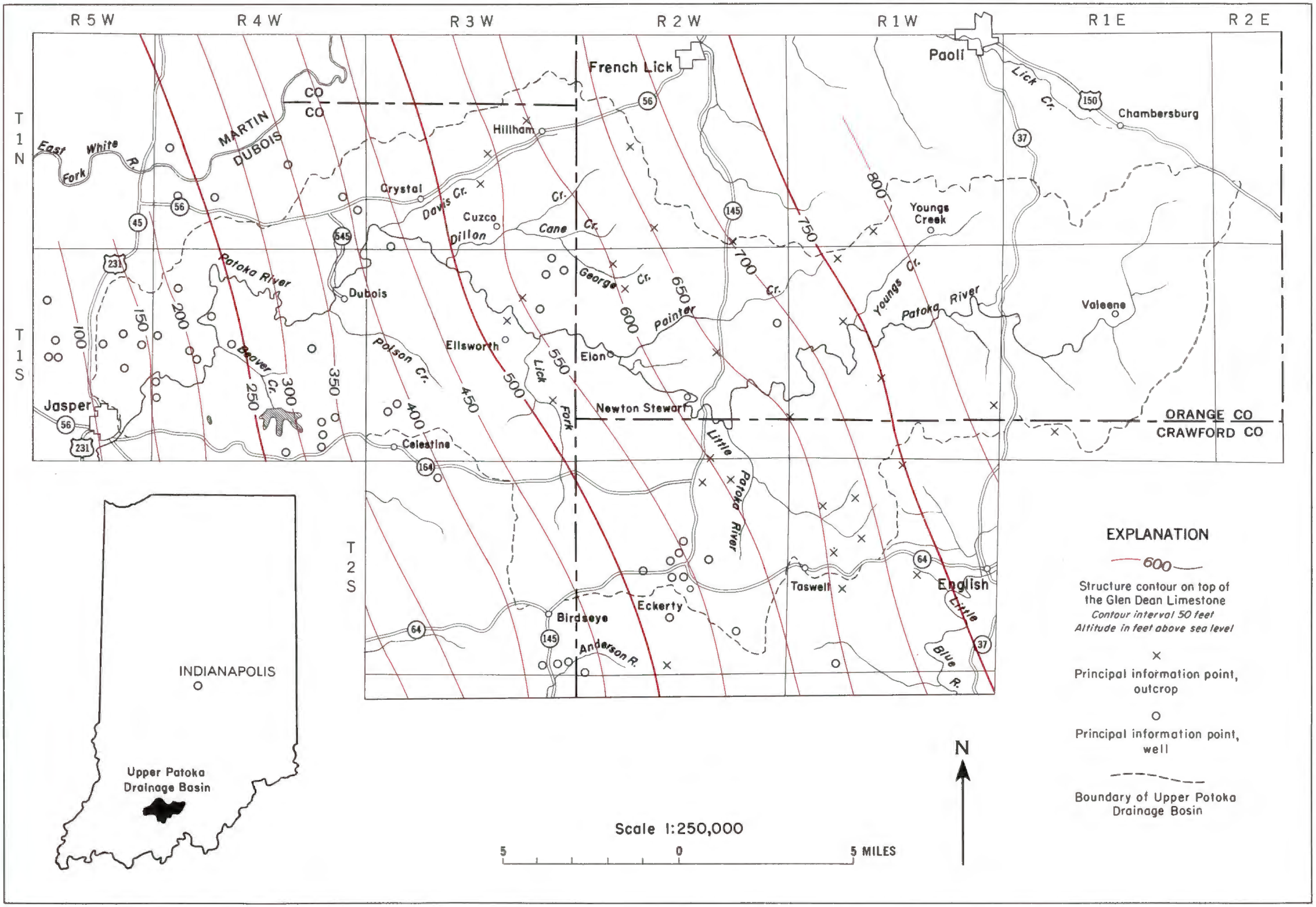

Figure 5.--Map of the Upper Patoka Drainage Basin showing generalized structure on top of the Glen Dean Limestone.

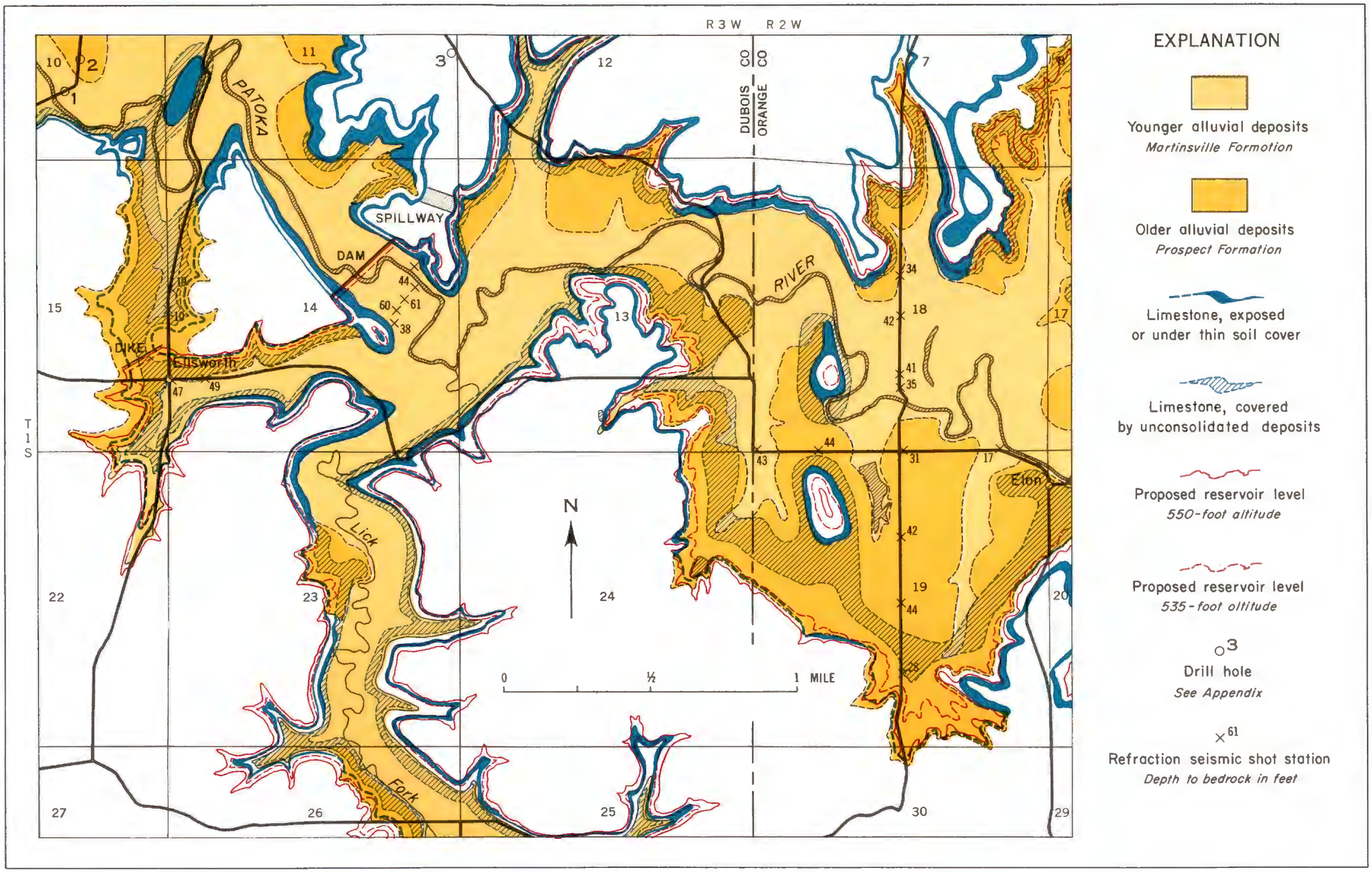

Figure 6.--Geologic map of proposed Ellsworth damsite area. Sites indicated are approximate pending further investigation.

sandstone beds are strong enough to resist direct wave attack, but the shales, especially where subjected to alternate wetting and drying due to fluctuating water levels, are likely to weather rapidly and slump, and thus the stronger beds are left unsupported. Large blocks may then separate along already existing fractures and tumble rapidly into the reservoir. Most of these induced land movements will take place soon after impoundment of the water, and in general they will be restricted to steep slopes unsuited to development. They therefore constitute no major hazard but will tend to reduce somewhat the permanent pool capacity of the reservoir.

Silt deposits belonging to the Prospect Formation present a unique stability problem because they stand in terraces with tops at about the proposed altitude of the flood-control pool, 550 feet (fig. 6). Alternate wetting and drying resulting from the fluctuating water level, varying pressure of ground water within the bodies of silt, and attack of the waves on silt exposed along the shoreline will cause slumping and movement of the silt into the reservoir and some loss of permanent pool capacity and possible damage to developed areas near the waterline. These terraces are probably too extensive to protect generally with riprap blankets, but local protection may be advisable.

Rockfill and riprap will be used to protect the face of the earthfill dam and the dike, other artificial fill, such as road grades, and perhaps some critical areas underlain by the Prospect Formation. Material suited to this use must in general be mechanically strong and not subject to rapid weathering, so that the fill will remain highly pervious. In this area only the limestones fit these specifications. Shales weather rapidly to impermeable clay; many of the sandstones are friable, and others weather and break down rapidly after artificial excavation.

There are no deposits of sand and gravel in the area and crushed limestone will probably be used as concrete aggregate. Within a short distance of the damsite are many suitable quarry sites; the lower of the two limestone beds (Golconda) is the better potential source mainly because of its greater thickness (Appendix, Log 3). There is little difference in the physical properties of the two limestones. Crushed limestone may also be obtained from a large commercial quarry about 10 miles southeast of the damsite.

For earthfill, the clayey silts of the Prospect Formation probably will prove more suitable than the clays of the Martinsville Formation. Atherton silty sands are likely to be runny when they are wet and thus are probably unsuitable for earthfill. Extensive areas underlain by Prospect deposits are found within a short distance of the proposed damsite. Some of these ought to remain undisturbed, however, because they serve as impervious blankets over potentially leaky limestone outcrops. Shales from some of the bedrock formations would make good earthfill, although at considerable expense for excavation, and only small areas of thin and stony unconsolidated materials are likely to be found on the hilltops.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

The aims of this report have been (1) to outline the generalities of the geologic setting of the damsite and reservoir area and (2) to point out the major geologically based problems of reservoir and structure design in the area.

No large dam and reservoir have been built in a geologically similar situation in Indiana, and thus there is no empirical guide to the geologic problems that the project may encounter. In summary, however, the following findings appear significant:

1. At proposed pool levels there will be little or no leakage from the reservoir eastward, southward, and westward. Some leakage northward into George Creek is to be expected, and a serious leakage problem exists at the damsite, where fractured and cavernous limestones will be in contact with the impounded water.
2. Earthfill of probably suitable character is available in large supply from deposits of the Prospect Formation, but some of these materials should remain undisturbed because they constitute an impermeable natural blanket over potentially leaky beds of limestone.
3. Extensive beds of limestone suitable for rockfill and riprap are found in the immediate vicinity of the damsite.
4. Gravel deposits are not found in the area, but limestone suitable for crushed stone aggregate is available in large supply.
5. Thickness of unconsolidated deposits at the proposed damsite is about 60 feet.

On the basis of this geologic study, the following recommendations for detailed engineering studies are indicated in connection with further planning:

1. The bearing strength of the unconsolidated deposits at the damsite should be tested, and the stony layer at the base of these deposits, if present at the damsite, should be pressure-tested.

2. Suitability of the clayey silt of the Prospect Formation for earthfill should be investigated by laboratory determination of Atterberg limits and other pertinent parameters.

3. Boring and pressure-testing programs should be carried out at the rock abutments of the dam, in the dike area, and along the entire narrow ridge across which the spillway is to be cut.

4. The area of outcrop of the Glen Dean and Golconda Limestones, where they lie at altitudes below 550 feet along the north bank of the reservoir, should be examined for solution channels.

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LOG 1

Auger hole along county road 200 ft southwest of bend in SE$\frac{1}{4}$ sec. 10, T. 1 S., R. 3 W. Altitude at top of hole, approximately 495 ft. Prepared from samples at 3-ft intervals from surface to 15 ft and at 5-ft intervals below 15 ft.

	Thickness (ft)	Depth (ft)
Quaternary System:		
Martinsville Formation, 12 ft drilled:		
Silt: clayey, medium yellowish-brown, moist, cohesive	3	3
Silt: clayey, dark yellowish-brown, moist, cohesive	6	9
Silt: clayey, medium yellowish-brown to medium-gray, moist, cohesive	3	12
Atherton Formation, 61 ft drilled:		
Silt: clayey, light yellowish-brown, wet, plastic	8	20
No sample	5	25
Silt: sandy, clayey, medium-gray, wet, plastic	10	35
Sand: silty, clayey, medium-gray, wet, cohesive	35	70
Sand: silty, clayey, medium-gray, wet, plastic	3	73
(Bedrock was not reached in this hole.)		

LOG 2

Auger hole along county road 500 ft north of bend in SE$\frac{1}{4}$ sec. 10, T. 1 S., R. 3 W. Altitude at top of hole, approximately 502 ft. Prepared from samples at 3-ft intervals from surface to 15 ft and at 5-ft intervals below 15 ft.

	Thickness (ft)	Depth (ft)
Quaternary System:		
Prospect Formation, 35 ft drilled:		
Silt: clayey, light to medium yellowish-brown, moist, cohesive	15	15
Silt: clayey, dark yellowish-brown, moist, cohesive	10	25
Sand: silty, medium brownish-yellow, wet, plastic	5	30
Silt: clayey, medium yellowish-brown, wet, plastic	5	35

LOG 2--Continued

	Thickness (ft)	Depth (ft)
Quaternary System--Continued		
Bedrock residuum, 5 ft:		
Clay: medium-gray, wet, plastic; abundant siltstone chips and fossil fragments -	5	40
(Bedrock, probably the shale just beneath the Golconda Limestone, was encountered at 40 ft.)		

LOG 3

Core from Indiana Geological Survey drill hole 83, NE$\frac{1}{4}$NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 11, T. 1 S., R. 3 W., on the property of Ralph Cobb, Dubois County. Altitude at top of hole, 615 ft.

	Thickness (ft)	Depth (ft)
Mississippian System:		
Unnamed group:		
Tar Springs Formation, 46 ft drilled:		
1. Sand and sandstone: not cored -	20.0	20.0
2. Sandstone: light yellowish-brown to light-gray; very thin contorted dark-gray shale strata abundant in some parts - -	21.5	41.5
3. Shale: medium greenish-gray; calcareous in lower part; marine fossils abundant -	4.2	45.7
Stephensport Group:		
Glen Dean Limestone, 14 ft:		
4. Limestone: light yellowish-brown, fine-grained, with sparse to abundant coarsely crystalline fossil fragments; some stylolites -	14.3	60.0
Hardinsburg Formation, 30 ft:		
5. Shale: medium greenish-gray; thinly interstratified with fine-grained light-gray sandstone in upper part - - - - - - - - -	14.0	74.0
6. Mudstone: light greenish-gray -	6.8	80.8
7. Shale: reddish-brown and greenish-gray; some thin strata of fine-grained sandstone in lower half - - - - - - - - - - - - - - -	9.2	90.0
(Circulation lost at 90.0 ft as bit fell into crevice. Moved rig 10 ft north, rock-bitted to 90.0 ft, and resumed coring.)		

LOG 3—Continued

	Thickness (ft)	Depth (ft)
Mississippian System--Continued		
Stephensport Group--Continued		
Golconda Limestone, 30 ft:		
8. Limestone: light yellowish-brown, fine-grained, with sparse to abundant coarsely crystalline fossil fragments; some of the larger fossils have been replaced by chert; scattered thin shaly strata; thin zone of green glauconite? at base - - - -	29.7	119.7
Big Clifty Formation, 62 ft:		
9. Shale: dark-gray, and medium yellowish-brown limestone - - - -	1.8	121.5
10. Shale: dark-gray; abundant calcareous fossils - - - - - - - - - - - -	11.3	132.8
11. Mudstone: light greenish-gray -	7.7	140.5
12. Sandstone: white, very fine-grained; scattered very thin shale strata -	41.1	181.6
Beech Creek Limestone, 11 ft:		
13. Limestone: light yellowish-brown; abundant coarsely crystalline fossil fragments in minor very fine-grained matrix - - - - - - -	4.0	185.6
14. Limestone: medium yellowish-brown, very fine-grained; fossil fragments sparse; scattered zones of glauconite? - - - - - - - -	7.1	192.7
West Baden Group:		
Elwren Formation, 15 ft drilled:		
15. Mudstone: light greenish-gray and medium reddish-brown, and light greenish-gray siltstone -	14.6	207.3

Total depth - 207.3 ft