Bulletin No. 38

GROUND-WATER RESOURCES OF VANDERBURGH COUNTY, INDIANA

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
Division of Water

Prepared by
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
Water Resources Division

1977

STATE OF INDIANA

DEPARTMENT OF NATURAL RESOURCES

BULLETIN NO. 38

OF THE

DIVISION OF WATER

Robert F. Jackson, Chief

GROUND-WATER RESOURCES OF VANDERBURGH COUNTY, INDIANA

By

L. W. Cable and R. J. Wolf

Hydrologists, U.S. Geological Survey

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GEOLOGICAL SURVEY

UNITED STATES DEPARTMENT OF THE INTERIOR

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GROUND-WATER RESOURCES OF VANDERBURGH COUNTY, INDIANA

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ABSTRACT

Sandstone units of Middle and Late Pennsylvanian age and sand and gravel of Quaternary age are the source of fresh (1,000 parts per million of dissolved solids or less) ground water in Vanderburgh County. Aquifers occur in older rocks, but, owing to their depth, the water is too highly mineralized to be useful for most purposes. Three sandstone units occur that are fresh-water bearing and areally extensive enough to be important aquifers. Together these sandstone units underlie most of the county. The fresh-water bearing sandstone units are in the Linton Formation, the Dugger Formation and the Patoka Formation (of local usage) of Wier and Gray (1961), and are herein named the Linton aquifer, the Dugger aquifer, and the Patoka aquifer, respectively. These sandstone units are similar in their lithologic and petrologic characteristics. At present (1966) the Linton aquifer is not a source of fresh ground water in Vanderburgh County. However, in the eastern part of the county the aquifer is near enough to land surface to contain fresh water. The estimated field coefficient of permeability of the sandstone aquifers is 10 gallons per day per square foot, and the maximum coefficient of transmissibility is estimated to be 1,000 gallons per day per foot. Yields reported from wells in the Dugger and Patoka aquifers range from less than 1 to approximately 20 gallons per minute. However, most wells in these aquifers are reported to yield 5 gallons per minute or less. The water in the Dugger aquifer is predominately a moderately hard sodium bicarbonate type, low in iron content. The water in the Patoka aquifer is mostly a hard to very hard calcium bicarbonate type with moderately high amounts of iron.

Sand and gravel deposits of the Ohio River valley are the best aquifer in Vanderburgh County. These deposits form a single hydrologic unit that is herein named the Ohio River valley aquifer. This is the only aquifer in the county capable of accommodating high-yield wells. Properly constructed wells in this aquifer could easily yield 1,000 gallons per minute and more. Transmissibilities in the Ohio River valley aquifer range from 120,000 gallons per day per foot and less near the valley walls to more than 200,000 gallons per day per foot in the thickest parts of the aquifer. The water in the aquifer is predominately a very hard calcium bicarbonate type having a high iron content.

INTRODUCTION

PURPOSE AND SCOPE

The purpose of this investigation is to determine ground-water availability in Vanderburgh County, Indiana, and to provide information to aid water users in the location and development of ground-water resources. No previous attempt has been made to collect and organize the data and present a quantitative evaluation of these resources. Demands for water are increasing constantly throughout the county because of the steady population growth in rural as well as in urban areas, and utilization of these resources is limited by a general lack of knowledge. Where is the water? How much is available? What is its quality? These are questions most often asked. To provide answers to these and other questions concerning ground-water availability, this report includes an identification of the important sources of ground water in the county, an evaluation of hydrologic characteristics and potential of these sources, and a determination of the chemical quality of the water.

The fresh ground water of Vanderburgh County is discussed in detail because of its importance to the growth and development of the county. Fresh water is water in which the dissolved mineral content (dissolved solids) does not exceed 1,000 ppm (parts per million). This definition follows that of Robinove, Langford, and Brookhart (1958).

The data upon which this report is based were compiled from approximately 900 water well and oil well drillers' logs, 230 oil well electric logs, 306 seismic shots, and 18 laboratory and 56 field chemical analyses of ground-water samples. These data are on file in the office of the U.S. Geological Survey, Indianapolis, Indiana. Pertinent literature concerning the soils, the geology, and the water resources of the county was reviewed and utilized. In addition, a geologic and hydrologic reconnaissance was made of the entire county.

COOPERATION AND ACKNOWLEDGMENTS

The ground-water resources of Vanderburgh County have been investigated by the U.S. Department of the Interior, Geological Survey, in cooperation with the Indiana Department of Natural Resources, Division of Water, as a part of the statewide investigation of the ground-water resources of Indiana. The authors wish to express their sincere thanks to all persons who contributed time, information, and assistance during the collection, tabulation, and processing of data for this report. We are especially grateful to the following State agencies for information furnished by them and used in this report: the Geological Survey, the Division of Oil and Gas, and the Division of Water, all under the Department of Natural Resources.

GEOLOGIC AND PHYSIOGRAPHIC SETTING

Geology

Vanderburgh County, in southwestern Indiana (fig. 1), is a part of the Eastern Interior Basin. The Eastern Interior Basin is a prominent structural feature of the central stable region of North America. The basin had its beginning in late Precambrian or Early Cambrian time as part of a larger structural basin which extended from northern Michigan to southern Illinois. This basin was relatively deep and elongate and roughly paralleled the Appalachian geosyncline. The emergence in Devonian time of the northwest-southeast trending Kankakee arch separated the original basin into two structures; the Michigan Basin to the north, and the Eastern Interior Basin to the south. With the exception of temporary regressions and transgressions of the sea, the Eastern Interior Basin continued to subside and receive sediment throughout most of the remainder of Paleozoic time. At the close of the Pennsylvanian Period the sea withdrew permanently from the basin leaving deposited upon the Precambrian basement complex a sequence of sedimentary rock more than 12,000 feet thick (pl. 1).

After the final withdrawal of the sea, there began an interval of subaerial weathering and erosion. The poorly consolidated Pennsylvanian clastic rocks of the basin offered little resistance to erosion, and the area was extensively peneplaned during Mesozoic and most of Cenozoic time. During the Pleistocene Epoch of the Quaternary Period much of the basin was mantled by till, outwash and other deposits resulting from successive waves of continental glaciation. The Recent Epoch began some 10,000 to 12,000 years ago with the northward retreat of the Wisconsinan glacier.

Physiography

The events of the Pleistocene Epoch profoundly affected the physiography of Vanderburgh County. Only a small part of the county, the northwest corner, was actually covered by glacial deposits. (See pl. 2.) Proglacial features rather than direct glaciation were responsible for the present physiography of the county. During Illinoian and Wisconsinan time, bedrock valleys in the county were either occupied by glacial lakes or served as sluiceways for sediment-laden glacial melt water. As a result, these valleys were aggraded by lake sediment and outwash deposits that remain today as broad, flat alluvial and lacustrine plains rimmed by hilly bedrock uplands.

Surface drainage is mostly to the Ohio River by way of Bayou Creek and Pigeon Creek and other small tributaries. However, in the northwest quarter of the county drainage is to the Wabash River through Big Creek and its tributaries.

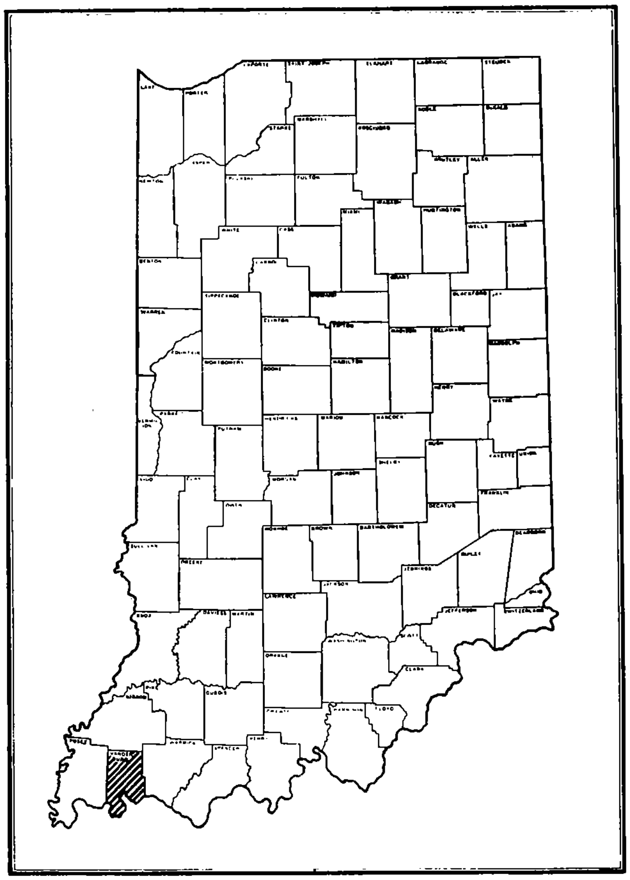


FIGURE I — Location of Vanderburgh County.

A knowledge of land-surface elevation is important in ground-water investigations. The depth to any subsurface stratigraphic horizon can be determined by subtracting the elevation of the horizon from that of land surface at the desired location. U.S. Geological Survey 7.5 minute topographic quadrangle maps are published for the entire county; therefore, a topographic map is not included in this report. These maps may be purchased from the Indiana Department of Natural Resources, Indianapolis, Indiana 46204 or the Distribution Section, U.S. Geological Survey, 1200 South Eads Street, Arlington, Virginia 22202.

CLIMATE

Continuous records of precipitation and air temperature at Evansville, Indiana, have been kept since 1895 by the U.S. Weather Bureau. Based on the records for the period 1931-1960 the normal annual precipitation is 41.45 inches. The normal monthly precipitation is shown in table 1. Precipitation is relatively abundant in this area and is spread fairly evenly throughout the year, a condition favorable to a uniform ground-water supply.

Table 1.--Normal monthly precipitation at Evansville, Indiana (1931-1960)

Month	Precipitation (inches)
January	3.98
February	3.18
March	4.31
April	3.98
May	4.19
June	3.74
July	3.32
August	3.07
September	2.87
October	2.57
November	3.16
December	3.08

SOURCES OF GROUND WATER

Ground water is the water in the zone of saturation. The water table marks the top of the zone of saturation, or the zone where the void spaces in the rock are completely filled with water. When the interconnected void spaces in a layer of rock are large enough to supply ground water to wells in sufficient quantities to satisfy domestic, industrial, municipal or other needs, the layer of rock is called an aquifer or source of water.

Oil-well electric logs indicate that aquifers are present in the rock sequence underlying Vanderburgh County from the top of the water table to depths of about 4,000 feet. Aquifers are probably also present in deeper rocks. All aquifers, regardless of depth and water quality, are part of the overall ground-water resources of the county. However, ground water in

Vanderburgh County becomes increasingly mineralized with depth, and water in the deeper aquifers is too mineralized to be useful for most purposes. Thus, this investigation is limited to the relatively shallow rocks of Pennsylvanian and Pleistocene Series because these rocks contain the important fresh-water aquifers.

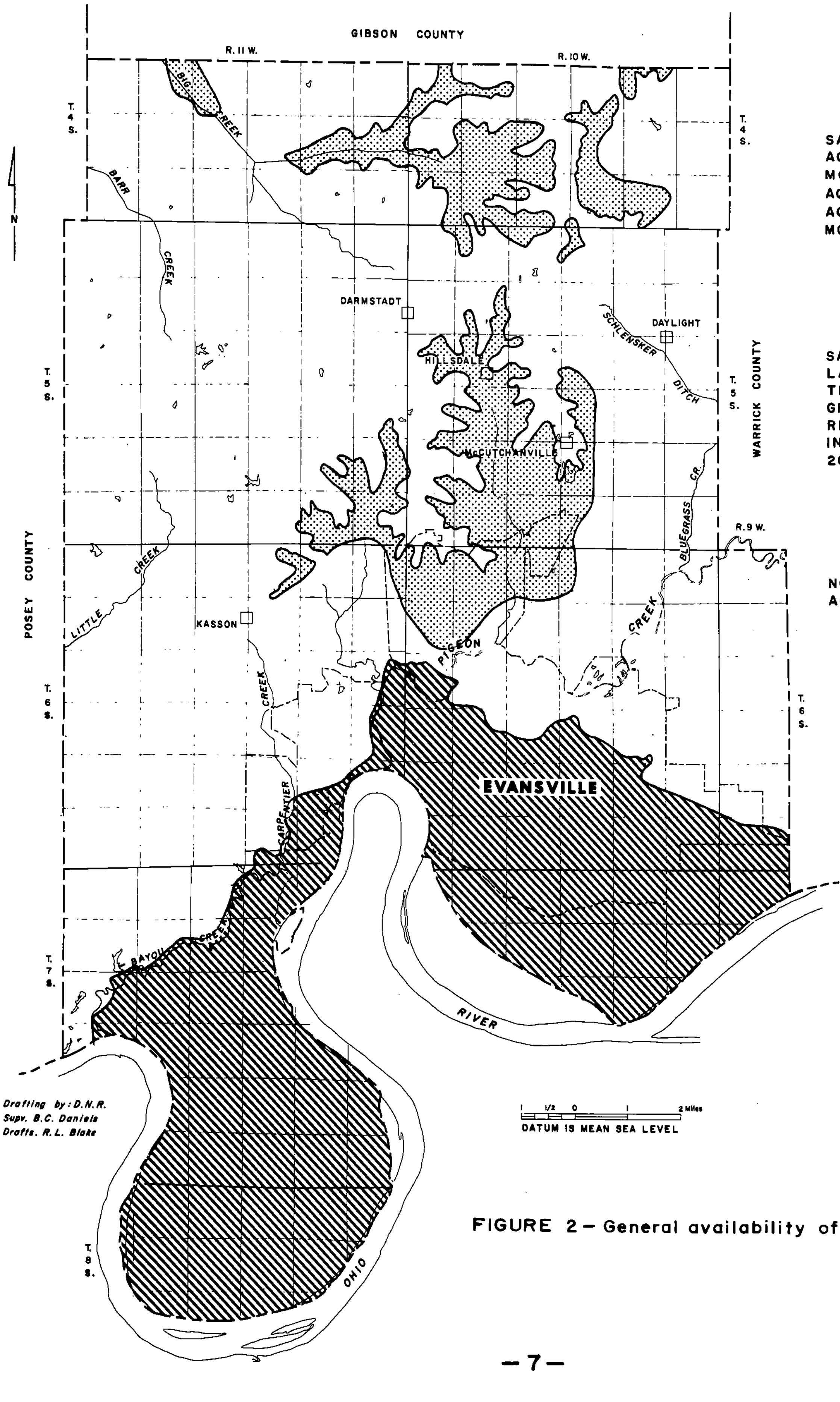
The general availability of fresh ground water in Vanderburgh County is summarized on figure 2.

THE PENNSYLVANIAN SYSTEM

The Pennsylvanian System of Vanderburgh County extends upward from the unconformity at the base of the Mansfield Formation to and including the lower part of Bond Formation of Kosanke and others (1960). (See fig. 3.) Rocks of Middle and Late Pennsylvanian age constitute the bedrock surface. (See pl. 1.) The maximum thickness of the Pennsylvanian section in Vanderburgh County is about 1,500 feet. Deposition during Pennsylvanian time was cyclical, and alternating layers of shale, sandy shale, and sandstone are the predominant lithologic units of the section with minor amounts of coal, underclay, and limestone present. The great areal persistence of many relatively thin (generally 5 feet or less in thickness) limestone members and coal beds is the most characteristic feature of these sediments, particularly in the middle and upper series. These limestone members and coal beds are important stratigraphic markers.

The Pennsylvanian sediments of Vanderburgh County have undergone no major structural deformation. The structure of individual rock units may be visualized as a gently rolling (undulating) surface dipping to the northwest at an average rate of 25 feet per mile. This uneven surface is probably the result of the differential compaction of sandstone and shale units.

An important zone of faulting, the Wabash Valley fault system, is just to the west of Vanderburgh County. However, no large faults are mapped in the county. Friedman (1954) shows the approximate and inferred location of two small normal faults in the western part of the county. These faults dip to the northwest and have a vertical displacement of approximately 20 feet in Middle and Upper Pennsylvanian strata. Though it is possible that these and other faults of similar vertical displacement exist in the county, the amount of subsurface data available for this investigation was insufficient to ascertain with any degree of certainty the presence of faults of this magnitude.



EXPLANATION

SAND & GRAVEL OF QUATERNARY AGE FORM THE THICKEST AND MOST PERMEABLE FRESH-WATER AQUIFER IN THE COUNTY. THIS AQUIFER IS CAPABLE OF ACCOMMODATING HIGH-YIELD WELLS.

SANDSTONE UNITS OF MIDDLE & LATE PENNSYLVANIAN AGE ARE THE PRINCIPAL SOURCE OF FRESH GROUND WATER. THE MAXIMUM REPORTED YIELDS FROM WELLS IN THESE AQUIFERS IS ABOUT 20 GPM.

NO IMPORTANT FRESH-WATER AQUIFERS PRESENT.

FIGURE 2 – General availability of fresh ground water.

<table>
<tr><th></th><th>System</th><th>Series</th><th>Formation and Significant Members</th></tr>
<tr><td rowspan="9">CARBONIFEROUS</td><td rowspan="9">PENNSYLVANIAN</td><td rowspan="3">Upper Pennsylvanian</td><td>Bond of Kosanke and others (1960)</td></tr>
<tr><td>Patoka of Wier and Gray (1961)
Inglefield Sandstone Member of Wier and Girdley (1963)</td></tr>
<tr><td>West Franklin Limestone Member of Wier and Gray (1961)
Shelburn</td></tr>
<tr><td rowspan="5">Middle Pennsylvanian</td><td>Dugger</td></tr>
<tr><td>Petersburg</td></tr>
<tr><td>Linton
Coxville Sandstone Member of Ashley (1899)</td></tr>
<tr><td>Coal III
Staunton</td></tr>
<tr><td>Brazil</td></tr>
<tr><td>Lower Pennsylvanian</td><td>Mansfield</td></tr>
</table>

Figure 3.--Stratigraphy of the Pennsylvanian System for Vanderburgh County.

Where are the Aquifers?

Sandstone units are the best aquifers in the Pennsylvanian sediments of Vanderburgh County although water wells are occasionally made in limestone, coal beds, or shale. Sandstone units occur regularly throughout these sediments and show a great deal of similarity in shape and orientation. However, the sandstone units are difficult to trace in the subsurface. They are subject to sharp variations in thickness in relatively short distances. Abrupt lateral changes in facies result in irregular and discontinuous areal distribution. A series of generalized geologic sections (pl. 2) show the formation boundaries and major sandstone units of the Pennsylvanian System.

The lithologic (physical) character of a rock unit directly affects its water-bearing characteristics. In rock units like those of the Pennsylvanian System of Vanderburgh County, lithology largely determines permeability or the capability of the rock units to transmit water. The lithologic character (and thus the permeability) of the sandstone units is not uniform throughout the Pennsylvanian section. In the Mansfield Formation, for example, sandstone units are composed mostly of rounded, medium-sized grains of quartz with relatively little detrital matrix (Greenburg, 1960). These are probably the most permeable sandstone units of the entire section. Near the top of the section, however, the individual quartz grains of the sandstone units are angular and there is a relatively large amount of detrital matrix in the intergranular void spaces thus decreasing permeability.

The Pennsylvanian sediments of Vanderburgh County are herein subdivided into two parts on the basis of the occurrence of fresh water. With the data available, however, it is not possible to determine the exact depths at which the water in these sediments ceases to be fresh. This varies from place to place and can only be approximated. Coal III of the Staunton Formation (fig. 3) was selected as the basis for subdividing the Pennsylvanian sediments because it is the only easily recognizable stratigraphic marker in the vicinity of the lower limit of fresh water. (See fig. 4.) Sandstone aquifers above coal III are either completely or partially fresh-water bearing. No fresh water-bearing aquifers are present anywhere below coal III. Figure 5 is a map of Vanderburgh County showing structure contours on coal III.

Aquifers Below Coal III

Sandstone units with good aquifer characteristics are present in the Pennsylvanian sediments below coal III. Very little information is available concerning the water-yielding potential of these units. The sandstone units of the Mansfield Formation are the best aquifers. These sandstone units are the thickest, and the most continuous of the entire Pennsylvanian section. (See pl. 2.) In Vanderburgh County, however, the top of the formation ranges in depth from approximately 800 to 1,200 feet below land surface. At these depths the water is highly mineralized as shown by the results of water analysis number 1, table 2.

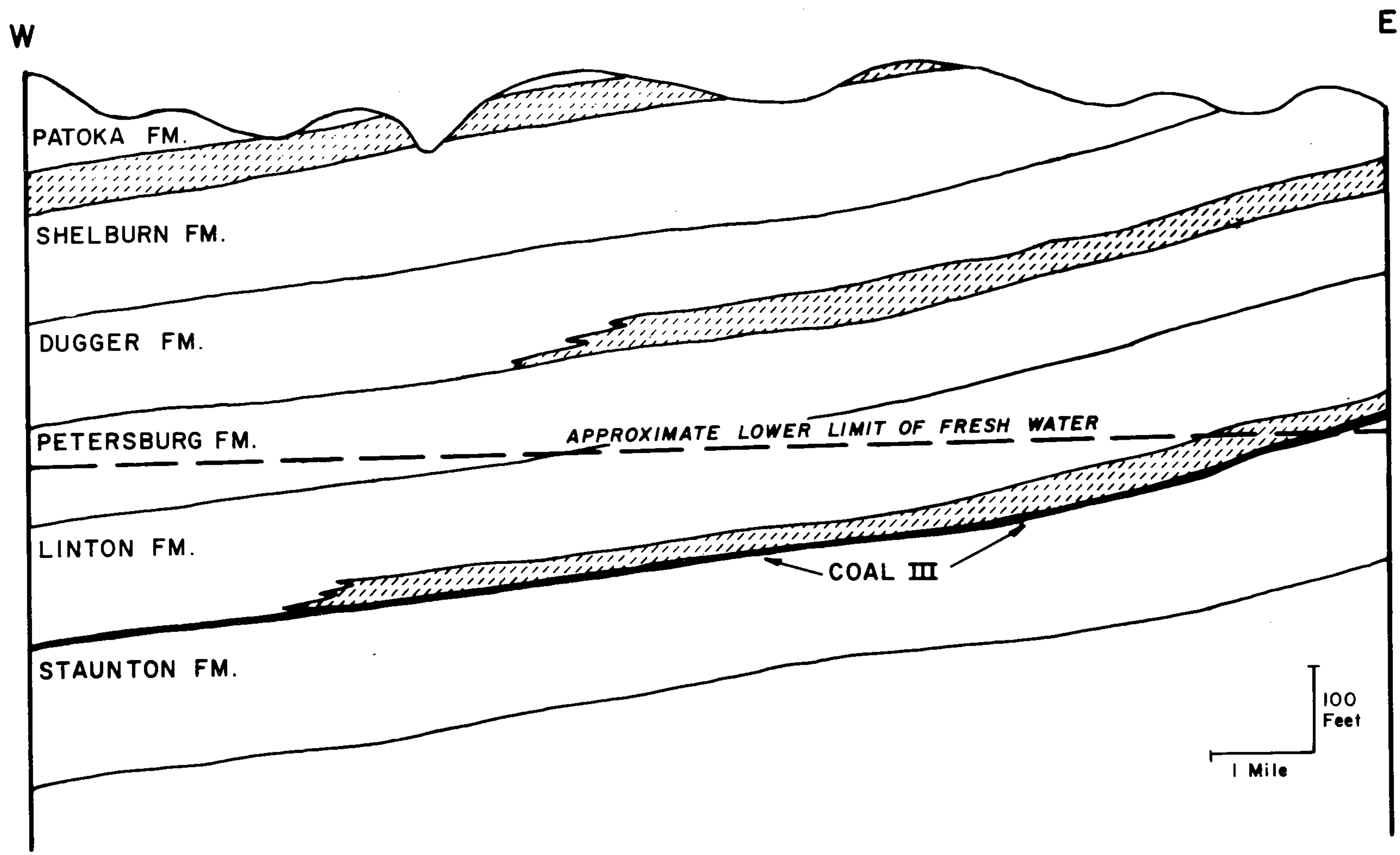
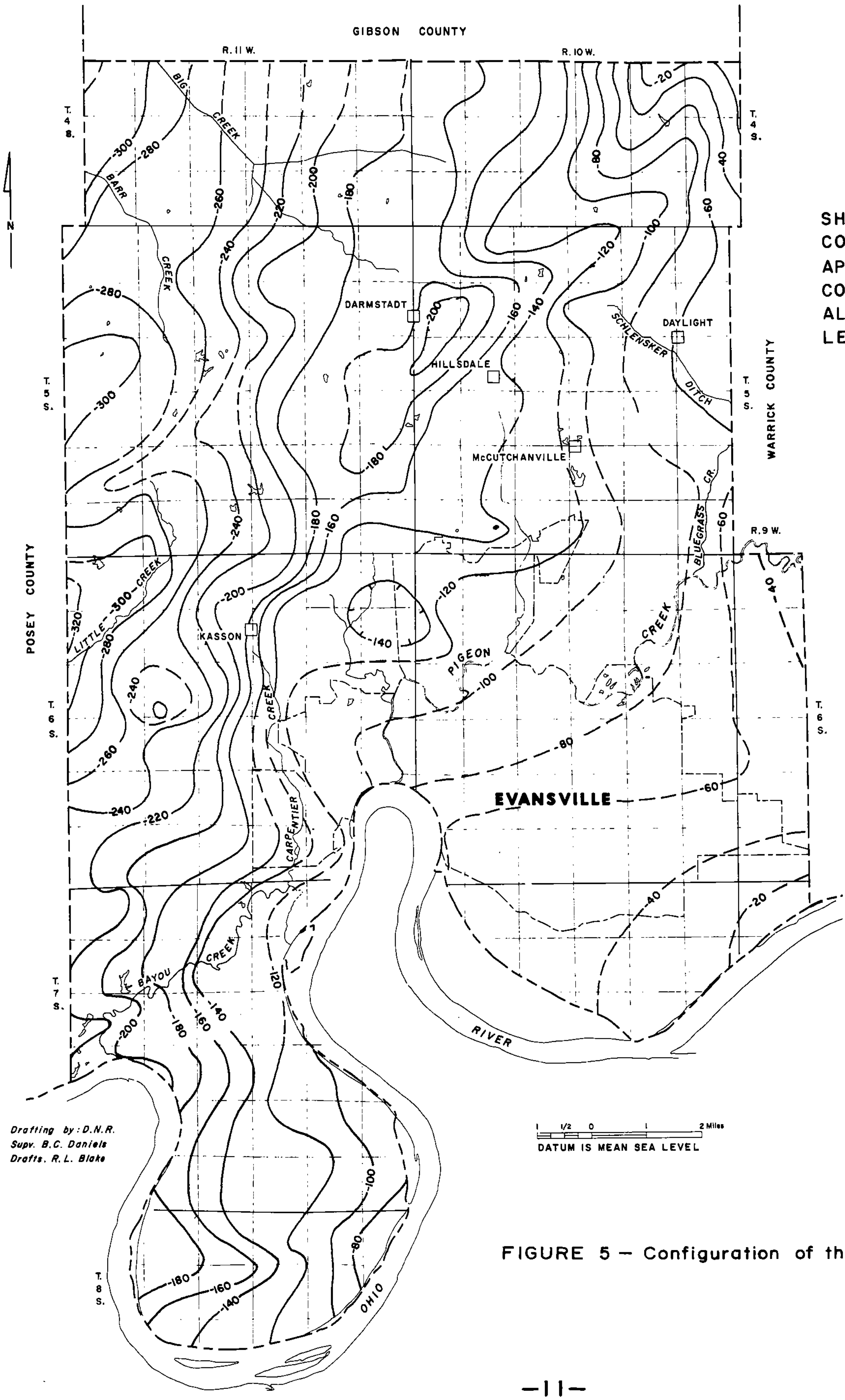


FIGURE 4.-- Generalized geologic section showing approximate lower limit of fresh water in relation to Coal III. Patterned areas represent sandstone aquifers.



EXPLANATION

-200

STRUCTURE CONTOUR

SHOWS ALTITUDE OF TOP OF COAL III. DASHED WHERE APPROXIMATELY LOCATED. CONTOUR INTERVAL 20 FEET. ALL DATUM IS MEAN SEA LEVEL.

FIGURE 5 – Configuration of the top surface of Coal III.

Aquifers Above Coal III

Sandstone aquifers above coal III are the source of fresh water for much of Vanderburgh County. There are three sandstone units above coal III that are areally extensive enough to be important aquifers. These sandstone aquifers are in the Linton and Dugger Formations as recognized by the U.S. Geological Survey, and in the Patoka Formation of Wier and Gray (1961). In this report, these aquifers will be referred to as the Linton aquifer, the Dugger aquifer, and the Patoka aquifer, respectively. North of the Ohio River terrace and flood-plain deposits (pl. 2), these aquifers constitute the principal source of fresh ground water.

The Linton aquifer

The Linton aquifer is at the base of the Linton Formation (fig. 6) and consists of the Coxville sandstone member of Ashley (1899) (fig. 3). This aquifer does not crop out in the county and has a rather limited areal distribution. At present (1966) the Linton aquifer is not used as a source of water in Vanderburgh County. Fresh-water aquifers in the rock sequence above make it unnecessary to drill down to this aquifer. In all probability much of the Linton aquifer is not fresh-water bearing, owing to its depth; however, in the eastern part of the county near the Vanderburgh-Warrick County line the aquifer is near enough to land surface to be fresh-water bearing. The areal extent, thickness, and altitude of top of the Linton aquifer are shown on figure 7.

The Dugger aquifer

The Dugger aquifer is in the upper part of the Dugger Formation (fig. 6). This aquifer is extensively used as a source of fresh water in eastern and southern Vanderburgh County. The aquifer crops out at the bedrock surface in the southern part of the county, and is present in the subsurface over much of the county. The Dugger aquifer is a single hydrologic unit consisting of an upper and lower sandstone unit separated by a relatively thin layer of limestone. It is rare to find all three of the lithologic units present at any one location in the aquifer. The upper sandstone unit and the limestone are present over most of the southern part of the county but shale out toward the north, whereas the lower sandstone unit is present over much of the eastern part of the county but shales out toward the south.

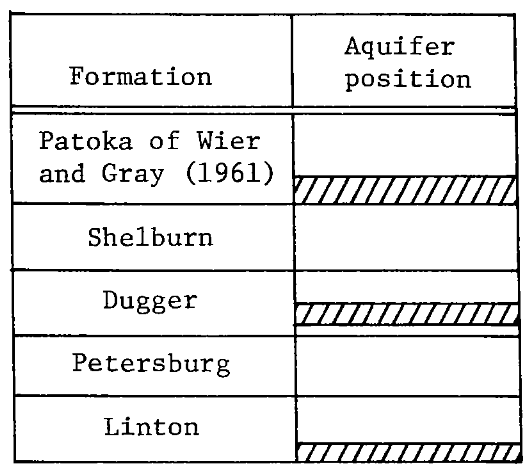


Figure 6.--Stratigraphy of the Pennsylvanian section above coal III with patterned areas showing the position of the aquifers.

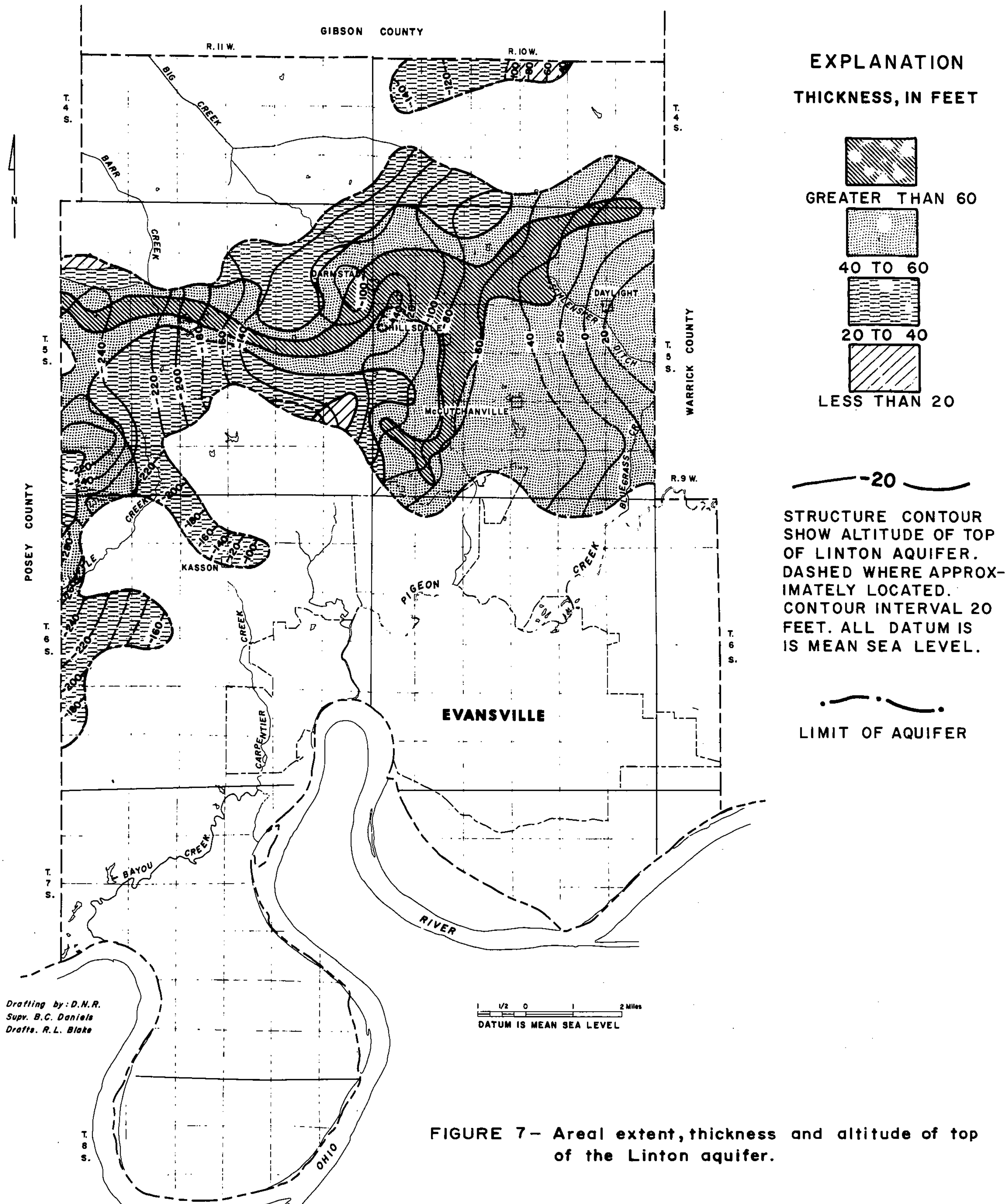


FIGURE 7 – Areal extent, thickness and altitude of top of the Linton aquifer.

The areal extent, thickness, altitude of top, and outcrop of the Dugger aquifer are shown on figure 8. The aquifer is very discontinuous and shows a highly irregular areal distribution. Except for a small area in the northwestern corner of the county, the aquifer shales out completely toward the northwest.

The Patoka aquifer

The Patoka aquifer is the thickest and most areally persistent of the fresh-water bearing sandstone aquifers in Vanderburgh County. More wells are supplied from this aquifer than from any other aquifer in the county. The Patoka aquifer is at the base of the Patoka Formation (of local usage) (fig. 6) and consists almost entirely of the Inglefield Sandstone Member of Wier and Girdley (1963) (fig. 3). In places, however, the underlying West Franklin Limestone Member of the Shelburn Formation of Wier and Gray (1961) (fig. 3) also may be part of the hydrologic unit. The outcrop of the aquifer extends in a broad band diagonally across the county from northeast to southwest, and the aquifer is present either at the bedrock surface or in the subsurface over almost all of the central and northwestern part of the county. The relatively deep, lacustrine-sediment-filled bedrock valley in the northwestern corner of the county cuts completely through the aquifer and exposes the underlying Shelburn Formation. (See pl. 1.) The areal extent, thickness, altitude of top, and outcrop area of the Patoka aquifer are shown on figure 9.

The dry hole problem

The sandstone aquifers of Vanderburgh County are dependable sources of water, and wells drilled into them are rarely reported to be dry. However, many of the dry holes that are drilled in the county seem to be the result of a general lack of understanding of the stratigraphic and structural relationship of the Dugger and Patoka aquifers. Stratigraphically these aquifers are one above the other with approximately 200 feet of shale, sandy shale, coal beds, and limestone separating them. Structurally each aquifer dips northwestward and becomes progressively lower in elevation or deeper below land surface. The aquifers are deepest, therefore, in the northwest parts of the county, and become progressively shallow updip toward the southeast until they end by cropping out at the bedrock surface. Except along the strike there is no uniform depth to any of the sandstone aquifers. In the central and northwest parts of the county, water wells are made in the Patoka aquifer because it is the aquifer nearest to land surface. Southeast of the outcrop of the Patoka, wells must be drilled down to this aquifer. It is in the area just southeast of the Patoka aquifer outcrop that most of the dry holes occur. Here the aquifer depth is significantly greater than in the adjacent area to the northwest where wells are made in the relatively shallow Patoka aquifer. In some parts of this area sandstone is absent, but many dry holes are the result of not drilling deep enough to reach the Dugger aquifer.

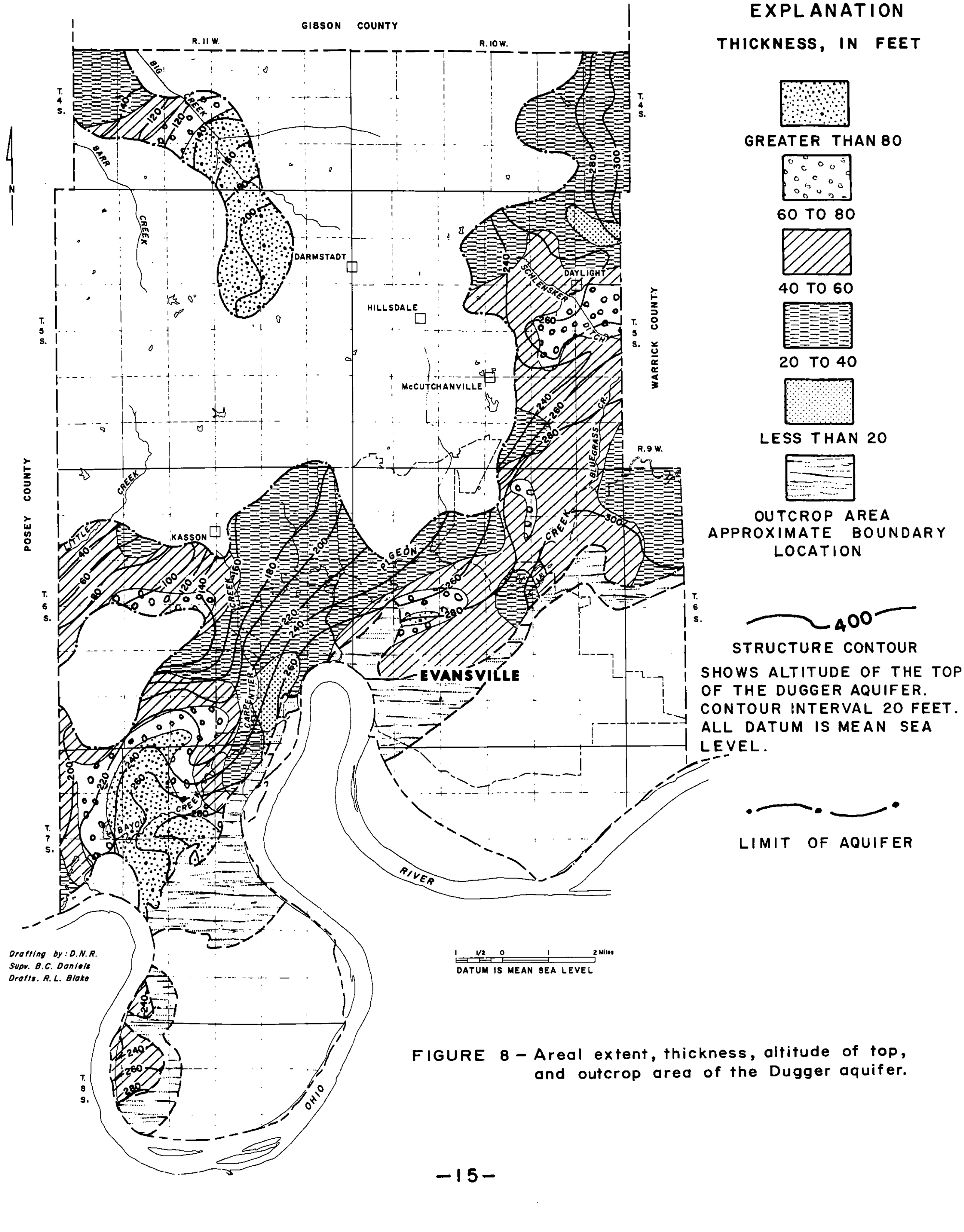


FIGURE 8 – Areal extent, thickness, altitude of top, and outcrop area of the Dugger aquifer.

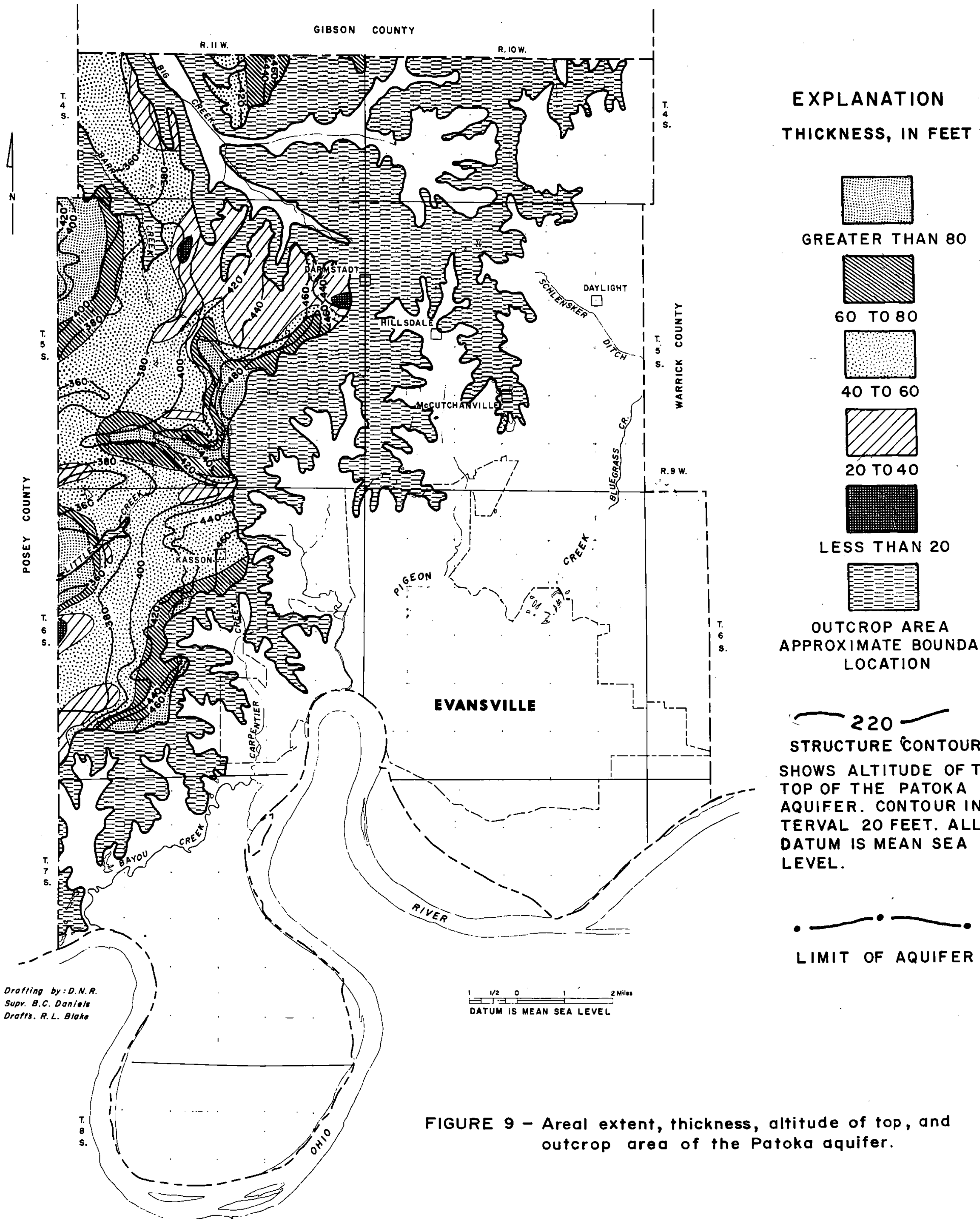


FIGURE 9 – Areal extent, thickness, altitude of top, and outcrop area of the Patoka aquifer.

Figure 10 is a generalized geologic section showing the stratigraphic and structural relationship of the Dugger and Patoka aquifers. Well A penetrates the Patoka aquifer at a depth of 25 feet, whereas well B, which is only 1 mile from well A but southeast of the Patoka aquifer outcrop, must be drilled to a depth of 200 feet before penetrating the Dugger aquifer. Well C penetrates the same aquifer as well A. Because it is northwest of well A, well C must be drilled deeper in order to reach the aquifer.

How Good are the Aquifers?

Reported yields from wells in the fresh-water sandstone aquifers of Vanderburgh County are relatively low. They range from less than 1 gpm to as much as 20 gpm. It is rare, however, to find a reported yield greater than 10 gpm and most wells are reported to yield 5 gpm or less. Any attempt to develop high-yield municipal or industrial wells in these aquifers would be impractical. The importance of these aquifers is that they are practically the sole source of fresh water throughout most of the rural areas of the county.

The amount of water presently being withdrawn from the fresh-water sandstone aquifers is estimated to be 2 mgd (million gallons per day).

Lithologic details of sediments penetrated by the observation well Vanderburgh 6 (SW 1/4 NW 1/4 sec. 8, T. 5 S., R. 11 W.), which is in the Patoka aquifer, are diagrammatically shown on figure 11. This well is generally representative of wells drilled in the Pennsylvanian sandstone aquifers of Vanderburgh County. The hydrograph of the observation well Vanderburgh 6 for a 1-year period is shown on figure 12. The amount of water-level fluctuation, as well as the general configuration of the hydrograph, is considered to represent the natural fluctuation in the sandstone aquifer.

The hydrologic characteristics of the fresh-water sandstone aquifers are in all probability very similar. This is indicated by the uniformity of the lithologic, petrologic, and geometric features of the sandstone units that constitute the aquifers. Direct information about the hydrologic characteristics is limited to the data from a specific capacity test of the observation well Vanderburgh 6. This test was conducted under optimum conditions. The well completely penetrates the Patoka aquifer and is cased to the top of the aquifer (fig. 11). The well was pumped for 8 hours at a constant rate of 8 gpm. The specific capacity (definition, p. 35) of the well is 0.134 gpm per ft. The field coefficient of permeability (definition, p. 35) of the aquifer is estimated to be 10 gpd per sq ft. These are considered to be generally representative of all fresh-water sandstone aquifers in the county. The maximum coefficient of transmissibility (definition, p. 35) for the sandstone aquifers in Vanderburgh County is estimated to be 1,000 gpd per ft.

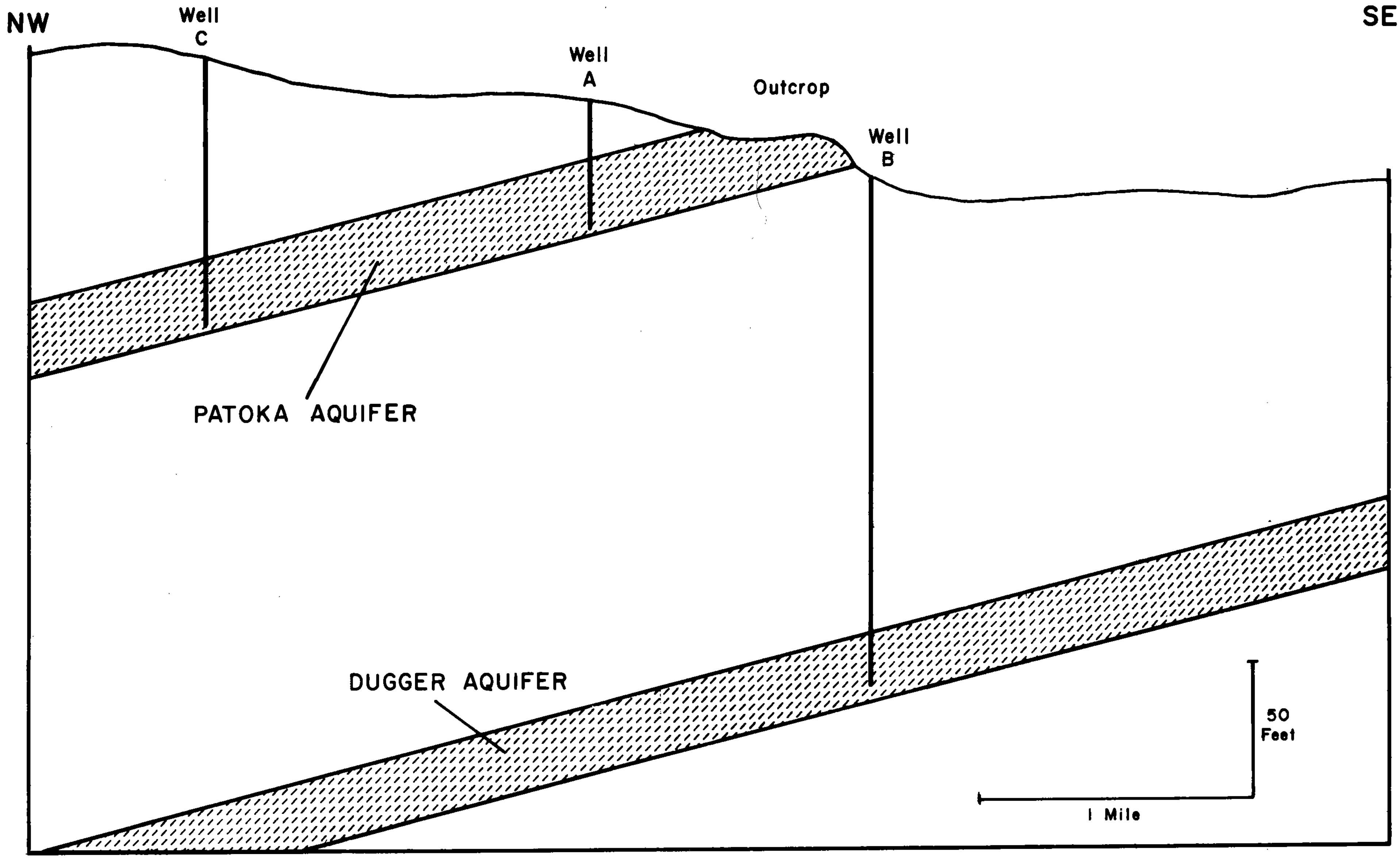


FIGURE 10.-- Generalized geologic section showing the stratigraphic and structural relationship of the Dugger and Patoka aquifers.

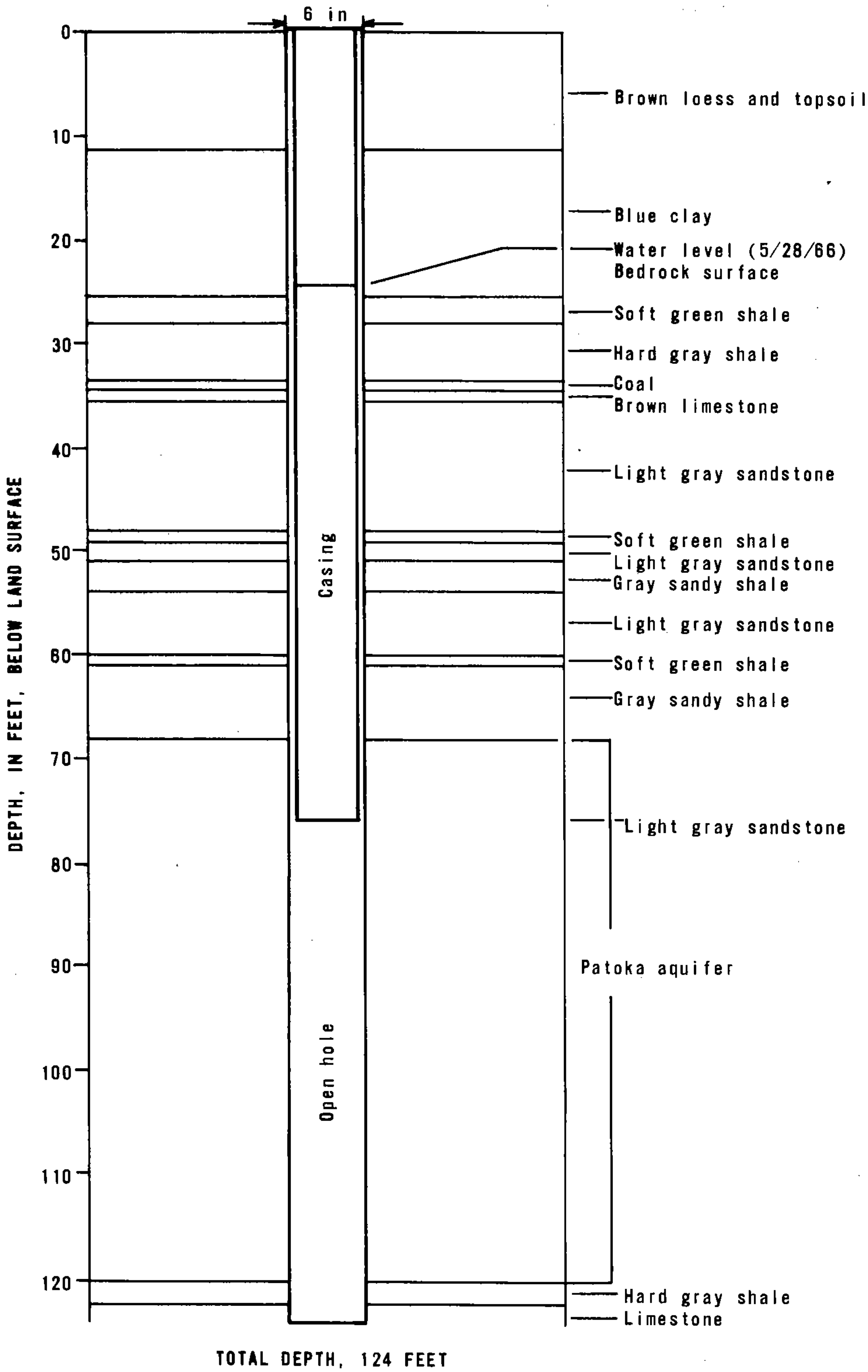


Figure 11.-- Total depth, depth of casing, diameter and lithology of the observation well Vanderburgh 6.

Water well drillers in Vanderburgh County frequently report that the lower part of the sandstone aquifers is the most productive. This is especially common where a well has penetrated a relatively thick section of aquifer. A grain-size analysis of samples of the Patoka aquifer taken during the drilling of the observation well Vanderburgh 6 shows that the grain-size distribution is not uniform throughout the aquifer. The depth of sampling and the median grain size of each sample are shown in figure 13. The material is generally coarser in the lower part of the aquifer than in the upper part. This feature has also been noted in other Pennsylvanian sandstones (Malott, 1948, p. 139; Hopkins, 1958, p. 33; and Andresen, 1961, p. 24). Where the sandstone aquifers are relatively thick, indications are that the coarsest material and, therefore, the highest permeability is in the lower part of the aquifer. For maximum yield, wells should completely penetrate the sandstone aquifers.

What is the Chemical Quality of the Water?

Water samples from wells in the Pennsylvanian sandstone aquifers of Vanderburgh County were collected and analyzed in order to ascertain the chemical quality of the water. The amount and type of dissolved mineral constituents present were defined, and characteristics of the water such as pH, hardness, specific conductance, and temperature were determined. Results of the laboratory analyses, which are more comprehensive than the field analyses, are given in table 2. The mineral constituents listed in the table are given in ionic form in parts per million.

The chemical quality of ground water in Vanderburgh County is controlled by several factors. Ground water generally becomes increasingly mineralized with depth. This can be seen by comparing the analyses given in table 2 of water samples from the Dugger and Patoka aquifers with that from the much lower Mansfield Sandstone. Although it is not possible to determine the exact depth at which the water ceases to be fresh, data indicate that there are two and possibly three sandstone aquifers which either partially or totally contain fresh water. The chemical quality of the water in these aquifers is not uniform and varies significantly throughout the county. The amount and kind of soluble minerals present in the rock as well as the length of time the water remains in the rock largely determine the chemical quality of the water. Variations in one or both of these features will result in corresponding variations in the chemical quality of the water. Locally the chemical quality of ground water may be affected by agents such as unplugged oil wells and improper waste disposal.

Analyses of water samples from the Dugger aquifer show the water to be mostly of the sodium bicarbonate type. Over most of eastern and southern Vanderburgh County where wells are supplied from this aquifer the water is fresh. Locally, however, areas occur in which the dissolved mineral content of the water is considerably in excess of 1,000 ppm owing to the presence of abnormally large amounts of sodium, bicarbonate, and chloride. This water is referred to by the local inhabitants as "soda water". Although this

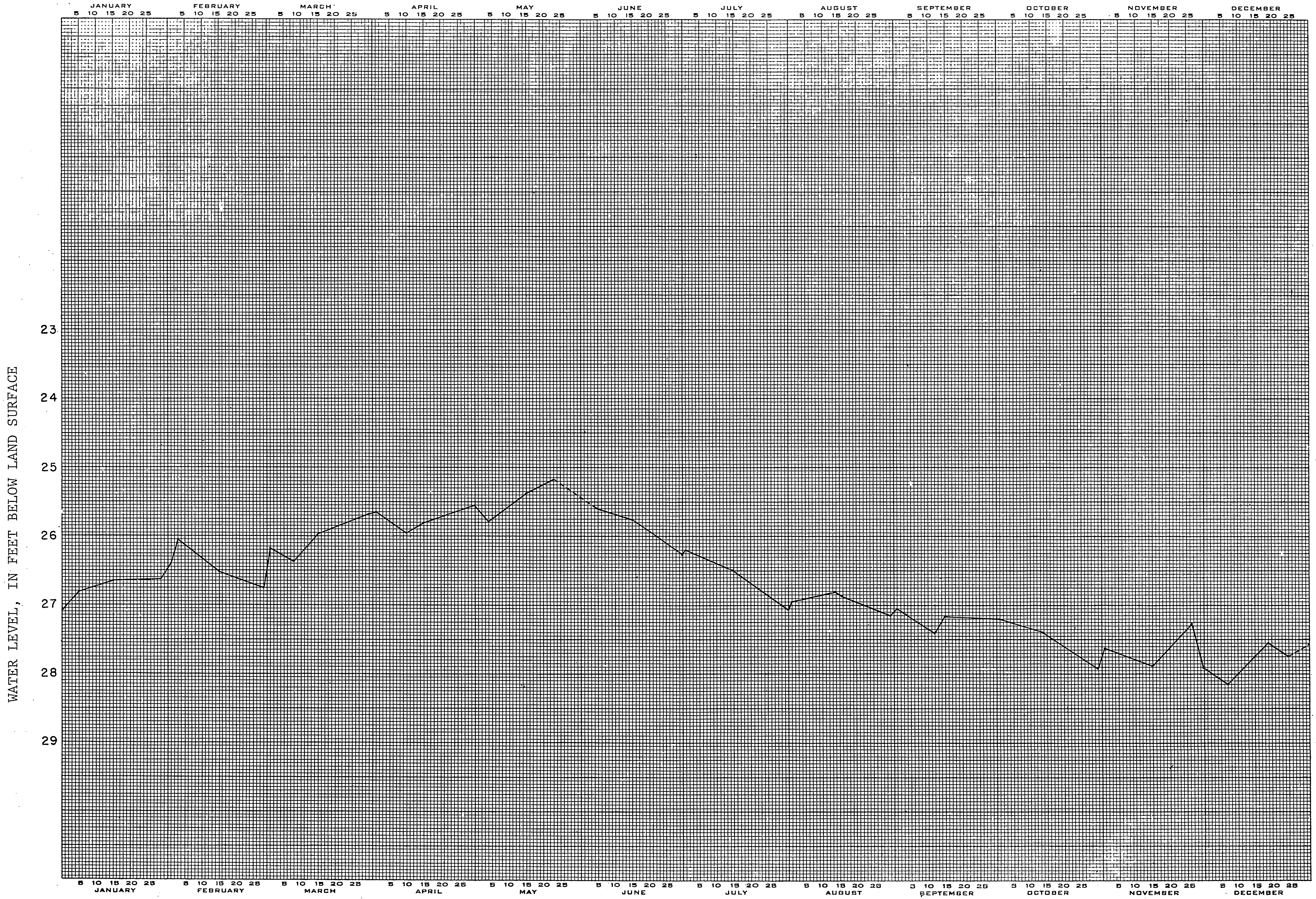


FIGURE 12.--Hydrograph of the observation well Vanderburgh 6 in 1966.

Table 2 .--Chemical analyses of ground water in Vanderburgh County, Indiana

(Results given in parts per million except as indicated)

Analysis Number	Source of Water	Well location	Land Surface Elevation (feet)	Well depth (feet)	Date of Collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids (Calculated)	Hardness as $CaCO_3$	Noncarbonate Hardness	Specific Conductance (Micromhos at 25° C)	pH
	Pennsylvanian System																							
1	Mansfield Formation	SE 1/4 SW 1/4 Sec.15 T. 7 S., R. 11 W.	365	930	10-26-65	63	12.0	2.00	0.55	107.0	38.0	3,060	16.0	740	0	195.0	4,420.0	0.4	---	8,210	423	0	14,000	7.6
2	Dugger aquifer	SE 1/4 NE 1/4 Sec.11 T. 6 S., R. 10 W.	385	98	10-27-65	61	21.0	.04	.02	78.0	40.0	36	8.0	508	0	.8	.5	.4	9.0	436	359	0	747	7.5
3	Do	NE 1/4 NE 1/4 Sec.25 T. 4 S., R. 10 W.	420	125	10-26-65	63	14.0	.98	0	16.0	9.3	206	2.1	540	0	32.0	31.0	.7	2.0	580	78	0	956	7.7
4	Do	SW 1/4 SW 1/4 Sec.25 T. 5 S., R. 10 W.	391	175	10-26-65	61	9.0	.78	.01	5.4	1.1	718	3.0	965	0	23.0	530.0	2.0	2.2	1,770	18	0	2,980	8.1
5	Do	NE 1/4 NE 1/4 Sec.27 T. 7 S., R. 11 W.	371	197	10-27-65	59	18.0	.44	0	25.0	8.3	109	1.6	340	0	3.8	43.0	.4	.9	377	96	0	634	7.8
6	Do	SW 1/4 NW 1/4 Sec.1 T. 5 S., R. 10 W.	410	118	10-28-65	58	12.0	.06	0	9.5	6.6	388	2.6	850	0	16.0	127.0	2.8	1.5	984	50	0	1,640	7.9
7	Patoka aquifer	SE 1/4 NE 1/4 Sec.13 T. 5 S., R. 11 W.	472	47	2-24-66	58	30.0	1.40	.05	102.0	27.0	51	1.0	380	0	132.0	20.0	.2	.3	552	366	54	860	7.0
8	Do	NE 1/4 NW 1/4 Sec.30 T. 5 S., R. 11 W.	543	228	2-24-66	57	23.0	.25	.03	39.0	10.0	71	1.8	316	0	27.0	9.0	.3	.2	336	136	0	544	7.7
9	Do	NW 1/4 NW 1/4 Sec.16 T. 5 S., R. 11 W.	535	193	2-24-66	55	32.0	.28	0	53.0	15.0	35	1.3	304	0	15.0	8.0	.3	.2	309	194	0	495	7.5
10	Do	SW 1/4 NW 1/4 Sec.8 T. 5 S., R. 11 W.	448	124	5-26-66	58	35.0	.50	.03	64.0	24.0	39	1.5	372	0	28.0	9.0	.1	1.2	385	258	0	616	7.6
	Quaternary System																							
11	Sand and gravel	NW 1/4 NE 1/4 Sec.34 T. 6 S., R. 10 W.	380	80	2-25-66	59	18.0	.19	.11	97.0	27.0	11	1.4	354	0	65.0	14.0	.3	.4	408	353	63	676	7.4
12	Do	NE 1/4 NE 1/4 Sec.22 T. 7 S., R. 11 W.	372	68	2-25-66	55	17.0	6.40	.10	73.0	15.0	20	.9	248	0	69.0	8.0	.2	.6	332	244	40	527	7.2
13	Do	NE 1/4 SE 1/4 Sec.20 T. 6 S., R. 10 W	385	71	7-10-56	66	20.0	4.10	1.40	169.0	54.0	27	3.5	499	0	268.0	22.0	.1	0	815	644	235	1,200	6.9
14	Do	SW 1/4 SW 1/4 Sec.19 T. 6 S., R. 10 W.	383	82	7-11-56	62	21.0	1.90	.93	193.0	52.0	41	7.1	525	0	314.0	36.0	.2	.6	926	695	265	1,340	6.9
15	Do	NE 1/4 NE 1/4 Sec.30 T. 6 S., R. 10 W.	382	80	7-23-53	61	18.0	1.90	.69	188.0	3.2	20	3.7	364	0	188.0	24.0	.2	1.3	621	484	---	931	7.6
16	Do*	NW 1/4 NW 1/4 Sec.31 T. 6 S., R. 9 W.	390	55	--------	--	----	----	----	115.0	40.0	30	2.0	500	-	45.0	30.0	0	---	518	450	---	-----	8.2
17	Do*	NE 1/4 NE 1/4 Sec.3 T. 7 S., R. 10 W.	379	104	--------	--	----	1.50	----	70.0	25.0	8	1.0	317	-	27.0	8.0	.2	0	315	290	---	-----	7.4

*Analysis from Indiana State Board of Health, Bull. S. E. 10, 1960.

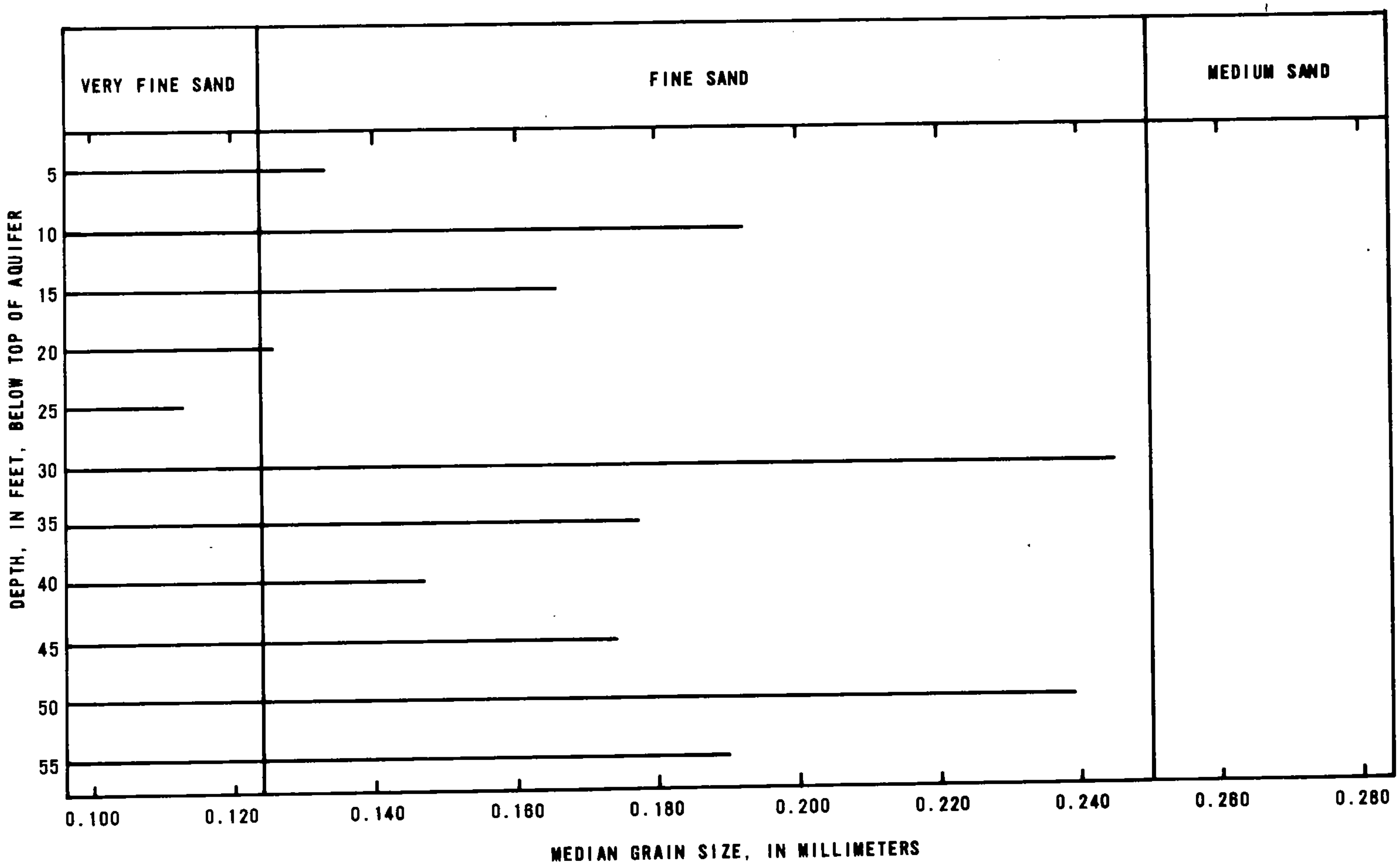


Figure 13.-- Grain-size distribution in the Patoka aquifer.

water is generally not fresh, it is excellent for such household and commercial purposes as laundering and cleaning owing to its softness and low iron content. Analysis 4 of table 2 is from a "soda water" area. The approximate boundaries of the two largest of these "soda water" areas is shown on figure 14.

Other significant characteristics of the water in the Dugger aquifer are the hardness and iron content. Except in the "soda water" areas where the water is predominantly soft, the water in the Dugger aquifer is moderately hard (table 3). Of the samples analyzed, hardness (as $CaCO_3$) ranged from 5 to 396 ppm with an average value of 108 ppm. The iron content was almost always less than 1.0 ppm.

Table 3.--U.S. Geological Survey Classification of Hardness (as $CaCO_3$) of Water (Durfur and Becker, 1964)

ppm	
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

Analyses of water samples from the Patoka aquifer show the water to be of the hard to very hard (table 3) calcium bicarbonate type. The dissolved mineral content is relatively low, and the water is fresh throughout Vanderburgh County. However, analyses show the hardness and iron content to be generally greater than in the Dugger aquifer. Of the samples analyzed, the hardness (as $CaCO_3$) ranged from 136 to 552 ppm with an average value of 260 ppm, and the iron content ranged from 0.1 to 7.5 ppm with an average value of 2.4 ppm.

THE QUATERNARY SYSTEM

The Quaternary System of Vanderburgh County consists of unconsolidated rocks of Pleistocene and Recent ages. In this report these rocks are subdivided into five units. These units include the flood-plain deposits and terrace deposits of the Ohio River valley, the lacustrine deposits and stream alluvium of the tributary valleys, and the loess, which mantles the bedrock hills. Plate 2 shows the surface distribution of these rock units throughout the county. The thickest and most hydrologically important of these rock units are the terrace and flood-plain deposits of the Ohio River valley. These deposits range in thickness from less than 40 feet to approximately 140 feet (fig. 15) and consist mostly of glacial outwash sand and gravel.

The Ohio River Valley Aquifer

Sand and gravel deposits of the Ohio River valley terraces and flood plain constitute a single hydrologic unit that is referred to as the Ohio River valley aquifer. In Vanderburgh County this aquifer is bounded on the south by the Ohio River and on the north by the bedrock hills of the river

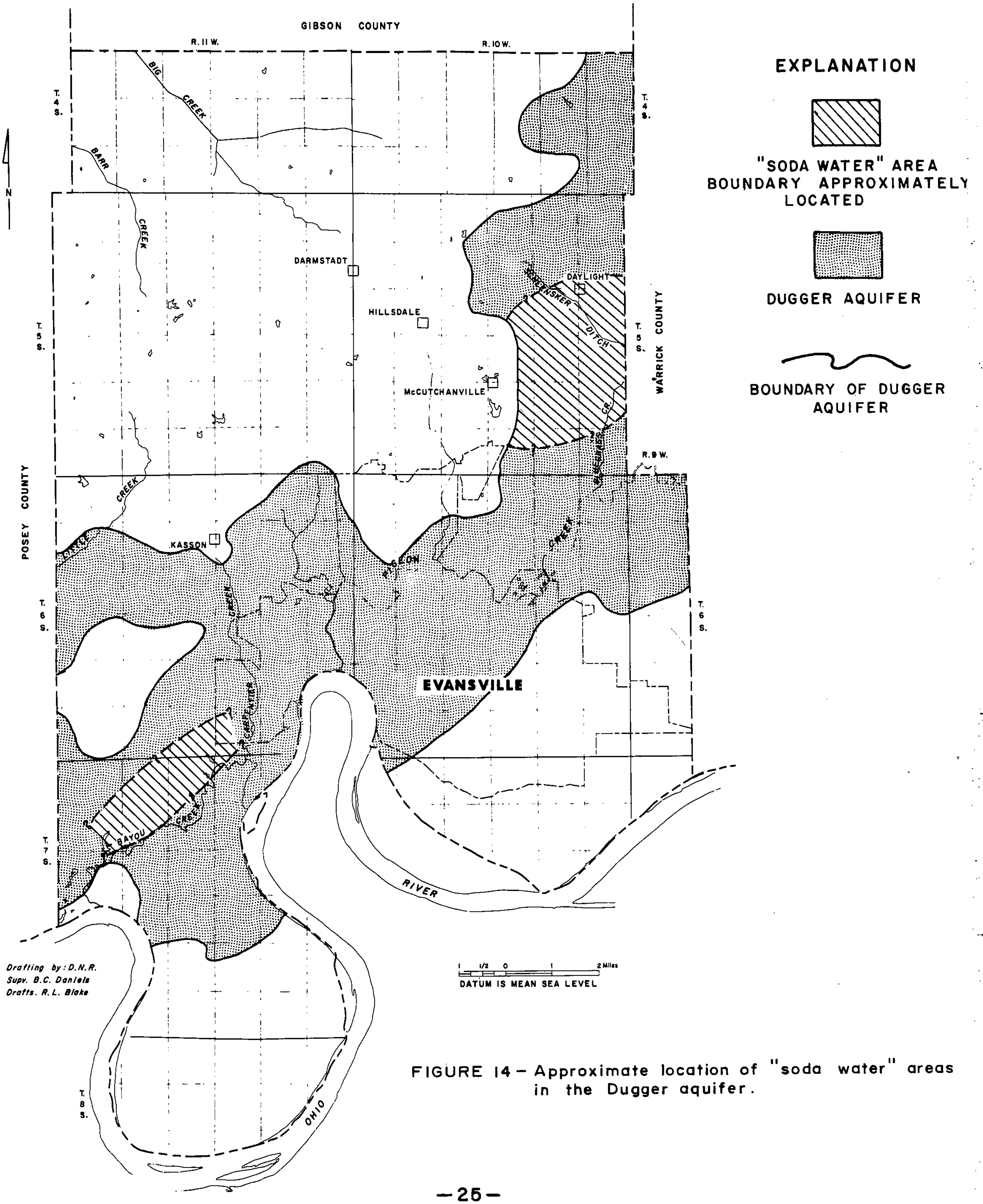
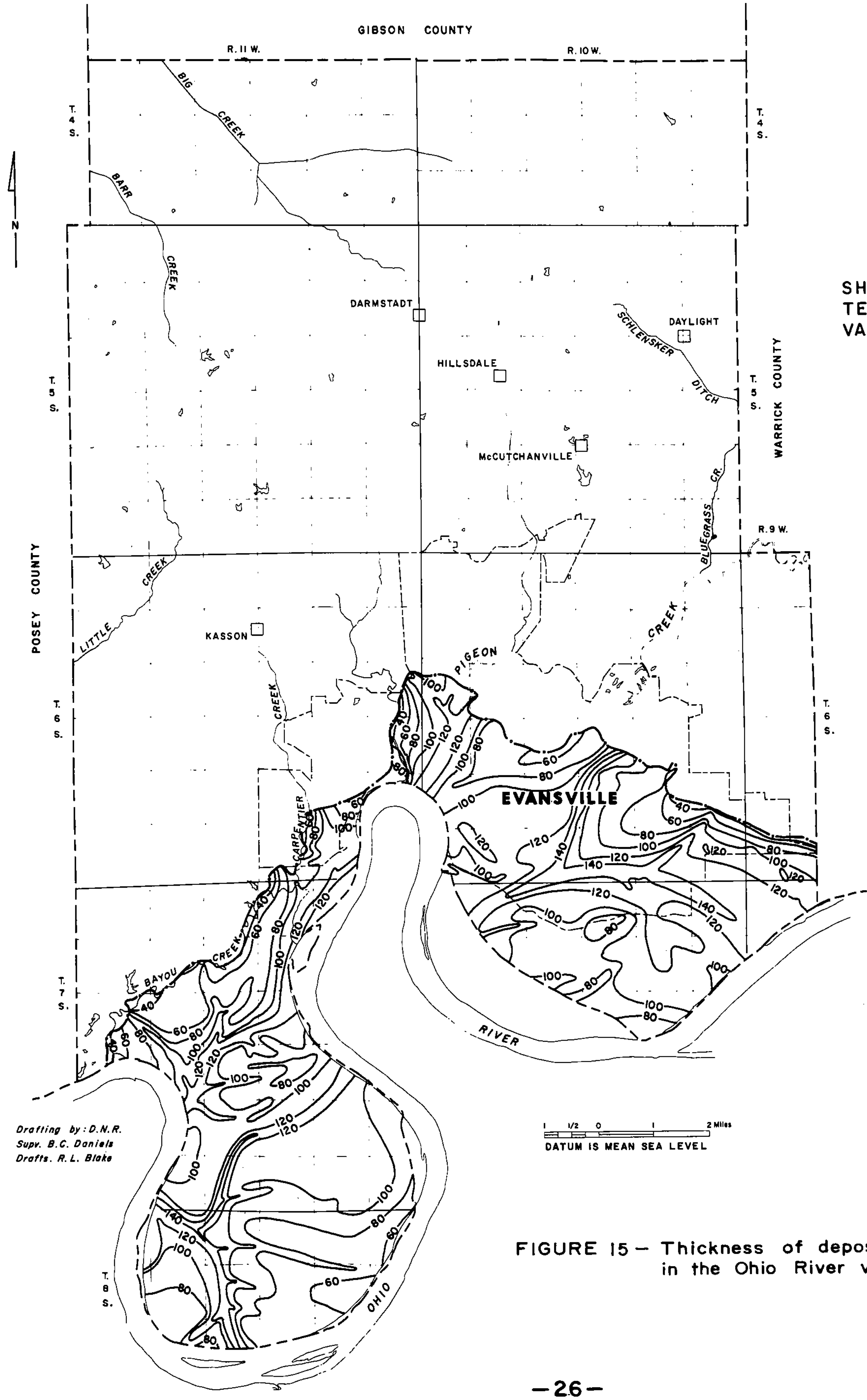


FIGURE 14 – Approximate location of "soda water" areas in the Dugger aquifer.



EXPLANATION

100

ISOPACH

SHOWS THICKNESS OF QUATERNARY DEPOSITS. INTERVAL IS 20 FEET.

LIMIT OF AQUIFER

FIGURE 15 – Thickness of deposits of Quaternary age in the Ohio River valley.

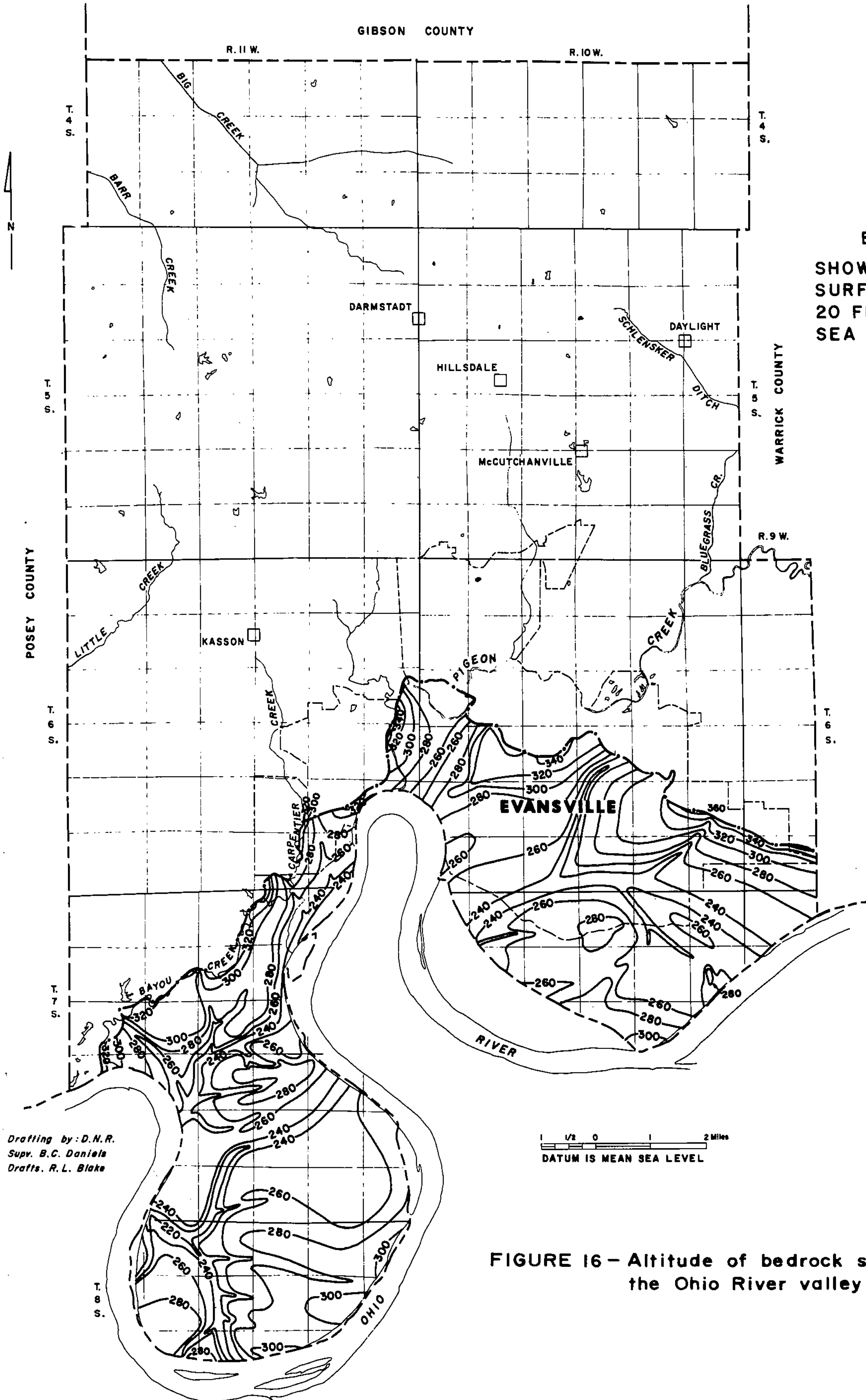
bluffs and the lacustrine deposits of the tributary valleys. In places, however, the sand and gravel deposits may extend into the deeper tributary valleys. A layer of silt and clay covers the sand and gravel, and over much of the area it causes leaky artesian conditions.

The Ohio River valley aquifer varies greatly in thickness and composition. Variations in thickness are due to differences in: (a) the elevation of the buried bedrock surface; (b) topography; and (c) the thickness of the overlying silt and clay. The main factor controlling the thickness of the aquifer is the differences in altitude of the buried bedrock surface. This buried surface varies from higher elevations near the valley wall to the lowest elevation in the old buried channel. (See fig. 16.) Consequently, the thickest area of the aquifer tends to follow the old buried channel. Differences in topography can affect the thickness of the aquifer; however, the area of the aquifer is relatively flat with a total relief of about 60 feet. The terrace deposits shown on plate 2 are generally at a higher elevation than the alluvial flood-plain deposits. Higher altitudes of the land surface generally will result in slightly thicker sections of the aquifer except where the factor of the thickness of the overlying silt and clay decreases the thickness from a few feet to over 30 feet with a probable average thickness of 15 feet.

The composition of the Ohio River valley aquifer changes with depth from a fine to medium sand just beneath the surface silt and clay to coarse sand and gravel near the bedrock surface. The coarse sand and gravel tends to occur most consistently in the thicker parts of the aquifer. Near the valley walls, however, fine to medium sand may persist down to the bedrock surface. In the vicinity of the tributary valleys, the sand and gravel of the terraces and flood plains grade laterally into lacustrine silt and clay.

The Ohio River valley aquifer is confined in some places and is unconfined in other places. According to available data, water-table conditions prevail in the area of the terrace deposits (pl. 2), except near the valley wall where artesian conditions exist. Artesian conditions prevail in the area of the flood-plain deposits (pl. 2) as a result of the overlying layer of silt and clay. Here the silt and clay layer is thickest, and, therefore, its ability to confine the water is greatest. This is especially true in the area adjacent to the Ohio River, where the confining layer reaches its maximum thickness of about 30 feet.

The saturated thickness of the Ohio River valley aquifer in September 1965 is shown in figure 17. The thickness of the saturated zone is determined by the fluctuations of the water table. These fluctuations represent the balance between water entering the aquifer by precipitation, bedrock seepage, and flooding and that leaving the aquifer by evapotranspiration, drainage, and pumpage. Figure 18 shows the correlation of the water level in the observation well Vanderburgh 3 which is in the Ohio River valley aquifer (SE 1/4 SE 1/4 sec. 22, T. 6 S., R. 10 W.,), with the cumulative departure from normal monthly precipitation at Evansville. Figure 18 shows that climatic conditions are almost simultaneously reflected by water-level fluctuations, which indicates direct infiltration during periods of precipitation. As shown by the hydrograph, the amount of water-level fluctuation over the entire length of record (10 years) was less than 5 feet, and



EXPLANATION

200

BEDROCK CONTOUR

SHOWS ALTITUDE OF BEDROCK SURFACE. CONTOUR INTERVAL, 20 FEET. ALL DATUM IS MEAN SEA LEVEL.

LIMIT OF AQUIFER

FIGURE 16 – Altitude of bedrock surface in the area of the Ohio River valley aquifer.

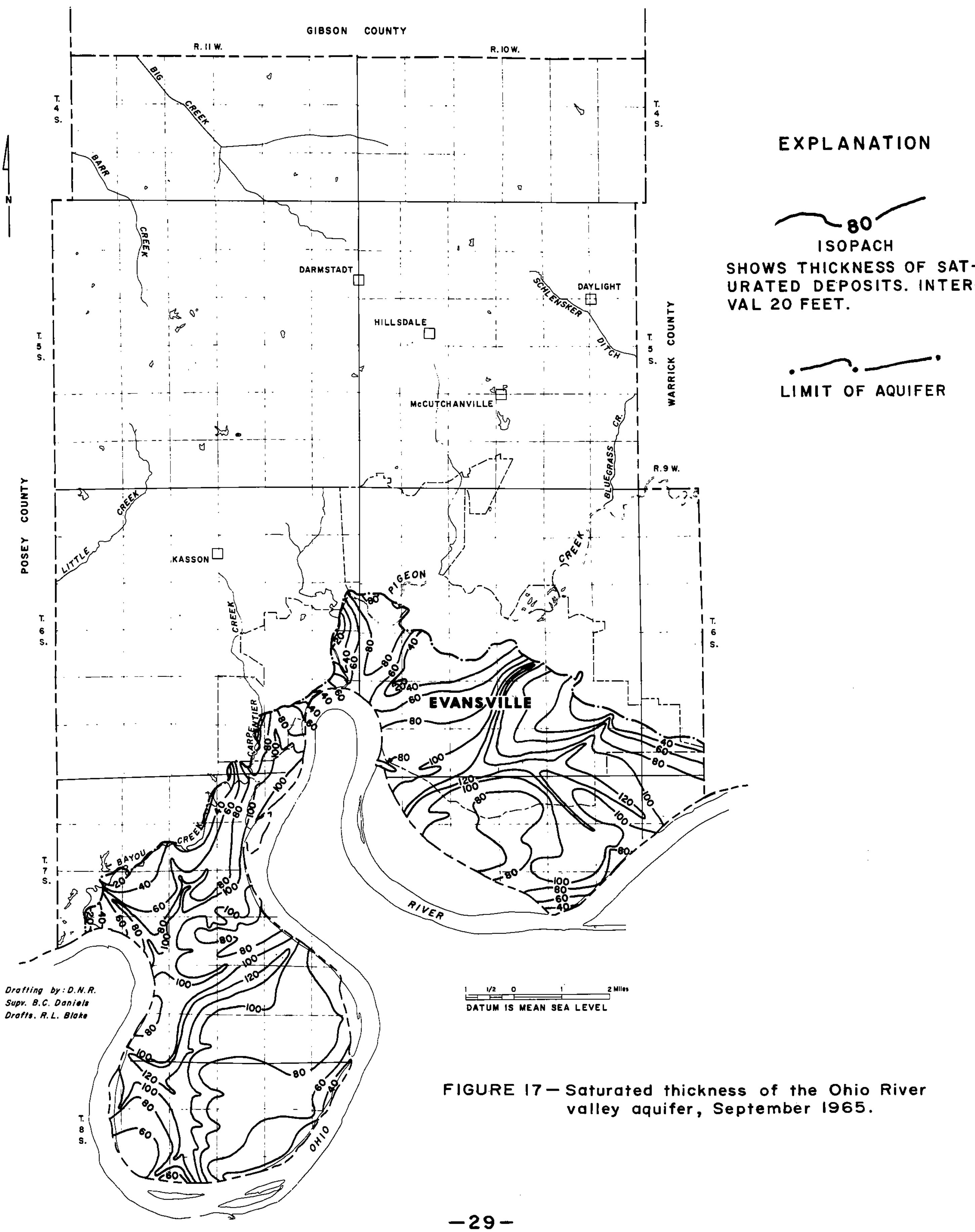


FIGURE 17 — Saturated thickness of the Ohio River valley aquifer, September 1965.

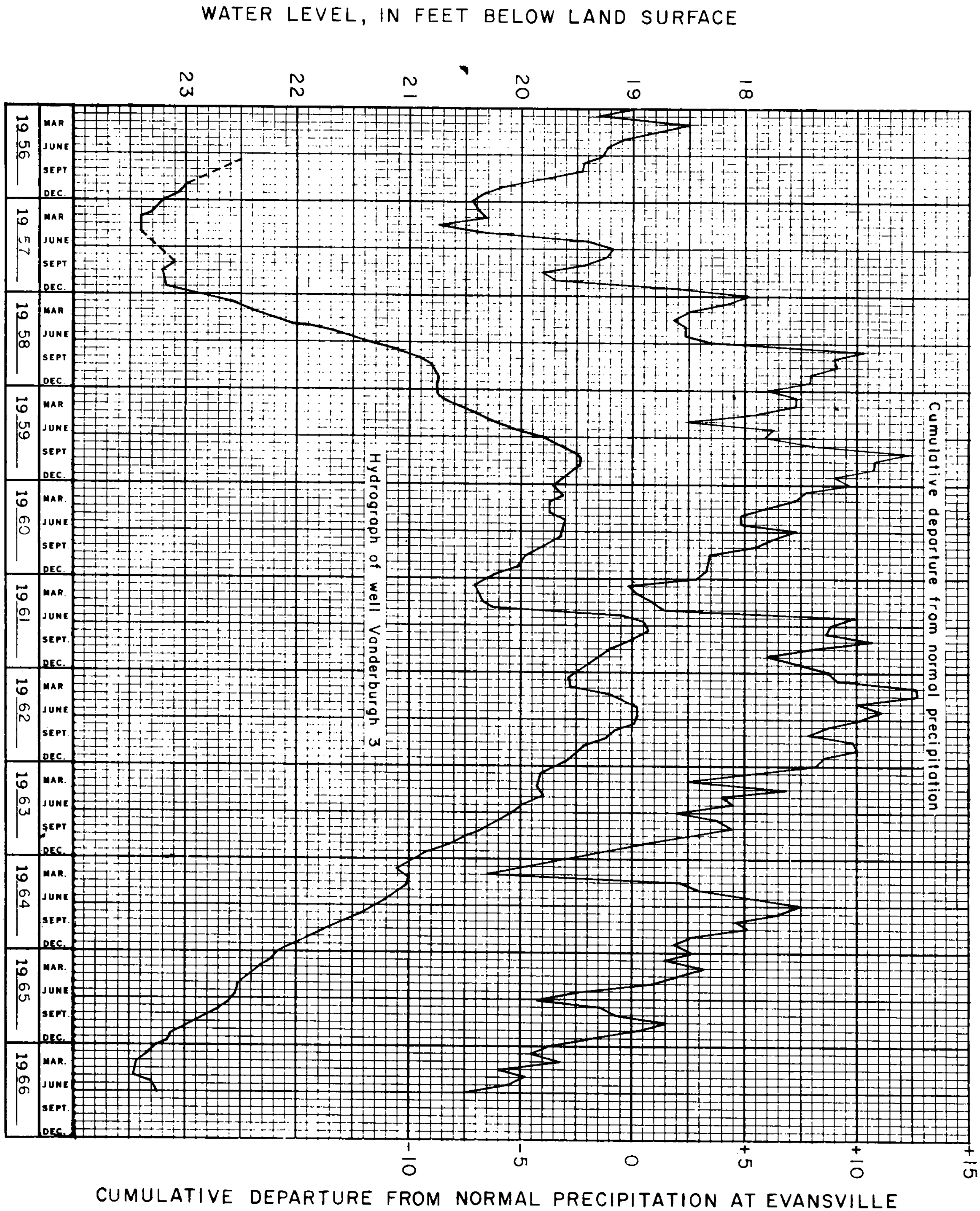


FIGURE 18 – Hydrograph of the observation well Vanderburgh 3 and cumulative departure from normal precipitation at Evansville.

the total fluctuation over any one year was less than 2 feet. In wells adjacent to the Ohio River, however, the amount of water-level fluctuation may be somewhat greater.

The saturated thickness of the Ohio River valley aquifer can be expected to increase after the completion of the larger navigation locks and dams now (1966) being constructed along the Ohio River. The resulting higher pool stages will raise the water table in the aquifer along the river and increase the amount of ground water in storage. In Vanderburgh County the greatest increase of saturated thickness of the aquifer will occur along the river downstream from the present Dam No. 48.

How Good is the Aquifer?

The Ohio River valley aquifer is the only aquifer in Vanderburgh County capable of accommodating high-yield wells. Based on water well drillers' reports, yields up to 1,000 gpm can be expected from efficient, vertically screened wells in this aquifer. Yields of 4,300 gpm are reported for 3 collector wells in the Ohio River valley deposits of Kentucky (Gallaher, 1964). These wells are opposite secs. 15 and 16, T. 8 S., R. 11 W., in Vanderburgh County. Yields should be similar from collector wells placed near the Ohio River in Vanderburgh County.

An aquifer-performance test was conducted by U S. Geological Survey personnel in April 1951 at the Evansville Waterworks Department. The test shows that the aquifer has a coefficient of transmissibility of 185,000 gpd per ft and a coefficient of storage of 0.0014 in the vicinity of the Evansville Waterworks. The test further shows that a free hydraulic connection exists between the aquifer and the river and that by pumping a well long enough to create a favorable hydraulic gradient, water can be induced to flow from the Ohio River into the aquifer.

Specific-capacity tests conducted by local drillers on wells completed in the Ohio River valley aquifer in the Evansville area indicate that the transmissibility is relatively high throughout the thicker part of the aquifer. Toward the valley wall, however, where the aquifer is thinner and the grain size is finer, there is a decrease in transmissibility. Figure 19 is a map of the Ohio River valley aquifer showing the estimated coefficient of transmissibility of the aquifer based on a regional field coefficient of permeability of 2,000 gpd per sq. ft.

The total amount of water presently (1966) being withdrawn from the Ohio River valley aquifer by pumping is estimated to be not more than 1 mgd. This figure includes the estimated pumpage for municipal (400,000 gpd), industrial (400,000 gpd), and other (200,000 gpd) needs. Currently, the pumpage from the aquifer is cyclical rather than uniform, with the bulk of the withdrawal occurring during the months of July, August, and September.

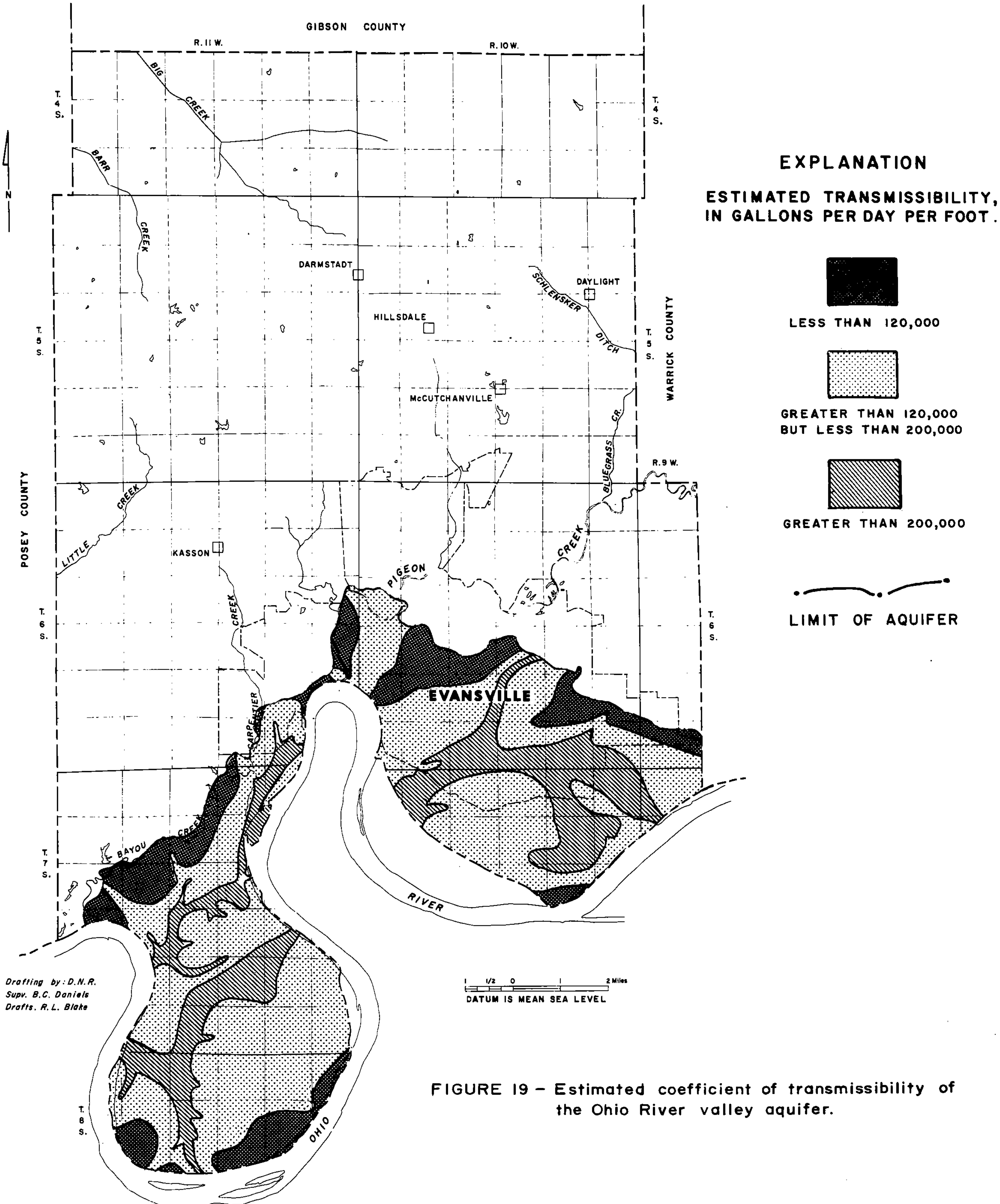


FIGURE 19 – Estimated coefficient of transmissibility of the Ohio River valley aquifer.

What is the Chemical Quality of the Water?

The chemical quality of ground water in the Ohio River valley aquifer varies throughout the county. The chemical quality of the water is related to several factors including depth, composition of rock materials, time of exposure to the rock materials, chemical composition of water derived from the bedrock, and the results of the activities of man. Nowhere in the aquifer was water encountered whose dissolved content exceeded 1,000 ppm.

The results of the laboratory analyses of water samples from wells in the aquifer are listed in table 2. The analyses show the water to be of the very hard (table 3) calcium bicarbonate type with high amounts of iron. Of the samples analyzed the hardness (as $CaCO_3$) ranged from 76 to 695 ppm with an average value of 298 ppm, and bicarbonate content ranged from 27 to 525 ppm with an average value of 285 ppm. The iron content of the water averaged 1.7 ppm and ranged from 0.1 to 7.5 ppm.

The sulfate content of the water ranged from 18 to 314 ppm with an average of 79 ppm. Of the samples analyzed, the sulfate content was found to be generally low, except in samples from wells in or near areas of relatively dense population (analyses 13, 14, 15, table 2). This agrees with the finding of Gallaher and Price (1966, p. 32) that a noticeable buildup in concentration of sulfate occurs in the ground water of the alluvial deposits of the Ohio River valley in densely populated areas and is attributed to the effects of the activities of man upon the water environment.

Discharge and Recharge

The hydraulic gradient in the Ohio River valley aquifer (and thus the direction of water movement) is toward the Ohio River--the major discharge boundary of the aquifer. The amount of water being discharged from the aquifer directly into the river is estimated to be 40 mgd in Vanderburgh County. This figure was determined with the following modified form of the Darcy equation:

$$Q = TIL$$

where:

- Q = discharge, in gallons per day
- T = coefficient of transmissibility, in gallons per day per foot
- I = hydraulic gradient, in feet per mile
- L = width of flow cross section, in miles

The amount of daily discharge was computed for each mile of the Ohio River in Vanderburgh County by using the transmissibilities given in figure 19 and an average hydraulic gradient of 7 ft per mile. The sum of the daily discharge rates for each of the 36 river miles equals approximately 40 million gallons.

The Ohio River valley aquifer is recharged from two sources: (1) the subsurface flow of ground water from the alluviated valleys and bedrock formations of the uplands, and (2) directly from precipitation. Because the amount of pumpage from the aquifer is insignificant, recharge must be approximately equal to discharge. Therefore, recharge to the aquifer is also estimated to be 40 mgd.

Other Rocks of Quaternary Age

Other unconsolidated rocks of Quaternary age in Vanderburgh County include the lacustrine deposits and stream alluvium of the tributary valleys and the loess which mantles the bedrock hills. (See pl. 2.) The lacustrine deposits consist mostly of thick layers of clay and silt. The stream alluvium consists of relatively thin deposits of reworked slope wash and lacustrine deposits. These are not considered to contain any significant aquifers except locally where some sand and gravel may occur at or near the base of these deposits. The loess deposits consist of wind-laid silt which was picked up from the stream areas and deposited on the surrounding hilltops during Pleistocene time. The hydrologic significance of these deposits is that they serve as a transmission medium for the infiltration of precipitation to the underlying bedrock aquifers and thus affect the recharge rate and the chemical character of the water.

SUMMARY

Sand and gravel of Quaternary age and sandstone units of Middle and Late Pennsylvanian age are the sources of fresh ground water in Vanderburgh County, Ind. Aquifers are present in older rocks, but, owing to their depth, the water is too highly mineralized to be useful for most purposes. The sand and gravel deposits of the Ohio River valley, which are herein named the Ohio River valley aquifer, constitute the thickest and most permeable aquifer in the county. Properly constructed wells in this aquifer could easily yield 1,000 gpm and more. Aquifer thicknesses in excess of 120 feet are noted. Based on a regional field coefficient of permeability of 2,000 gpd per sq. ft., the coefficient of transmissibility of the aquifer ranges from 120,000 gpd per ft or less in areas near the valley wall to 200,000 gpd per ft and more in the thickest parts of the aquifer. For the most part the Ohio River valley aquifer is unconfined; however, relatively thick layers of silt and clay near the Ohio River may produce artesian conditions. The water in the aquifer is predominantly a very hard calcium bicarbonate type with a high iron content. A noticeable buildup in sulfate concentration occurs in the densely populated areas and is attributed to the effects of the activities of man upon the ground-water environment.

Three sandstone units occur that are partially or totally fresh-water bearing and areally extensive enough to be important aquifers. These sandstone aquifers are in the Linton, the Dugger, and the Patoka Formations and

are referred to in this report as the Linton aquifer, the Dugger aquifer, and the Patoka aquifer, respectively. At present (1966) the Linton aquifer is not used as a source of water in Vanderburgh County, but in the eastern part of the county near the Vanderburgh-Warrick County line the aquifer is near enough to land surface to be fresh-water bearing. The Dugger aquifer is used extensively as a source of fresh water in eastern and southern Vanderburgh County. The aquifer is discontinuous and has a highly irregular areal distribution. The Patoka aquifer is used as a source of fresh water throughout central and northwestern Vanderburgh County. More water wells are supplied from the Patoka aquifer than from any other aquifer in the county. Yields reported from wells in the sandstone aquifers range from less than 1 gpm to approximately 20 gpm. Most wells, however, are reported to yield 5 gpm or less. The estimated field coefficient of permeability of the sandstone aquifers is 10 gpd per sq. ft., and the maximum coefficient of transmissibility is estimated to be 1,000 gpd per ft. Where the sandstone aquifers are relatively thick, indications are that the coarsest material and, therefore, the highest permeability are in the lower part of the aquifer. The water in the Dugger aquifer is mostly a moderately hard sodium bicarbonate type and generally low in iron content. Locally, areas occur in the Dugger aquifer in which the water is not fresh due to the presence of abnormally large amounts of sodium, bicarbonate, and chloride. The water in the Patoka aquifer is a hard to very hard calcium bicarbonate type with an average iron content of 2.4 ppm and is fresh throughout Vanderburgh County.

GLOSSARY

Permeability, Field Coefficient of --Measure of a material's capacity to transmit water; expressed as rate of flow of water in gallons per day through a cross sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot at the prevailing water temperature.

Specific capacity --Yield of a well in gallons per minute per foot of drawdown for a given period of continuous pumping.

Transmissibility, Coefficient of --Rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 1 foot per foot.

LITERATURE CITED

Andresen, M. J., 1961, Geology and petrology of the Trivoli Sandstone in the Illinois Basin: Illinois State Geol. Survey Circ. 316, 31 p.

Ashley, G. H., 1899, The coal deposits of Indiana: Indiana Dept. Geol. and Nat. Resources, Ann. Rept. 23, 1573 p.

Durfor, C. N., and Chase, E. B., 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geol. Survey Water-Supply Paper 1812, 364 p.

Friedman, S. A., 1954, Distribution, structure, and mines areas of coals in Vanderburgh County, Indiana: Indiana Dept. Conserv., Geol. Survey Preliminary Coal Map 5.

Fuller, M. L., and Ashley, G. H., 1902, Description of the Ditney quadrangle (Indiana): U.S. Geol. Survey Geol. Atlas, Folio 84.

Fuller, M. L., and Clapp, F. G., 1904, Description of the Patoka quadrangle (Indiana and Illinois): U.S. Geol. Survey Geol. Atlas, Folio 105.

Gallaher, J. T., 1964, Geology and hydrology of alluvial deposits along the Ohio River in the Henderson area, Kentucky: U.S. Geol. Survey Hydrol. Inv. Atlas HA-91.

Gallaher, J. T., and Price, W. E., Jr., 1966, Hydrology of the alluvial deposits in the Ohio River valley in Kentucky: U.S. Geol. Survey Water-Supply Paper 1818, 80 p.

Greenburg, S. S., 1960, Petrography of Indiana sandstones collected for high-silica evaluation: Indiana Dept. Conserv., Geol. Survey Bull. 17, 64 p.

Hopkins, M. E., 1958, Geology and petrology of the Anvil Rock Sandstone of southern Illinois: Illinois State Geol. Survey Circ. 256, 49 p.

Indiana State Board of Health, 1960, Data on Indiana public water supplies: Indiana State Bd. Health, Bull. S.E. 10.

Kosanke, R. M., Simon, J. A., Wanless, H. R., and Willman, H. B., 1960, Classification of the Pennsylvanian strata of Illinois: Illinois State Geol. Survey Rept. Inv. 214, 84 p.

Malott, C. A., 1948, The geology of the Dicksburg Hills, Knox County, Indiana: Indiana Acad. Sci. Proc., v. 57, p. 125-141.

Robinove, C. J., Langford, R. H., and Brookhart, J. W., 1958, Saline-water resources of North Dakota: U.S. Geol. Survey Water-Supply Paper 1428, 72 p.

Vessel, A. J., Wade, J. G., and Myers, Sutton, 1944, Soil survey of Vanderburgh County, Indiana: U.S. Dept. Agriculture, Soil survey Series 1939, No. 2.

Wier, C. E., and Girdley, W. A., 1962, Distribution of the Inglefield and Dicksburg Hills Sandstone Members in Posey and Vanderburgh Counties, Indiana: Indiana Acad. Sci. Proc. v. 72, p. 212-217.

Wier, C. E., and Gray, H. H., 1961, Geologic map of the Indianapolis 1°x2° quadrangle, Indiana and Illinois: Indiana Dept. Conserv., Geol. Survey.

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DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

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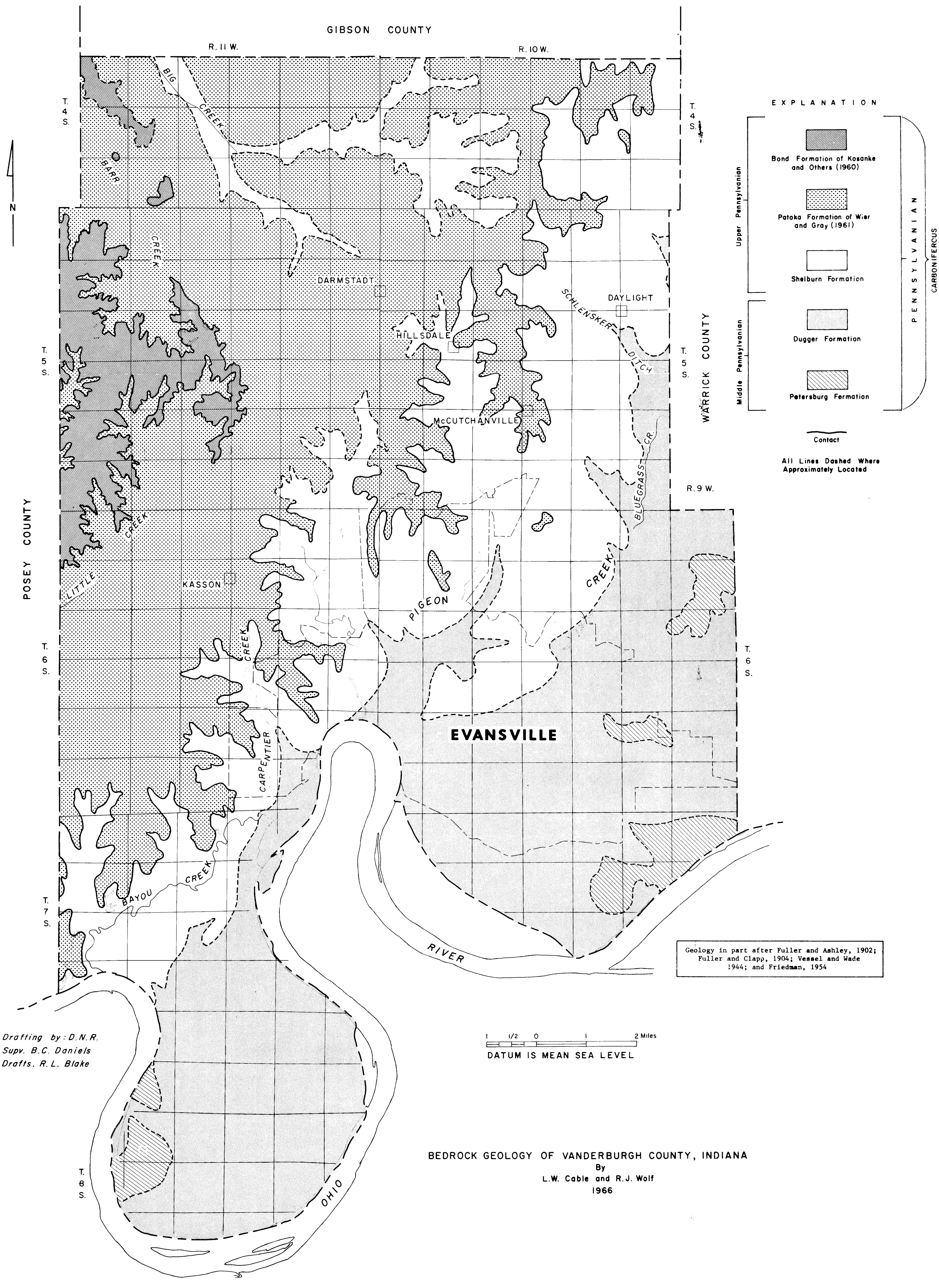

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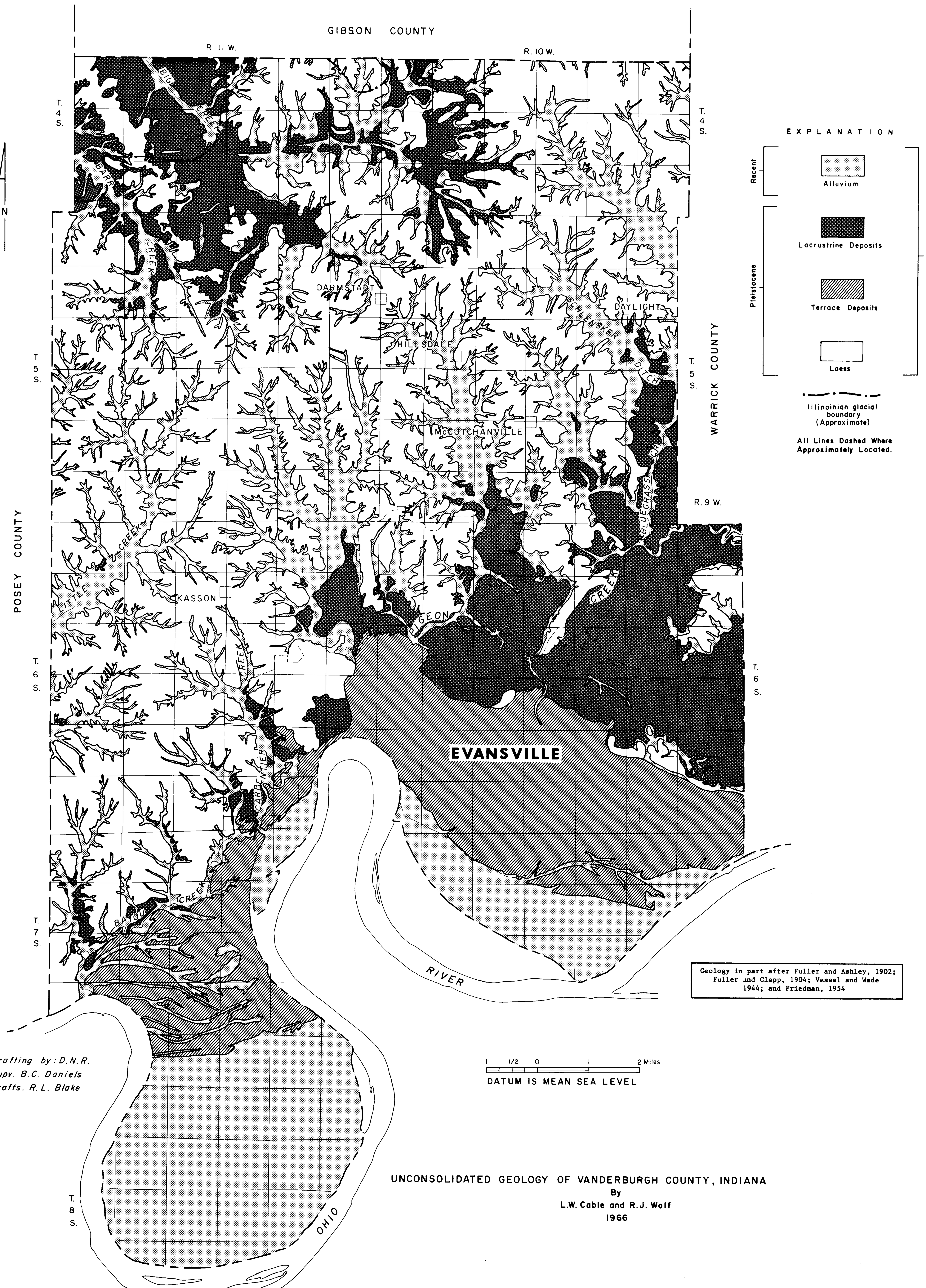
1966



UNCONSOLIDATED GEOLOGY OF VANDERBURGH COUNTY, INDIANA

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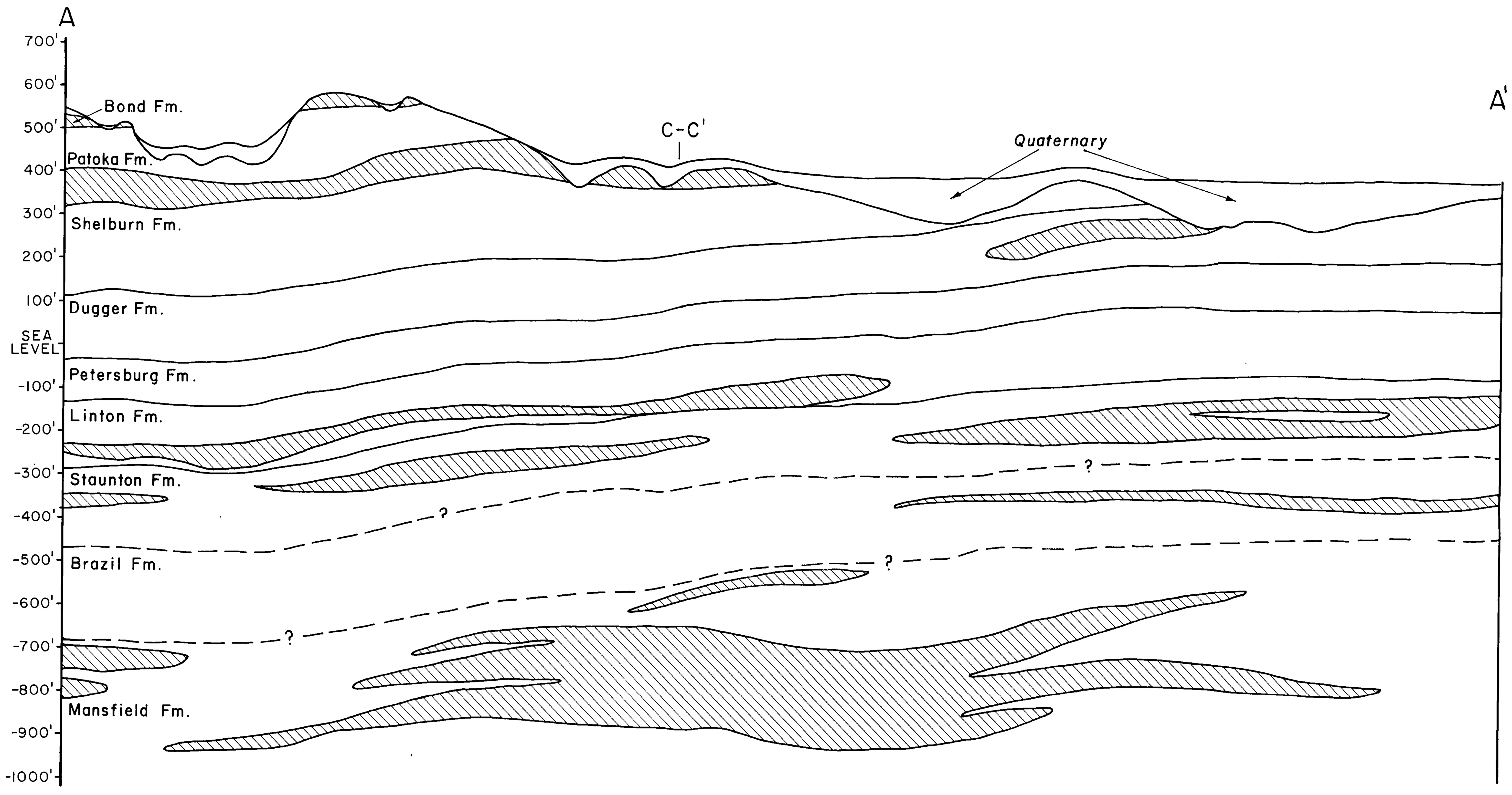

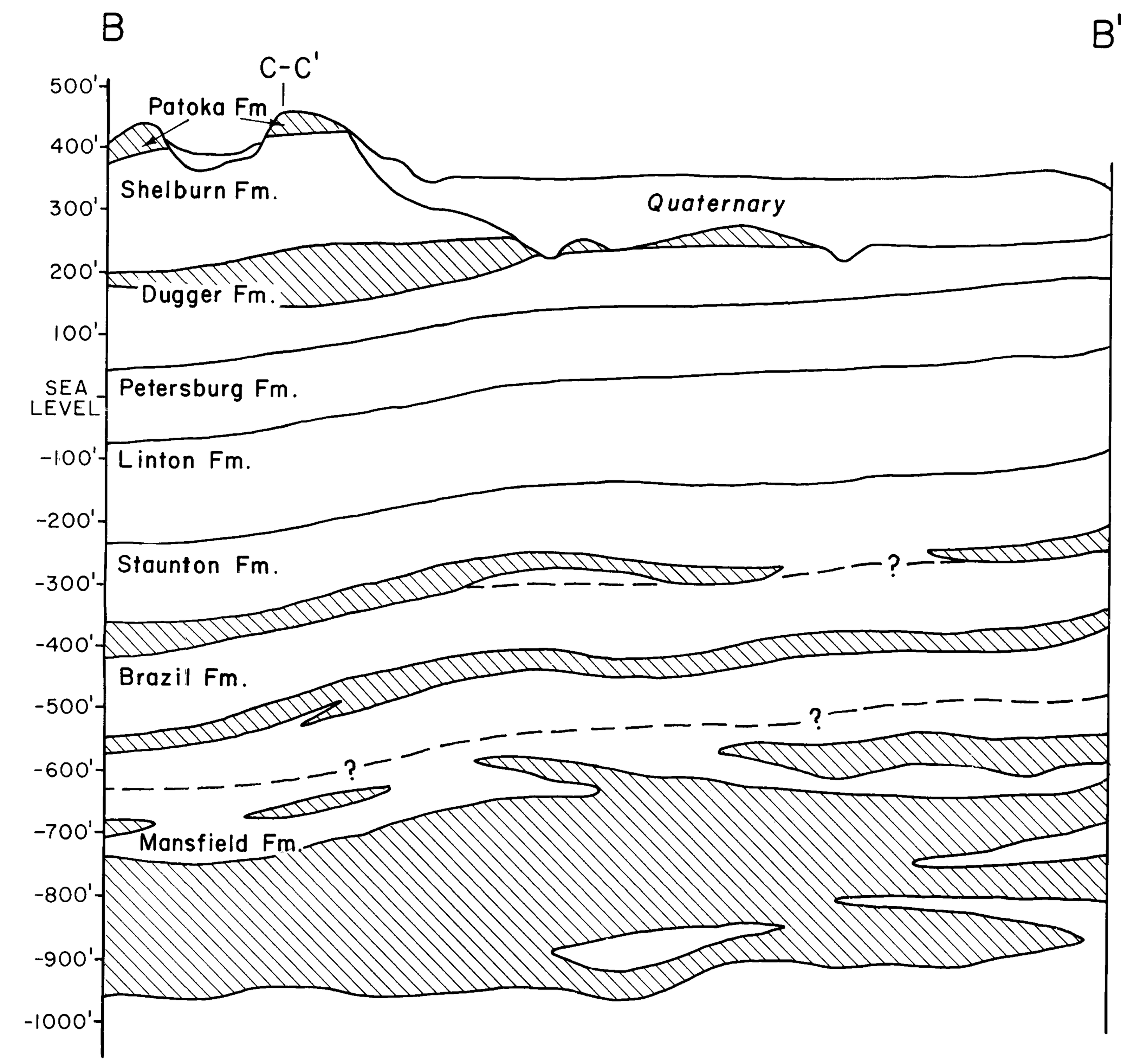

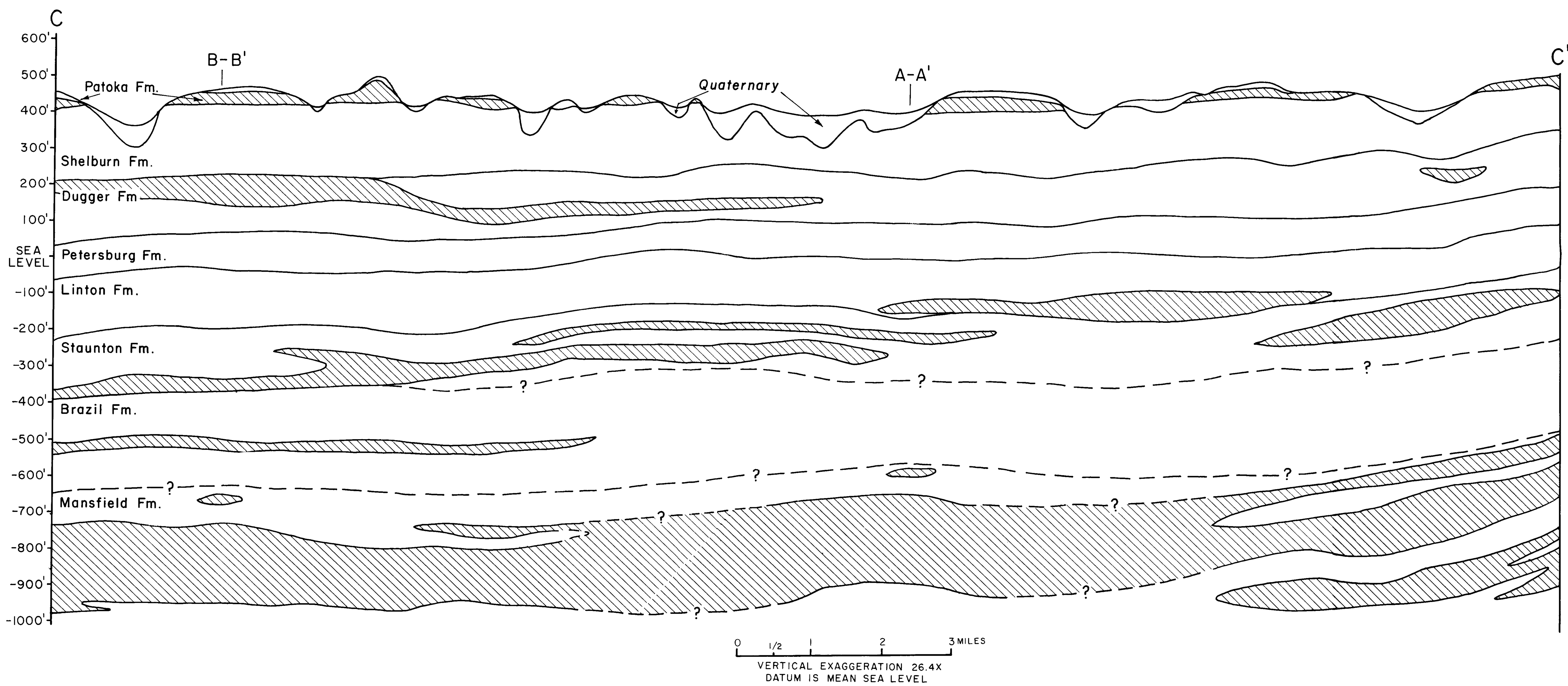

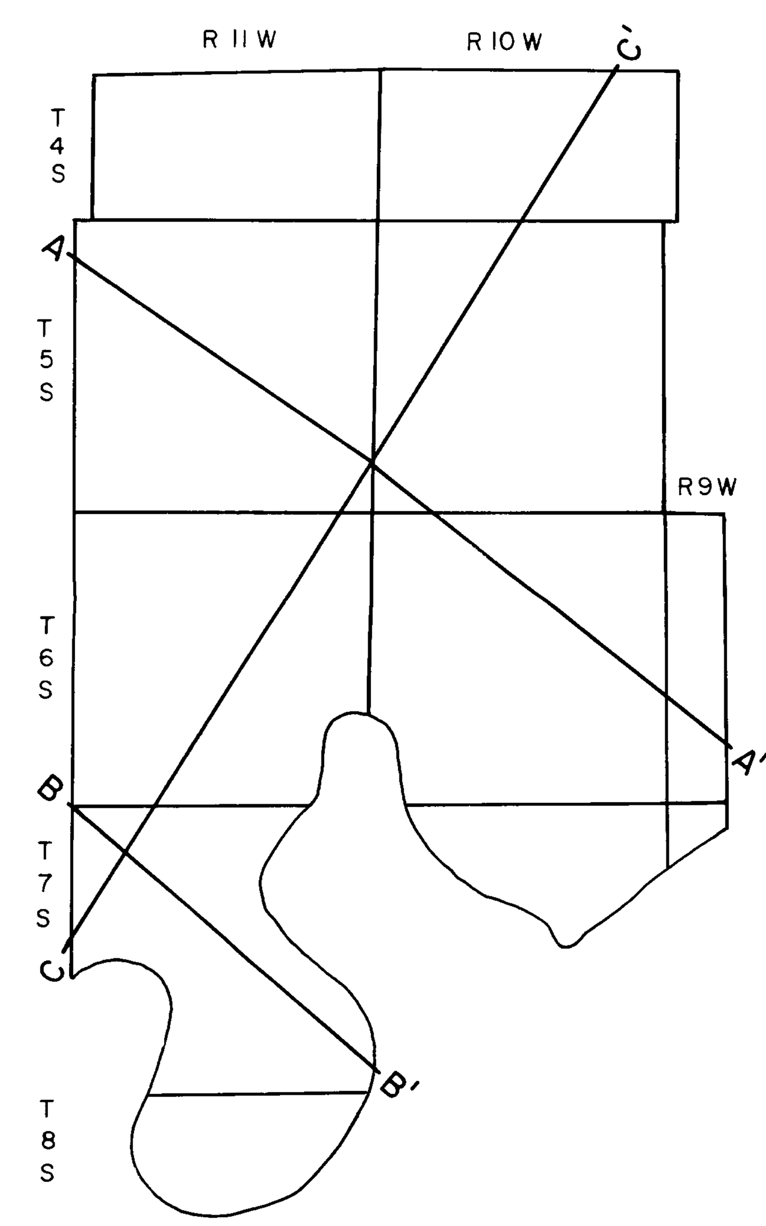

MAP SHOWING LOCATION
OF GEOLOGIC SECTIONS

Drafting by: D.N.R.
Supv. B.C. Daniels
Drafts. R.L. Blake

GEOLOGIC SECTIONS OF THE PENNSYLVANIAN SYSTEM WITH PATTERNED AREAS SHOWING THE POSITION OF THE PRINCIPAL SANDSTONE BODIES.