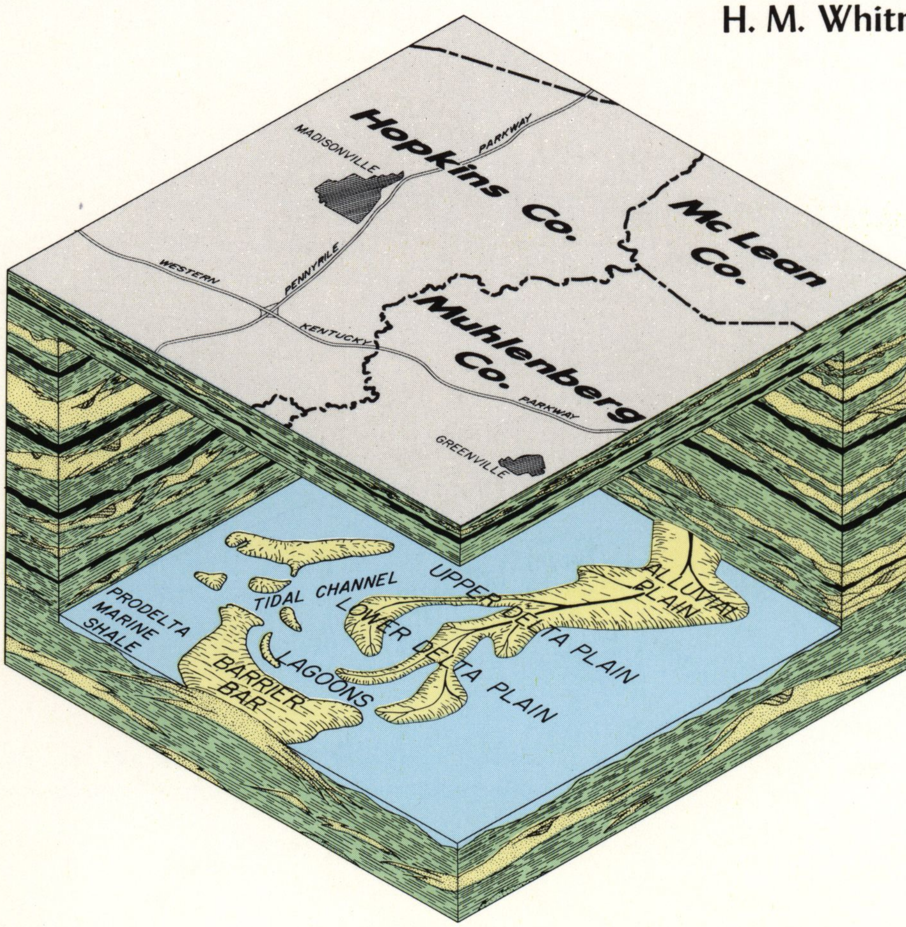
KENTUCKY GEOLOGICAL SURVEY
UNIVERSITY OF KENTUCKY, LEXINGTON SERIES X, 1974
Wallace W. Hagan, Director and State Geologist

HYDROLOGY AND GEOLOGY OF DEEP SANDSTONE AQUIFERS OF PENNSYLVANIAN AGE IN PART OF THE WESTERN COAL FIELD REGION, KENTUCKY

R. W. Davis
R. O. Plebuch U.S. Geological Survey
H. M. Whitman Kentucky Geological Survey



REPORT OF INVESTIGATIONS 15

KENTUCKY GEOLOGICAL SURVEY
UNIVERSITY OF KENTUCKY, LEXINGTON SERIES X, 1974
Wallace W. Hagan, Director and State Geologist

HYDROLOGY AND GEOLOGY OF DEEP SANDSTONE AQUIFERS OF PENNSYLVANIAN AGE IN PART OF THE WESTERN COAL FIELD REGION, KENTUCKY

R. W. Davis
R. O. Plebuch
United States Geological Survey
H. M. Whitman
Kentucky Geological Survey

Prepared by the United States Geological Survey in cooperation with the Kentucky Geological Survey

REPORT OF INVESTIGATIONS 15

LETTER OF TRANSMITTAL

July 22, 1974

Dr. Wimberly C. Royster
Dean of Graduate School
and Coordinator of Research
University of Kentucky

Dear Dean Royster:

The Western Kentucky Coal Field has considerable potential for industrial and mineral-resource development. Surface and ground water supplies are essential to such development. This report, prepared by the Kentucky Water Resources District of the Water Resources Division of the United States Geological Survey in cooperation with the Kentucky Geological Survey, "mainly delineates the major deep Pennsylvanian sandstone fresh-water aquifers . . . and provides information on occurrence, availability, movement, and chemical quality of the water in these aquifers."

The great demand for energy and the proposed coal gasification plant in this area make a study such as this particularly timely.

Respectfully submitted,

Wallace W. Hagan

Wallace W. Hagan
Director and State Geologist

CONTENTS

ILLUSTRATIONS

TABLE

HYDROLOGY AND GEOLOGY OF DEEP SANDSTONE AQUIFERS OF PENNSYLVANIAN AGE IN PART OF THE WESTERN COAL FIELD REGION, KENTUCKY

R. W. Davis, R. O. Plebuch, and H. M. Whitman

ABSTRACT

Sandstone aquifers of Early Pennsylvanian age in parts of the Western Coal Field region of Kentucky yield fresh water from wells as deep as 1,000 feet. The aquifer sands were deposited within valleys cut on the Late Mississippian surface and as deltaic and barrier-bar deposits that overlie both the Mississippian and earlier Pennsylvanian valley-filling deposits.

The deep Pennsylvanian aquifers that are presently in use have low transmissivity and storage properties, no perceptible recharge from the surface, and steadily declining water levels in the vicinity of centers of pumping. The low-yield characteristics of part of one aquifer were confirmed by a digital computer model. One aquifer, however, not presently developed, may yield as much as 300 gpm (gallons per minute) to individual wells and probably can receive recharge from the surface.

Because of their poor hydrologic characteristics, the deep Pennsylvanian aquifers do not seem capable of supplying water for any large-scale economic development of the region.

INTRODUCTION

This report was prepared cooperatively by the U. S. Geological Survey and the Kentucky Geological Survey in response to the anticipation by planners that industrial development would increase in the Western Coal Field, especially in the Green River valley area. The basic needs of the industries will include coal, water transportation, and large quantities of water. Ground-water development is an alternative to the development of surface-water reservoirs. Thus, an appraisal of the potential ground-water supply is needed.

Fresh ground water occurs at depths as great as 1,000 feet in certain sandstones of Pennsylvanian age in the region, but the extent of the sandstones, their water-bearing characteristics, and the amount of water available from them were virtually unknown before the present study was made. (See "References cited" for previous geologic and hydrologic studies.) Shallow ground water generally is present, but it is of poorer quality and is available in less quantity than water from the deep Pennsylvanian aquifers.

This report mainly delineates the major deep Pennsylvanian sandstone fresh-water aquifers in part of the Western Coal Field and provides information on occurrence, availability, movement, and chemical quality of the water in these aquifers. The study is based primarily on the interpretation of electric logs of oil-test holes from the files of the Kentucky Geological Survey. Data obtained from oil companies, petroleum engineers, municipal officials, well drillers, and property owners supplement interpretation of the logs. Thus, the authors are indebted to many organizations and people for their cooperation.

The study area, consisting of about 1,755 square miles in west-central Kentucky, includes all of Muhlenberg County and parts of Butler, Christian, Daviess, Hopkins, Logan, McLean, Ohio, Todd, and Webster Counties (Fig. 1). Physiographically, the study area is within the Interior Low Plateaus province of the Interior Plains; geologically, it is

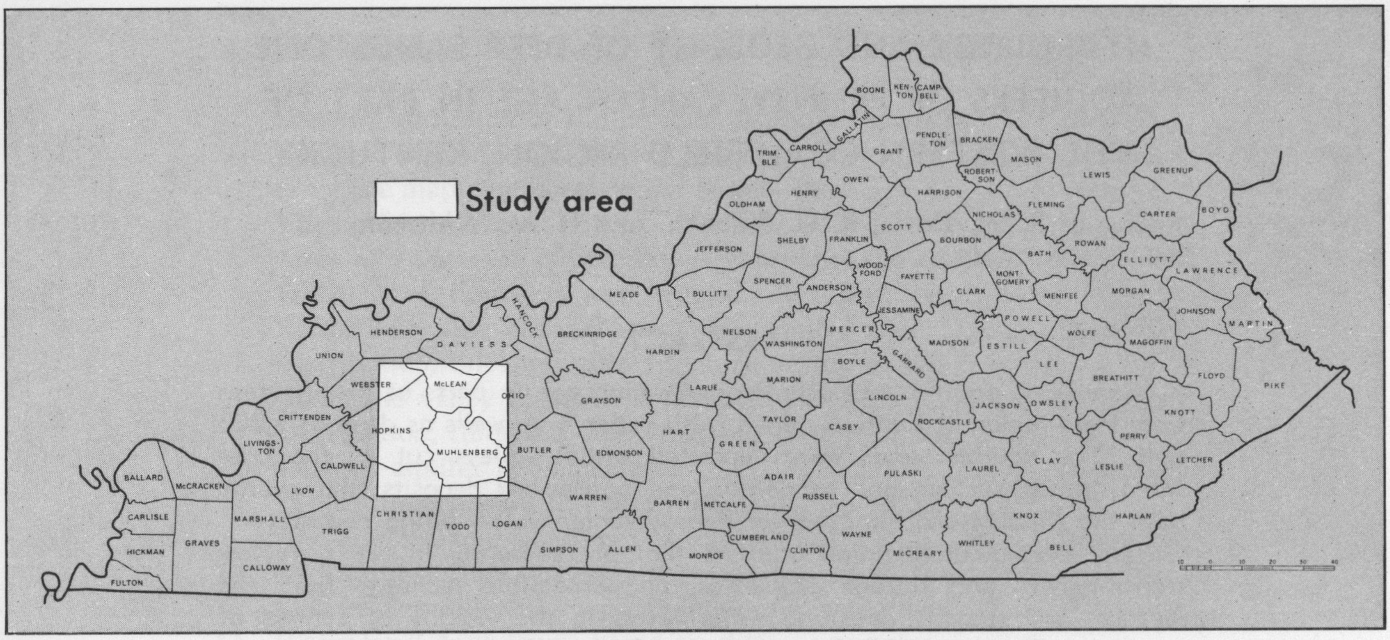


Figure 1. Map of Kentucky showing location of study area.

in the southeastern part of the Eastern Interior (or Illinois) basin. Most of the region is a rolling upland 400 to 550 feet above sea level, except near the southern boundary in a belt of rugged hills where elevations are more than 800 feet. These hills generally coincide with the outcrop of the lowermost rocks of Pennsylvanian age. Another belt of hills lies in an east-west direction along the Rough Creek fault zone which extends across the northern part of the area. Flood plains and alluvial terraces of low relief, ranging in elevation from 340 to 430 feet, border the major streams and their tributaries.

Most of the area is drained by the Green River and its tributaries, flowing northwestward toward the Ohio River. The extreme southwestern part of the area is within the Tradewater River drainage basin.

GEOLOGY

Most rocks exposed in the Western Coal Field are of Pennsylvanian age. A generalized geologic map (Plate 1) shows the distribution of the various formations. The oldest Pennsylvanian rocks crop out around the edge of the basin and dip toward the axis. In the southern part of the basin, south and east of the Hopkins-Christian County line, the rocks have been downfaulted on the north side of a major fault system. The lowermost Pennsylvanian rocks that are aquifers north of the fault system do not crop out and are not in physical or hydraulic contact with outcropping equivalent rocks on the south side of the fault system. Progressively younger Pennsylvanian rocks are exposed toward the center of the basin, but their outcrop pattern is interrupted at numerous places by faults having displacements as much as several hundred feet.

Mississippian rocks of Chesterian age are exposed in the southern part of the study area and in parts of the Rough Creek fault zone. The columnar section (Fig. 2) lists the lithology and summarizes the hydrology of the Pennsylvanian rocks and of the Mississippian rocks above the base of the Vienna Limestone. Because this study is an appraisal of the ground-water resources of the area, no attempt is made to subdivide the subsurface Pennsylvanian rocks into formal stratigraphic units; rather, where considered to be sufficiently extensive, the aquifers have been given informal names based on their area and manner of occurrence or on their distance above the base of the Vienna Limestone. Generally, however, the aquifers occur within the interval comprising the Caseyville Formation and possibly part of the Tradewater Formation.

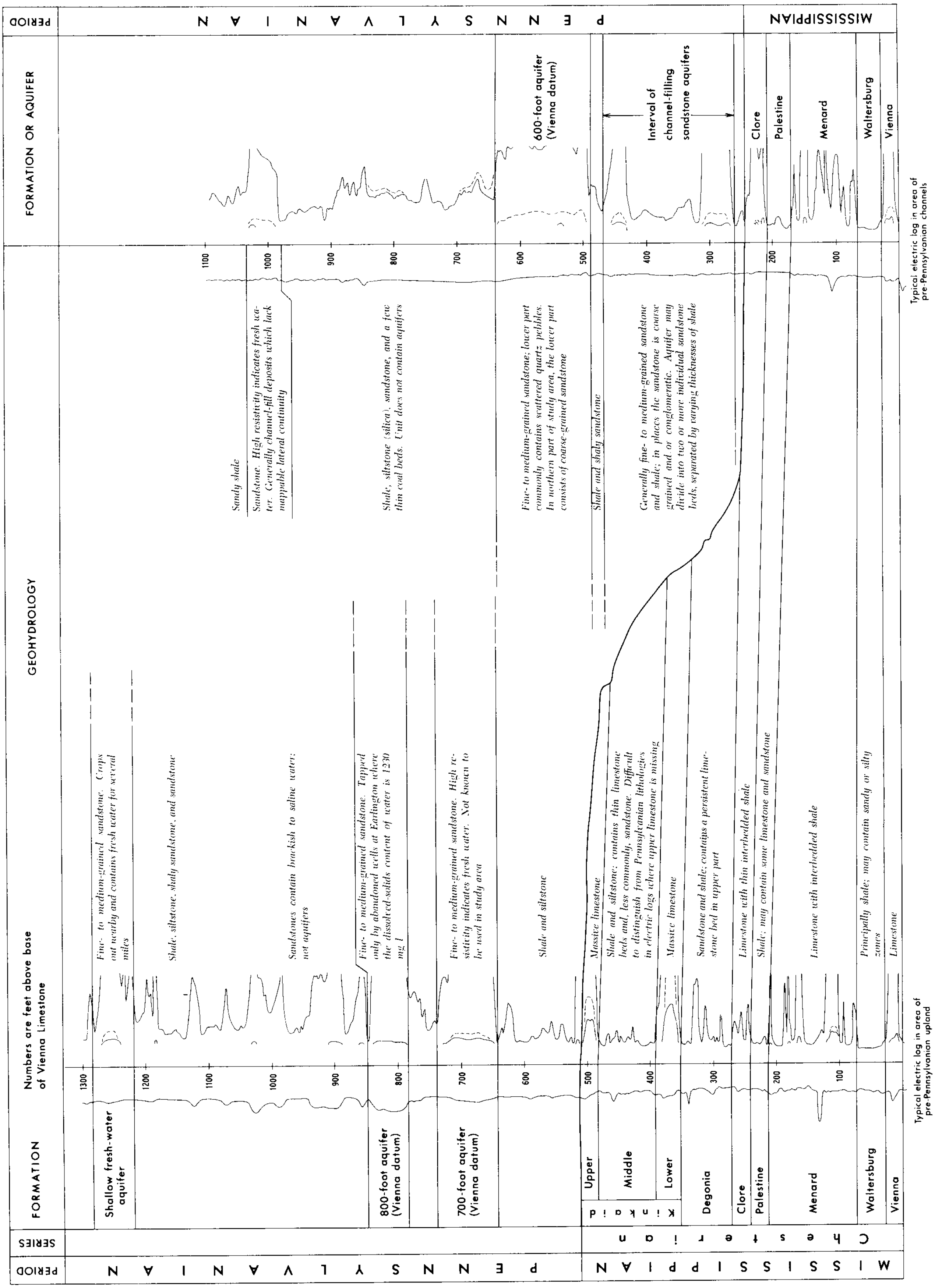


Figure 2. Generalized stratigraphic column showing the relationship of the pre-Pennsylvanian surface to the geologic formations and Pennsylvanian aquifers.

Mississippian-Pennsylvanian Contact

The Mississippian-Pennsylvanian contact is important because it marks the lower limit of fresh water in the area. Throughout the Western Coal Field region in Kentucky, Pennsylvanian rocks are separated from the underlying Chesterian Series of Mississippian age by a major unconformity. Rose (1963, p. 53), in describing the Mississippian-Pennsylvanian unconformity in Muhlenberg County, has aptly described it for our entire study area:

> At the conclusion of Chester deposition there was a general uplift of the entire basin region. There followed a period of peneplanation during which the basin edges were beveled owing to their higher uplift relative to the basin center. A second period of uplift followed by a second subaerial erosional cycle of much shorter duration was characterized by deep channeling into the surface of the original peneplain; these channels are widespread throughout the basin area.
>
> * * *
>
> In Muhlenberg County, channeling during the second pre-Pennsylvanian erosional cycle has resulted in a maximum relief of about 400 feet on the Mississippian-Pennsylvanian unconformity surface. . . . An apparent relief greater than 400 feet is indicated . . . and is due to the truncating or beveling effect of the first cycle of post-Chester erosion, the uppermost Chester rocks present beneath the unconformity being in general progressively older from west to east.

Because the Caseyville Formation, the oldest Pennsylvanian formation in the study area, is considered to be Middle Pennsylvanian (Kosanke and others, 1960, Pl. 1), the cycle of beveling and channel cutting probably happened during earliest Pennsylvanian time.

The channels cut into the Mississippian rocks are filled by Pennsylvanian deposits consisting of shale, siltstone, sandstone, thin limestone beds, and some coal; at places near the steeper valley walls the channels contain slump blocks of Kinkaid Limestone of Late Mississippian age. The general trend of the channels is southwesterly, and they tend to parallel some of the faults. Locations of the channels are shown on Plate 2 which shows the surface on which the Pennsylvanian sediments were deposited, and on Plate 3 which shows the relationship of the pre-Pennsylvanian[1] valleys to presently known fault systems.

The electrical-resistivity characteristics of electrical logs of the upper part of the Chesterian Series, especially where the upper part of the Kinkaid Limestone is present, provide a means for accurate identification of units within the series. Thus, where wells penetrated fault planes, the absence of relatively thin units generally is noticeable. The identification of the uppermost Chesterian unit, where it occurs beneath thick Pennsylvanian sandstones, can generally be readily and accurately made. However, identification of the Pennsylvanian-Mississippian contact is difficult where a basal Pennsylvanian shale rests on the middle or lower part of the Kinkaid Limestone, because of the similarity of lithology of the Pennsylvanian shale to the shale of the middle part of the Kinkaid. Electrical-resistivity characteristics of the middle part of the Kinkaid are generally sufficiently different from those of Pennsylvanian rocks to enable the authors to recognize the contact, or to estimate its location. Rose (1963, p. 55) and Atherton and others (1960) commented on this problem and gave criteria for differentiating basal Pennsylvanian units from the upper Chesterian units. Rose (1963, p. 56) believed that he could pick the contact within 10 to 20 feet. However, in parts of Hopkins County and other areas where the Pennsylvanian channel fill is mostly shale, the margin of error may be greater, especially where sandstone beds are present at the base of the middle part of the Kinkaid.

Drillers' logs were used only in areas where electric logs were not available, and as supplemental control where electric-log coverage was sparse. In areas where parts of the Kinkaid Limestone are present, drillers consistently log the uppermost Chesterian limestone as the top of the Chesterian Series; therefore, if the upper part of the Kinkaid Limestone is missing, there is no way of knowing from a driller's log whether an overlying shale or shaly sandstone is part of the Chesterian Series or part of the Pennsylvanian System.

Channel Deposits

The locations of the valleys that contain the channel deposits are shown on Plate 2. The channel deposits in Rochester valley, in the south-

[1] Pre-Pennsylvanian, as used in this report, refers to geologic time prior to deposition of the oldest Pennsylvanian rocks in the study area, not necessarily to time prior to the Pennsylvanian Period.

eastern part of the area, are sandstone, commonly coarse grained to conglomeratic in the lower part and fine to medium grained in the upper part. At places, shale beds within the channel sandstones are common. The Greenville valley, from near Greenville to the southern part of Hopkins County, contains sandstone and shale of varying ratios. Some drillers' logs record coarse-grained sand; however, the grain size of the sandstone in the Greenville valley appears to be finer than that in the Rochester valley, and thick shale beds are more commonly noted on electric logs. Greenville valley merges with a tributary valley, the southward-trending West Branch of Greenville valley, that passes between Nortonville and Mortons Gap. Southwest of Carter coordinate J-26 this channel deposit is mostly black shale and contains almost no sandstone, as shown by the electric log of Cox Drilling Co. No. 1 Merrill (Plate 3). (Carter coordinates are explained on Plate 2.)

The large east-west trending Madisonville valley in the northern part of the area is filled with shale and sandstone. Petroleum is produced from the basal Pennsylvanian channel sandstones at places in this valley. On the basis of electric-log interpretation, none of the sandstones in this channel contains fresh water.

At the onset of this study, it was thought that the sandstones supplying fresh water to existing wells from depths as great as 1,000 feet were within major valleys cut into the Chesterian surface. However, the study revealed that the aquifers supplying water to these deep wells were not channel sandstones and were not in such valleys. Therefore, the ground-water potential of channel sandstones in such valleys is largely unknown.

Deltaic and Barrier-Bar Deposits

The sandstones supplying fresh water to the existing deep wells in the study area are deltaic and barrier-bar deposits. These sandstones were not deposited in the basal Pennsylvanian channels and commonly are not hydraulically connected with sandstones deposited within the channels. Unlike the channel deposits that overlie Mississippian rocks within former valleys, the deltaic and barrier-bar deposits overlie both Mississippian rocks in former upland areas and older Pennsylvanian channel deposits in former valley areas. The sandstones are predominantly fine and medium grained with a small fraction of coarse to pebble-size particles and were deposited after the valleys were filled by the channel deposits. Distribution and thickness of these sandstones suggest that they were deposited in a delta and associated barrier-bar system adjacent to a Pennsylvanian sea. The continuity of the aquifers has been traced by referencing them to the base of the Vienna Limestone.

STRUCTURE

The regional geologic setting of the Western Coal Field is shown on Figure 3, and the structure of the area is shown on Plate 4. The base of the Vienna Limestone is used as the datum for the structure map because marker beds in the Pennsylvanian System do not extend across the entire study area. Other marker beds of Mississippian age could have been used, but the Vienna is the youngest Mississippian formation that has not been extensively removed by post-Mississippian erosion.

The deepest part of the Western Coal Field is in Hopkins County about 2 miles southwest of Slaughters. Here the Vienna Limestone is slightly more than 2,300 feet below mean sea level, and the Pennsylvanian System is about 1,900 feet thick.

Attitude and Nomenclature of Pennsylvanian Sandstone Aquifers

Because of the irregularity of the Mississippian-Pennsylvanian contact and lack of marker beds in the lower part of the Pennsylvanian System, it is difficult to trace the lower Pennsylvanian aquifers without referring them to their distance above an underlying marker bed in the Mississippian System. Therefore, in order to show continuity and correlation of the Pennsylvanian aquifers, the base of the Vienna Limestone is used as a datum. This arrangement eliminates offsets by faults and tilting by regional dip but still shows the irregular contact.

The geologic sections on Plate 3 show the aquifers in relation to both the Vienna Limestone datum and to sea level datum. When referenced to the Vienna datum, the aquifer sandstones are shown virtually in the position in which they were

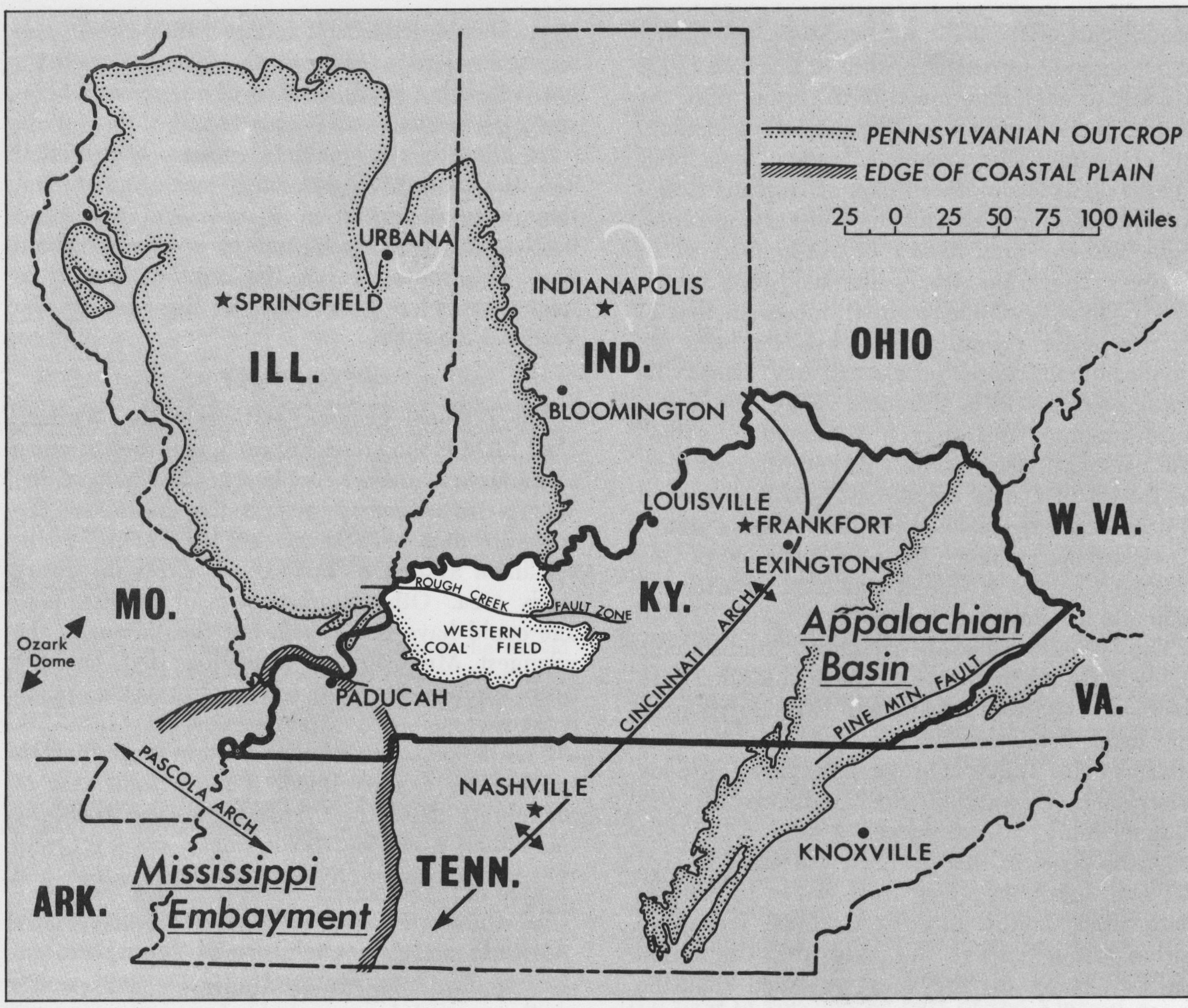


Figure 3. Map showing regional geologic setting of the Western Coal Field, Kentucky.

deposited during the Pennsylvanian Period. Referenced to sea level, they are shown in their present positions, in places having been divided by faults into compartments having little or no hydraulic connection with each other. The system of referring the aquifers to the Vienna datum was used throughout the study to differentiate between the various Pennsylvanian aquifers and to separate them into hydrologic units while compiling and analyzing data.

In this report, the deep aquifers that overlie the channel deposits are named by the approximate distance from their midpoint to the base of the Vienna Limestone. To avoid confusion with depth below land surface, the words "Vienna datum" are added, such as the 600-foot aquifer (Vienna datum). The deeper channel deposits are in pre-Pennsylvanian valleys, named according to the valley in which they occur, such as the sandstone aquifer in Rochester valley.

Pre-Pennsylvanian Paleogeology and Relief of the Pennsylvanian-Mississippian Unconformity

To locate the areas of pre-Pennsylvanian valleys that might contain Pennsylvanian channel sandstones, the character of the pre-Pennsylvanian surface was mapped. Plate 2 shows the thickness of the interval from the base of the Pennsylvanian

System to the base of the Vienna Limestone as was done by Rose (1963, Plate 11) for Muhlenberg County. Although the map shows the thickness of an interval, this interval can be visualized as a contour map using the base of the Vienna as datum. The total relief between the high areas underlain by the upper part of the Kinkaid Limestone and the valley bottoms probably represents the total amount of downcutting by streams. Truncation of Chesterian units around the edges of the basin is greater than pre-Pennsylvanian channeling in the valleys in the eastern part of the area. Thus, Chesterian units preserved in the eastern uplands are older than those preserved in the uplands in the central part of the mapped area.

The valley names on Plate 2 used in this report are modified from those used by Bristol and Howard (1971, p. 9) in their report of the sub-Pennsylvanian paleogeology of the entire Illinois basin. Several differences are noted as follows.

The West Branch of Greenville valley, only partially mapped and unnamed by Bristol and Howard (1971), is newly named in this report. It is based on additional well data unavailable to Bristol and Howard and on a slightly different interpretation of the pre-Pennsylvanian geomorphology.

The Madisonville channel, as shown in this report, does not extend across Daviess County as shown by Bristol and Howard (1971, Pl. 1). Instead, in Carter coordinate M-29, between Nuckols and Utica, the channel bends eastward and continues slightly southeastward to the edge of the study area. Drillers' logs were used almost exclusively to outline this channel. Near Buford, sandstones in this channel yielded oil prolifically (McFarland, 1943, p. 370).

Rochester valley, the easternmost valley in the study area, is the combined Drakesboro and Brownsville valleys of Bristol and Howard. Additional data on sandstone thickness obtained from drillers' logs indicate that the thick sandstones in the Brownsville valley swing northeastward in Butler County to connect with thick sandstone deposits in Drakesboro valley. This change is similar in direction to the change of Madisonville valley in northern Ohio County.

On most of Plate 2 isopach lines and paleogeology show the pre-Pennsylvanian topography and drainage patterns of the area; however, in several areas the paleogeology tends to show post-Mississippian structural movement before Pennsylvanian deposition. The most significant indication of structural movement of the Mississippian strata prior to Pennsylvanian deposition is a subtly expressed lineament that extends southeastward from the center of Carter coordinate K-24 to the northeast corner of H-30. The lineament is composed of southeast-northwest trending valleys (perpendicular to the regional trend of the main valleys); a similar trend in the direction of saddles in the upland areas; and the stratigraphically deepest downcutting of the main channels in the area—cutting below the Vienna Limestone in H-30 (Carter coordinate area), to the Menard Limestone in K-24, and to the Palestine Sandstone in the northeast part of I-27. The lineament suggests a southeast-northwest trending fold or fault in the Mississippian strata, which was truncated by post-Mississippian erosion and further eroded in the channel areas prior to deposition of Pennsylvanian sediments.

Another area that suggests post-Mississippian structural movement prior to Pennsylvanian deposition is in the Rough Creek fault zone. In the northwest corner of the area an east-west trending, pre-Pennsylvanian valley is parallel to, if not congruent with, the Rough Creek fault system. West of the study area, this valley continues southwestward to connect with the Madisonville valley near Clay in Webster County. In the study area, the parallelism of the valley with the Rough Creek fault system (a highly faulted anticline) may indicate uplift along an anticlinal structure that was truncated by pre-Pennsylvanian erosion.

Less clearly shown, but possibly of pre-Pennsylvanian tectonic origin, is the peculiar subcrop pattern in and near Carter coordinate 20-M-25. This is also in a faulted area. Although almost all tectonic activity in the Rough Creek fault system has been considered to have occurred after the Pennsylvanian Period (Sutton, 1953, p. 18), the two anomalous subcrop patterns indicate that tectonic activity may have occurred along and near part of the Rough Creek fault system after the Mississippian rocks were deposited, but prior to deposition of Pennsylvanian sediments. Similar pre-Pennsylvanian faulting has been recognized by Shaw and Gildersleeve (1969, p. D207) in an area about 30 miles east of Rochester, Butler County.

The parallelism of some of the valleys with the presently recognized fault systems (Fig. 4) indicates post-Mississippian structural movements may have influenced the location of the valleys.

HYDROLOGY

Four types of sandstone aquifers in Pennsylvanian rocks are recognized in the study area. The distribution of the aquifers is determined mainly by the environment in which the Pennsylvanian sediments were deposited. The four types of aquifers are shown on the geologic sections on Plate 3 and their area of occurrence is shown on Plate 5. In ascending order of stratigraphic position (except type 4), the types of aquifers are:

1. Channel-sandstone aquifers, such as the aquifer in Greenville valley, that were deposited in valleys that had been cut into the Mississippian rocks. These aquifers generally are basal Pennsylvanian deposits and, except for the easternmost aquifer, have no known source of recharge from the surface.
2. A deltaic, barrier-bar, and channel-filling sandstone aquifer, the 600-foot aquifer (Vienna datum), which was deposited on older Pennsylvanian rocks or on Mississippian rocks that comprised the pre-Pennsylvanian upland surface. This aquifer extends laterally over older Pennsylvanian channel-filling shales or sandstones and has no known source of recharge from the surface, but in places it may receive recharge from underlying channel-sandstone aquifers.
3. Channel-sandstone aquifers, such as the 700-foot aquifer (Vienna datum), that were deposited in channels cut in Pennsylvanian rocks several hundred feet above the uppermost Mississippian rocks.
4. Sandstone aquifers within any part of the Pennsylvanian rocks that are recharged at their outcrop and contain fresh water for varying distances down the regional dip. Two examples of this type of aquifer are cited.

Channel-Sandstone Aquifers

Both the Rochester and Greenville valleys contain channel-sandstone aquifers. Distribution, thickness, and structure on top of the aquifers are shown on Plates 6 and 7 and Figure 5.

Rochester Valley

The hydrology of the channel-sandstone aquifer in the Rochester valley is inferred from drillers' logs, electric-log data, and well cuttings from oil-test drilling. Medium sand is the most common size of aquifer material seen in well cuttings, but it includes considerable sand in both the fine and coarse range. The upper part (top 50 feet) of the aquifer generally is fine sand, with some very fine sand. Gravel may be present throughout the lower half and in cuttings occurs as broken quartz fragments associated with coarse and very coarse sand.

Location and dimensions of the aquifer within the study area are shown on Plate 6. Because it was apparent that the Rochester valley aquifer extended considerably east of the study area, it was studied and mapped to the outcrop near Reedyville (Fig. 5).

The sandstone aquifer in Rochester valley may be the largest potential source of potable ground water from Pennsylvanian deposits in western Kentucky. Well yields as great as 300 gpm (gallons per minute) may be available because of the coarse grain size, the thickness of the aquifer (as much as 400 feet), and the aquifer's large areal extent. However, no quantitative data are available on the hydrologic characteristics of the aquifer, and only two wells are known that tap the aquifer in the study area.

The aquifer either is entrenched within the valley walls of the pre-Pennsylvanian valleys or in its upper part changes to shale abruptly. In the south it is downfaulted against Mississippian rocks along the Pennyrile[1] fault system; however, the aquifer extends eastward to an area of outcrop near Reedyville. This aquifer may receive recharge in its outcrop area, unlike the other channel-filling sandstones in the pre-Pennsylvanian valleys that do not crop out. In its recharge area the aquifer may be presently rejecting re-

[1] "Pennyrile fault system" is the name proposed by H. R. Schwalb (oral commun.), Kentucky Geological Survey, for the major system of individually named faults that extend along the southern part of the study area. (See Plate 4 for location.)

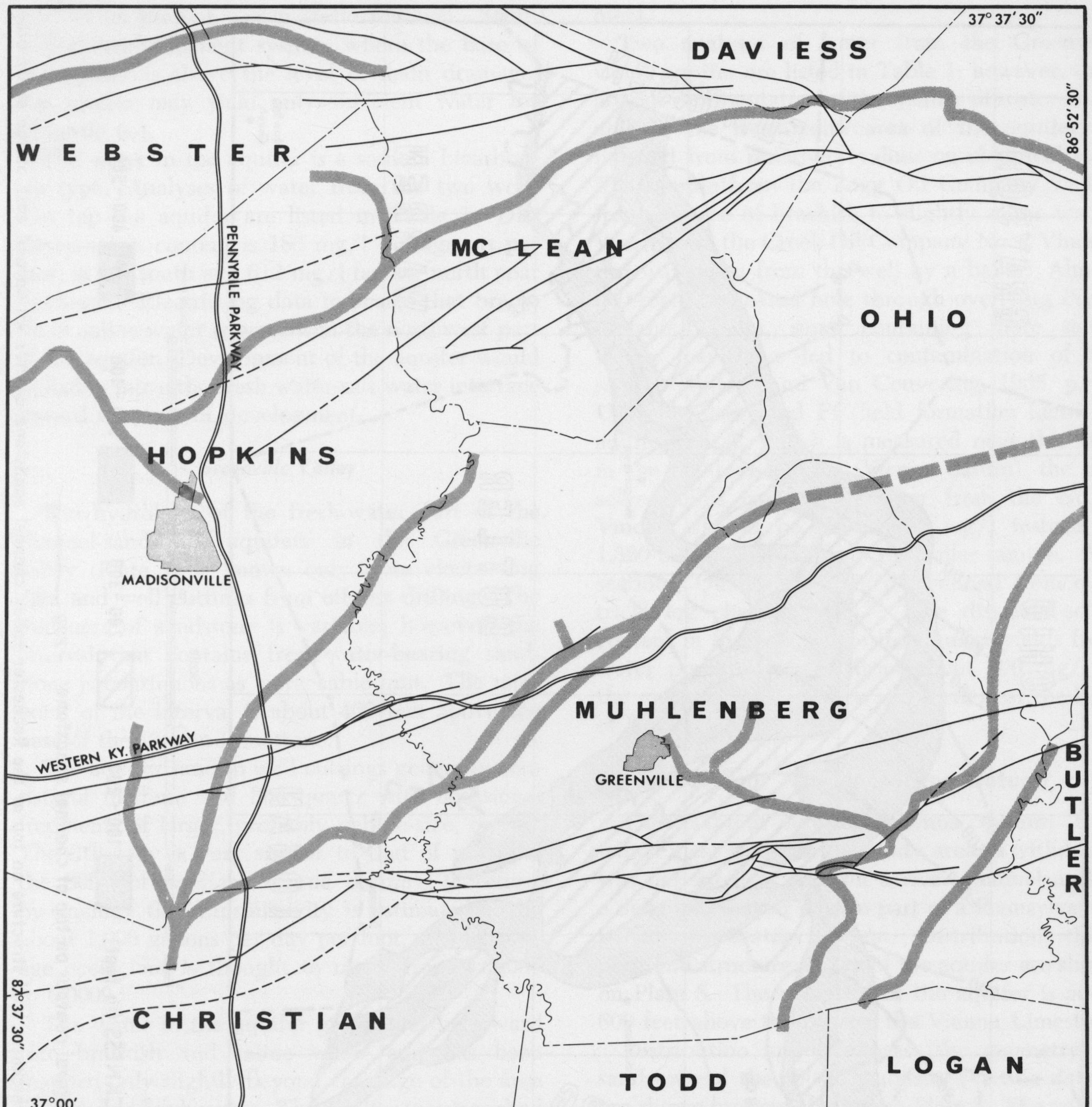


Figure 4. Map showing main pre-Pennsylvanian drainageways and present major fault systems.

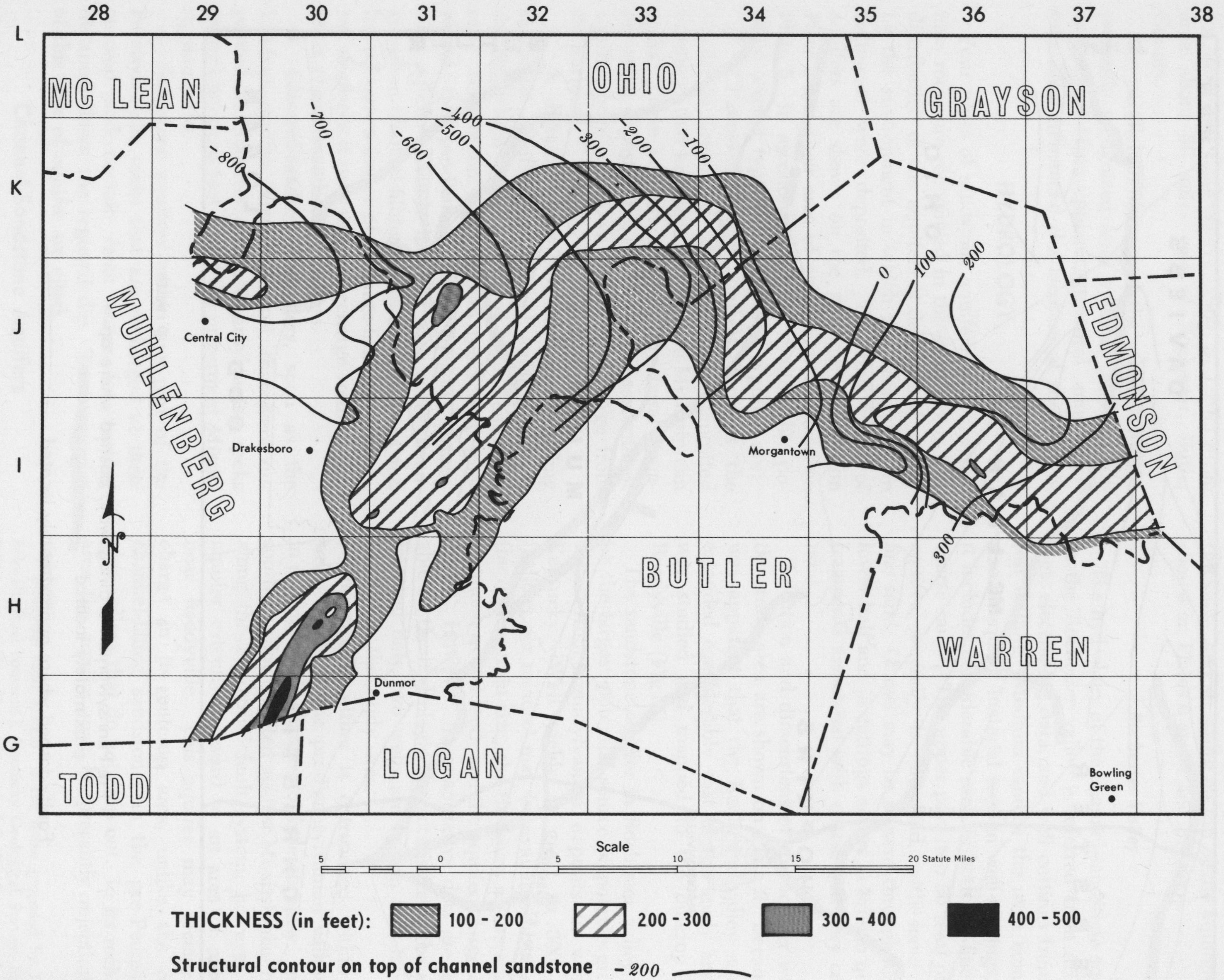


Figure 5. Distribution, thickness, and structure on top of the Rochester valley channel sandstone aquifer within and east of the study area.

charge because it contains all of the water it can hold in its present nearly static regimen. South of the Pennyrile fault system, where the base of the aquifer is above the level of main drainage, the aquifer may yield only sufficient water for domestic use.

The water in the aquifer is a sodium bicarbonate type. Analyses of water from the two wells that tap the aquifer are listed in Table 1. Dissolved-solids content is 186 mg/l (milligrams per liter) in the south and 612 mg/l farther north near Rochester. Electric-log data indicates that brackish or saline water is present in the northwest part of the aquifer. Development of the aquifer would probably move the fresh water-salt water interface toward the area of development.

Greenville Valley

The hydrology of the fresh-water part of the channel-sandstone aquifers in the Greenville valley (Plate 7) is known only from electric-log data and well cuttings from oil-test drilling. The thickness of sandstone is variable; however, the interval that contains fresh-water-bearing sandstone is continuous as a traceable unit. The midpoint of the interval is about 400 feet above the base of the Vienna Limestone.

The aquifer sand in well cuttings generally consists of medium and fine quartz with occasional fragments of larger, probably pebble-size, quartz. The lithology is very similar to that of much of the 600-foot aquifer (Vienna datum); therefore, by analogy the transmissivity is estimated to be about 1,000 gallons per day per foot, and its storage coefficient is thought to range from 0.00006 to 0.0009.

The water in the aquifer grades northeastward into brackish and saline water and has been mapped only slightly beyond the edge of the area of probable fresh water. The aquifer is entrenched within the walls of the pre-Pennsylvanian valleys and on the south is downfaulted against Mississippian rocks along the Pennyrile fault system. The aquifer is isolated hydraulically from the surface and is not known to be able to receive fresh-water recharge; therefore, water removed from the aquifer will be taken from storage and will probably not be replenished. Development of the aquifer would probably move the fresh water-salt water interface toward the area of development.

Two analyses of water from the Greenville valley aquifer are listed in Table 1; however, they are not representative of the quality of water available in the fresh-water area of the aquifer, as inferred from resistivity values on electrical logs. The sample from the Zogg Oil Company well is from an area of brackish to slightly saline water. Water from the Creek Oil Company No. 2 Vincent test was taken from the well by a bailer. Almost 900 feet of uncased hole through overlying Pennsylvanian rocks, some containing more saline water, may have led to contamination of the sample (Wilson and Van Couvering, 1965, p. 5). Using an estimated Ff (field formation factor of aquifer) of 22, which is measured near this area in the 600-foot aquifer (Vienna datum), the dissolved-solids content of water from the No. 2 Vincent should be about 650 mg/l instead of 1,320 mg/l analyzed from the bailer sample. (See section, "Quality of water determined from electrical log characteristics.") The dissolved-solids content in the area where the aquifer yields fresh water probably ranges from about 400 mg/l in the south to 1,000 mg/l in the north near the limit of fresh water.

600-Foot Aquifer (Vienna Datum)

The 600-foot aquifer (Vienna datum) from which most water in the study area is withdrawn was deposited as sand in a river channel and as a delta and barrier bars in part of a Pennsylvanian stream distributary system. Distribution, thickness, and structure on top of the aquifer are shown on Plate 8. The midpoint of the aquifer is about 600 feet above the base of the Vienna Limestone.

Distribution and thickness (the geometry) of sandstone of the 600-foot aquifer (Vienna datum) are shown by isopach lines on Plate 8. The various parts of the stream distributary system are shown schematically in the diagram that accompanies Plate 8. Prodelta shale deposits in the south and overbank shale deposits in the north surround the aquifer except in the extreme south where they have been removed by faulting. The ancient stream system was not studied north of the northernmost faults where electrical logs show that the water is saline. The faults that trend in an east-

Table 1.--Chemical constituents in ground water from various Pennsylvanian aquifers in the Western Coal Field region of Kentucky (Analyses by U.S. Geological Survey, except where noted. Chemical constituents in milligrams per liter.)

Well[1/] no.	Owner	Date of collection	Depth of well (feet)	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 (residue at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color (Platinum-cobalt units)
Channel-sandstone aquifers in Rochester valley																						
1	John G. Craig...............	June 10, 1954	700	9.7	0.25	0.01	2.8	0.9	248	1.9	370	0	1.9	173	0.2	0.5	612	11	0	1,100	8.0	1
2	L. R. Fox..................	Sept. 22, 1969	940	14	.20	.09	20	4.7	44	.9	156	0	26	3.6	.2	.5	186	70	0	305	8.1	2
Channel-sandstone aquifers in Greenville valley																						
3[2/]	Creek Oil Co. No. 2 Vincent..	Oct. 25, 1958	1,138	-	1.2	-	6.0	2.7	520	-	865	0	31	295	-	-	1,320	26	0	2,200	8.2	-
4	Zogg Oil Co.................	Oct. 30, 1969	800-900	23	.32	.02	22	5.0	1,350	1.7	814	0	15	1,720	1.7	.1	3,710	76	0	6,530	7.9	2
600-foot aquifer (Vienna datum)																						
5	Ames Oil and Gas Co.........	Oct. 21, 1970	1,000±	15	.14	.04	1.3	.1	250	1.2	525	39	4.0	44	.7	.0	668	4	0	1,050	8.8	5
6	City of Mortons Gap well No.1	May 3, 1954	943	10	.52	.25	2.3	1.9	222	3.2	531	0	11	36	.6	.1	552	14	0	910	7.3	1
7	City of Mortons Gap well No.2	Sept. 27, 1966	1,015	22	.10	.05	2.1	.5	218	.9	550	2	3.2	27	.8	.1	523	7	0	866	8.3	2
8	South Hopkins Co. High School	Aug. 18, 1970	891	13	.13	.03	2.4	.1	180	1.0	425	10	11	15	.2	1.1	430	6	0	732	8.4	5
9	William Glowe...............	June 8, 1954	1,400[3/]	9.6	.16	.11	1.4	.2	278	1.7	615	9.8	1.3	54	1.3	.0	668	4	0	1,090	8.3	2
10	City of White Plains.........	Oct. 28, 1965	800	11	.55	.01	4.4	1.7	119	.6	332	0	3.2	5.5	.2	1.0	324	18	0	514	8.1	10
11	City of Nortonville..........	Nov. 14, 1951	740	12	.23	.00	3.2	1.5	107	1.7	280	12	.3	3.5	.2	.0	283	14	0	447	8.4	1
12	..............do...........	Nov. 19, 1958	733	-	.07	-	-	-	-	-	304	0	2.8	4.0	.3	.1	-	14	0	435	7.8	-
13	Texas Gas Exploration Corp. 16637.	-	937+	13	-	-	6.7	2.5	336	8.6	625	24	13	42	2.3	1.1	800	32	0	1,350	8.6	-
14	Har-Ken Oil Co..............	July 21, 1971	965	10	.14	.05	1.1	0	290	1.4	614	0	.4	80	.5	.0	672	2	0	1,120	8.2	1
800-foot aquifer (Vienna datum)																						
15	Western Kentucky Coal Co.....	Dec. 17, 1970	800+	12	.46	-	7.0	1.2	500	4.4	1,280	25	7.6	32	2.7	.0	1,230	22	0	1,990	8.4	5
Shallow Pennsylvanian aquifer near Richland (sandstone below No. 6 coal)																						
16	Ames Oil and Gas Co.........	July 21, 1966	250	18	.06	.00	18	8.8	242	1.4	518	0	38	94	.7	.2	650	81	0	1,130	7.7	5
17[4/]	..............do...........	Sept. 15, 1965	191	-	.10	.00	14	6.0	-	-	288	3	64	7	-	-	-	62	-	-	7.6	-
Shallow Pennsylvanian aquifers near Sebree area																						
18	City of Sebree well No. 2....	July 31, 1950	216	36	5.0	-	52	11	17		182	0	43	12	.0	.3	264	175	26	395	7.1	2
19	City of Sebree well No. 1....	Mar. 12, 1958	255	-	7.9	-	-	-	-	-	200	0	68	.42	.2	.4	358[5/]	215	51	561	7.2	-
20	Milton Ashby................	Feb. 17, 1953	700	-	2.3	-	-	-	-	-	218	-	68	4.8	.1	.0	308[5/]	196	-	482	-	-
21	City of Sebree well No. 3....	Dec. 23, 1964	230	36	3.0	.25	40	10	11	.7	182	0	12	4.0	.2	.2	208	141	0	314	7.6	20
Miscellaneous, from undesignated deep Pennsylvanian aquifers within study area																						
22	James S. Powell.............	July 29, 1966	462	13	.07	.00	4.0	.3	580	1.8	1,400	5	1.2	71	3.4	.1	1,340	11	0	2,190	8.3	5
23	L. H. Terry.................	June 21, 1968	375	11	.40	.04	6.0	1.8	132	3.3	372	0	1.6	9.5	.4	.7	341	22	0	570	7.3	2
24	Mrs. Charles Wright..........	July 29, 1966	461	-	.01	.00	-	-	-	-	1,210	123	2.8	164	4.2	1.8	1,520	12	0	2,560	9.0	-
25	Williams Coal Co............	Dec. 12, 1951	840	13	.36	.00	13	7.8	240	1.2	562	14	58	34	1.5	.9	662	64	0	1,080	8.3	3
26	Nashville Coal Co. (formerly Williams).	Nov. 21, 1958	840	-	.21	-	-	-	-	-	594	0	109	40	.9	.2	710[5/]	146	0	1,190	7.2	-

1/ For location of wells, see aquifer maps. Index to aquifer maps is Plate 5.
2/ Open hole from 252 to 1,138 feet. Possibly contaminated from sandstone logged 550 to 627 feet (Wilson and Van Couvering, 1965). Sodium estimated as if calculated Na-K content of 22.62 epm (equivalents per million) were all sodium. Dissolved-solids content estimated from specific conductance.
3/ Aquifer sandstone from about 680 to 770 feet.
4/ Analysis by Bradford Laboratory, Evansville, Ind.
5/ Calculated.

west direction through Nortonville (Plate 4) separate the sandstone into two discrete aquifers, one north of Nortonville and the other south of Nortonville.

Area North of Nortonville

The 600-foot aquifer (Vienna datum) north of the faults at Nortonville is composed of fine- to medium-grained sandstone. The grain size in the lowest part of the aquifer becomes larger northward. Coarse-grained sandstone is present near the base of the aquifer in the northernmost areas. Occasional pebble-size quartz is present throughout the area.

The aquifer's ability to store and transmit water is low. On the basis of two aquifer tests and a computer simulation of the aquifer for verification purposes, the transmissivity of the aquifer ranges from 800 to 1,200 gallons per day per foot and its storage coefficient ranges from 0.00004 to 0.0009. (See section, "Ground-water levels.") Low storage capacity and transmissivity, along with lithologic changes and faults acting as hydrologic boundaries, have caused excessive drawdowns of the water levels, even though pumpage is low. Hydrographs of the water levels in two observation wells tapping this aquifer are shown on Figure 6. Changes in the rate of drawdown of the water

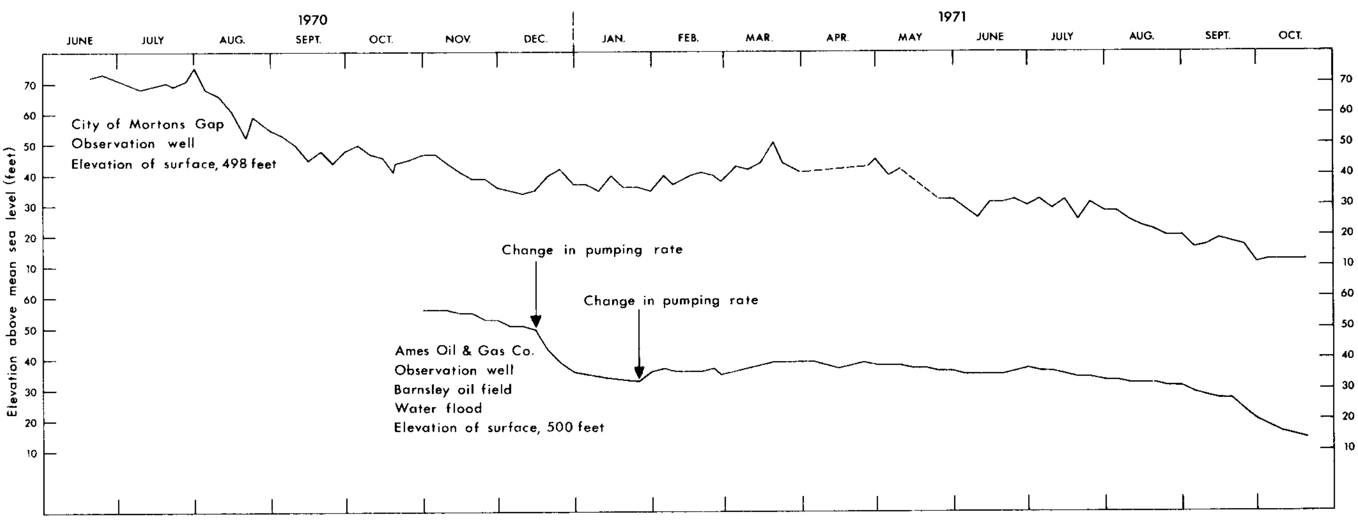


Figure 6. Hydrographs of wells tapping the 600-foot aquifer (Vienna datum).

levels are caused by increased or decreased pumpage in nearby wells. For the short period of record, the decline in water level at Mortons Gap is 60 feet,[1] and that at Barnsley oil field is 40 feet.

The table at the top of page 14 shows data on all the wells known to yield water from the aquifer north of the faults.

The table shows that the continuous pumping rate from the entire aquifer has averaged no more than 100 to 110 gpm, but that the continuously falling water levels have necessitated lowering the pump intakes to keep pace with the declining water levels.

[1] In June 1973, the water level at Mortons Gap had declined an additional 27 feet, a total measured decline of 87 feet since June 1970.

The aquifer's northern and southern boundaries are against faults. Laterally the sandstone changes abruptly to shale which forms the eastern and western boundaries. The aquifer has no outcrop and probably has no source of surface recharge.

The water in the aquifer is a sodium bicarbonate type (Table 1). Dissolved-solids content ranges from 430 mg/l (well 8) in the south to 672 mg/l (well 14) near the center of the aquifer. Water near the northern boundary is estimated to have a dissolved-solids content of about 1,000 mg/l. The faults that form the northern boundary of the aquifer are considered to be sufficiently impermeable to movement of water that the saline water north of the faults will not move southward into the area of fresh water.

Well owner and location	Well yield (gpm)	Static water levels (feet below surface, 1971)	Pump intake setting (feet below surface, 1971)
City of Mortons Gap	100± Intermittent	492[a] Reported	730[b]
Ames Oil & Gas Co., Barnsley oil field waterflood (1 mile north of Mortons Gap)	40± Continuous	—	600
Stanoco Oil Co., Oak Hill oil field waterflood (2.5 miles south of Mortons Gap)	9± Average daily rate	—	—
South Hopkins County High School (1.5 miles south of Mortons Gap)	—	359[c]	480[d]
Har-Ken Oil Co., Harps Hill oil field waterflood (about 3.5 miles northeast of Mortons Gap)	1[e] Average daily rate	—	700

[a] 180 feet when drilled in 1965
[b] 615 feet when drilled in 1965
[c] About 100 feet when drilled in 1955
[d] 200 feet when drilled in 1955
[e] Test pumped at 70 gpm when drilled in 1969

Area South of Nortonville

The 600-foot aquifer (Vienna datum) south of the faults at Nortonville consists of fine- to medium-grained sandstone. Occasional pebble-size quartz is present in all the area. Storage coefficients and transmissivities are low. At Nortonville the transmissivity is about 2,600 gallons per day per foot and the storage coefficient is 0.00006. Similar conditions can be expected throughout the aquifer. As in the aquifer north of the faults, low transmissivities and storage coefficients cause large drawdowns in wells. Lithologic changes and faults acting as hydrologic boundaries have contributed to accelerated water-level decline, but not as greatly as in the aquifer north of the faults.

The boundaries of the aquifer south of the faults at Nortonville are similar to the boundaries of the aquifer north of the faults. They consist of faults to the north and south and abrupt lithologic changes from sandstone to shale to the east and west. The aquifer is at the surface at several places south of the Pennyrile fault system, but there is no apparent hydraulic continuity with the subsurface aquifer because of the faulting. The authors believe that the aquifer has no perceptible recharge along any of the fault systems and, for practical purposes, the aquifer has no recharge from the surface. However, where the aquifer overlies or is in close proximity to the channel-filling sandstone aquifers in Greenville valley, the aquifer probably receives recharge from the underlying aquifer. This source of additional water probably is the reason that water-level declines in the aquifer south of the faults are much less than water-level declines in the aquifer north of the faults at Nortonville. This inter-aquifer recharge is the main reason for the hydrologic differences north and south of the faults.

The table at the top of page 15 shows data on all of the wells known to obtain water from the aquifer south of the faults at Nortonville.

The table indicates that the continuous pumping rate has averaged only about 150 to 170 gpm from the entire aquifer. Water levels have declined, but not as much as those north of the faults.

The water in the aquifer is a sodium bicarbonate type (Table 1). The dissolved-solids content is lower in the southern part of the aquifer than in the northern part. It ranges from 283 mg/l (well 11) to 668 mg/l (well 9).

Well owner and location	Well yield (gpm)	Static water level (feet below surface, 1970)	Pump intake setting (feet below surface, 1970)
City of Nortonville[a]	200 Intermittent	152[b]	400
City of White Plains	140 Intermittent	40[c] Reported	500

[a] One of three wells; not all pumped at the same time.
[b] 50 feet reported in 1951; pumping level of 308 feet after 2 hours of pumping.
[c] 52.5 feet measured after 3 hours of recovery; water level still rising slowly.

700- and 800-Foot Aquifers (Vienna Datum)

A channel-filling sandstone aquifer, which has a midpoint about 700 feet above the base of the Vienna Limestone, is present southwest of Madisonville. Distribution, thickness, and structure on top of the aquifer are shown on Plate 9. An overlying sandstone aquifer, apparently deposited by a braided stream system, has a midpoint about 800 feet above the base of the Vienna Limestone and is shown on Plate 9 in areas where it is thicker than 60 feet.

The 700-foot aquifer (Vienna datum) is not continuous with the 600-foot aquifer (Vienna datum), and at a few places one aquifer overlies the other, separated by shale beds. The 700-foot aquifer (Vienna datum) appears to extend southwestward from the study area to Dawson Springs where it is about 6 miles wide and is thicker and probably coarser grained than in the study area.

In the study area the hydrologic properties of the 700-foot aquifer (Vienna datum) are known only from electric-log data and well cuttings from oil-test drilling. The aquifer sandstone is very fine to medium grained; the smaller size fraction is predominant, and by comparison with other finer grained aquifers in the area, the transmissivity and storage coefficient are estimated to be low—about 1,000 gallons per day per foot and about 0.0001 to 0.0009, respectively.

Sandstone of the 700-foot aquifer (Vienna datum) extends north of the area mapped on Plate 9. Northward, water in the aquifer is brackish and saline and is separated from the mapped aquifer by faulting; laterally the aquifer is entrenched within valley walls of Pennsylvanian shale. Southwestward it crops out near Dawson Springs where it may receive recharge. The aquifer is faulted between the outcrop area and the study area and hydraulic continuity is unknown.

No wells are known to tap the 700-foot aquifer (Vienna datum) in the study area; however, the overlying 800-foot aquifer (Vienna datum) shown on Plate 9 was formerly used at Earlington. An analysis of water from one of these wells (well 15) is shown on Table 1. The dissolved-solids content of 1,230 mg/l is slightly greater than that inferred from resistivity data. Water having a dissolved-solids content of 1,000 mg/l or less can be expected from the aquifer within the area outlined on Plate 9.

Sandstone Aquifers that Receive Recharge at their Outcrop and Locally Contain Fresh Water Downdip

Another type of aquifer in the Western Coal Field region is a relatively shallow sandstone that receives recharge at its outcrop and contains fresh water for varying distances downdip. Identification of all aquifers of this type in the study area is beyond the scope of this report. Recognition of them has been greatly simplified by studying lithology and structure shown on the geologic quadrangle maps published for the area. Two examples of this type of aquifer are: (1) the Richland area, southwest of Madisonville, where the detailed geology has been published, and (2) the area of the Rough Creek fault system near Sebree, where the detailed geology has not been published.

Shallow Aquifer near Richland

A shallow sandstone, just below the base of the No. 6 coal bed (Palmer, 1967), yields water to domestic wells and to an oil-field waterflood project near Richland. The sandstone is generally fine grained and micaceous (Palmer, 1967). It crops out as shown on Plate 10 and dips northward. The aquifer contains fresh water several miles from the outcrop area. Records for almost 5 years from an observation well tapping this aquifer at Richland show seasonal water-level fluctuations of about 6 feet, but no downward trend is indicated. No data on transmissivity and storage coeffiicient of the aquifer are available. Data showing the chemical quality of water are listed in Table 1.

Shallow Aquifers near Sebree in the Rough Creek Fault System

The Rough Creek fault system extends across the northern part of the study area. The fault system near Sebree is a complexly folded, highly faulted horst, where Mississippian, basal Pennsylvanian, and other younger beds are brought to the surface. Wells for the city of Sebree and domestic wells in this area yield fresh water from lowermost sandstone aquifers of Pennsylvanian age. Electric logs of oil-test holes in this area also show high resistivity values for the sandstones, indicating fresh water. However, the structure of the area is so complex that no interpretation of the hydrology can be attempted until detailed geologic maps are available.

The Green River, which crosses the fault system just east of Sebree, is the probable source of recharge to the aquifer. An aquifer test, using one of the city wells, gave a transmissivity of 2,160 gallons per foot per day and a storage coefficient of 0.00016. Data showing the chemical quality of water are listed in Table 1.

CHEMICAL QUALITY OF WATER

The chemical quality of water from the deep Pennsylvanian aquifers generally is good, especially if compared with the chemical quality of ground water from most shallow Pennsylvanian aquifers in the area. The dissolved-solids content of the slightly alkaline water is generally less than 600 mg/l; and the pH generally exceeds 7.0. Sodium bicarbonate is the dominant constituent in the water. For purposes of this study, water with less than 1,000 mg/l dissolved solids is considered fresh, and water with more than 1,000 mg/l is considered as brackish or saline. Analyses of water from the aquifers are listed in Table 1.

Fresh and Saline Water Characteristics

A comparison of the chemical quality of the ground water from the lower Pennsylvanian aquifers in the southern and northern parts of the study area is shown on Figure 7. Whereas the fresh water in the southern part of the area is predominantly a sodium bicarbonate type, the saline water in the north is a sodium chloride type; however, the water also contains a large amount of bicarbonate.

The water from the lower Pennsylvanian sandstones in most of the study area generally is brackish or saline, except in the fresh-water aquifers shown on Plate 5. The saline water is not potable but is used at places for repressuring oil fields in secondary-recovery waterflood projects.

Quality of Water Determined from Electrical Log Characteristics

Oil-test holes drilled by the rotary method can be logged with equipment that measures and records the electrical characteristics of the various geologic formations and the fluids that the formations contain. Three measurements—spontaneous potential, short normal resistivity, and long normal resistivity—on standard electrical logs of wells in the study area denote the electrical and electrochemical characteristics of the aquifers and their water, and can be interpreted for water-quality determinations. Induction logs were studied, but their measurements in the fresh-water zone generally were too erratic to be used quantitatively.

Determination of Water Quality from Long Normal Resistivity Measurements

The long normal curve on electrical logs measures the resistivity of the rocks and their contained fluid or gas, if any. For an aquifer, the measurement is of the resistivity of the aquifer and its contained water.

Since most chemical analyses include values for dissolved-solids content and specific conductance (the reciprocal of resistivity), the relationship of the dissolved-solids content to the specific conductance of water from an aquifer is relatively

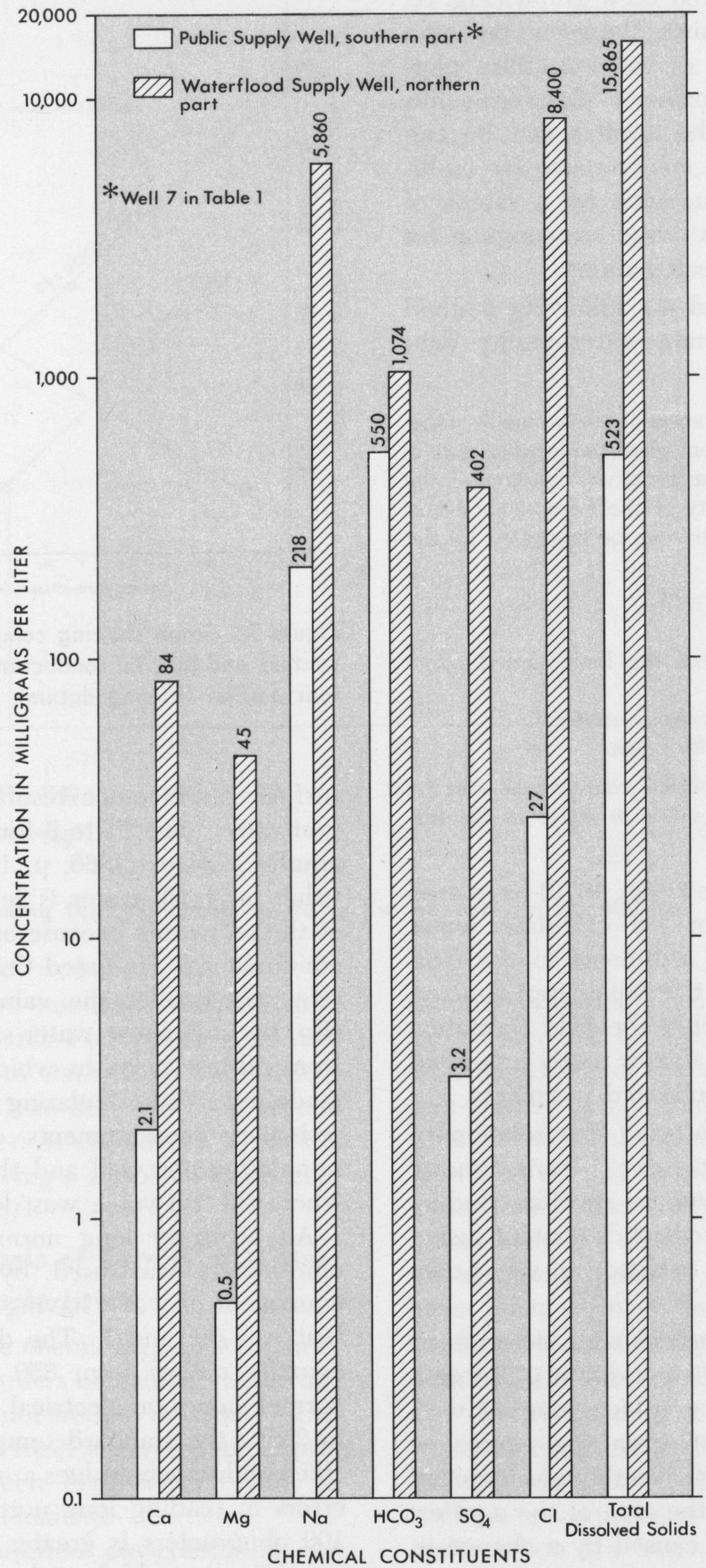


Figure 7. Graphs showing examples of water quality in the northern and southern parts of the study area.

which have been subjected to sulfate reduction can be expected to contain some hydrogen sulfide unless conditions have existed which allowed the gas to escape or react with metals to form metallic sulfides. Many of these waters have a high content of bicarbonate and often of carbon dioxide which can be gained at the expense of sulfate." Pyrite, an iron sulfide, is moderately common in well cuttings, and the bisulfide ions may have reacted with iron ions to form the iron sulfide. In addition, methane, or some other combustible gas, is present in water from many of the wells. W. F. Meents (written commun., April 12, 1972), Illinois State Geological Survey, collected a gas sample for analysis from a well tapping the 600-foot aquifer (Vienna datum) (Table 1, well 9). The gas contained 90.8 percent methane, 8.9 percent nitrogen, and 0.3 percent oxygen.

Ion exchange, in which the original calcium ions in the water replaced sodium ions in shales, may explain the low calcium and high sodium content of the water.

GROUND-WATER LEVELS

Before Development of the Aquifers

Data from both early water wells and oil-test wells that were plugged at depth and converted to water wells tapping the deep Pennsylvanian aquifers show that all of their water levels were approximately 405 to 410 feet above sea level. In other words, at the beginning of development of the deep Pennsylvanian aquifers, the potentiometric surface (the levels to which water will rise in tightly cased wells) was horizontal.

According to Hubbert (1953, p. 1974), "If the potentiometric surface for a given stratum is horizontal, the potential of the water in that stratum will be constant and the water will be at rest." Therefore, before usage of the water in the deep Pennsylvanian aquifers, the water in them was at rest; the aquifers neither received recharge from the surface or elsewhere nor discharged their contained water at the surface or to other aquifers.

After Development of the Aquifers

Data on water levels in all the deep aquifers are far too sparse to make meaningful maps for the various aquifers. The table at the top of page 21 shows the elevation of water levels in wells tapping the deep Pennsylvanian aquifers.

The data show that water levels have declined only in the wells that tap aquifers that are being significantly used. Water-level decline in the 600-foot aquifer (Vienna datum) is greatest north of the faults at Nortonville. South of the faults, water levels are also being lowered. In the future, the wells at the cities of Nortonville and White Plains may experience problems of low water levels; however, there seems to be no immediate problem.

Because of the rapidly declining water levels in the 600-foot aquifer (Vienna datum) north of the faults at Nortonville, verification of the field-derived hydrologic parameters was needed to predict the performance of the aquifer under the present (1971) pumping conditions. This verification was done by simulating the aquifer's response to pumpage by analysis with a digital computer evaluation. The methods used were modified from those described by Pinder (1970). The assistance of Mr. Hayes Grubb, U. S. Geological Survey, Louisville, Ky., in making the study is gratefully acknowledged.

Plate 11 shows the computed decline in water level in the aquifers after development began at Mortons Gap in 1954. Pumpage data shown on Plate 11 are estimates of average continuous pumpage. Accurate records were not kept, and pumpage was intermittent at all wells except the Ames Oil and Gas Company's waterflood well at Barnsley oil field.

The following assumptions were used for computing the drawdown:

1. The potentiometric surface was horizontal at an elevation of 405 feet before development.
2. The transmissivity of the aquifer was uniformly 800 gallons per day per foot.
3. The thickness of the aquifer varies as shown on the isopach map (Plate 8). Therefore, because of variations in thickness, permeability (transmissivity/thickness of the aquifer) was used to calculate movement of the ground water.
4. The storage coefficient of the aquifer was uniformly 0.00004.
5. The aquifer received no recharge from any source.

Aquifer and well owner	Water-level measurement: Feet above mean sea level	Date
Rochester valley		
L. R. Fox (15-I-32)[1]	410	1969
J. G. Craig (2-H-30)	400± flowing	1954
	400± flowing	1971
Greenville valley	——	——
600-foot aquifer (Vienna datum):		
North of faults at Nortonville:		
City of Mortons Gap	404	1954
	285	1965
	72	June 1970
	12	Oct. 1971
Ames Oil & Gas Co. Barnsley oil field (24-J-25)	56	Nov. 1970
	14	Oct. 1971
South Hopkins High School (13-I-25)	370±	1955
	111	1970
South of faults at Nortonville:		
City of White Plains	398 reported	1963
	370 reported	1970
City of Nortonville	410 to 430 reported	1951
	332	1970
William Glowe (6-I-27)	422 flowing[2]; reported about	1920
	374	1970
800-foot aquifer (Vienna datum):		
Western Kentucky Coal Co. (at Earlington)	406 flowing	1951
	404 not flowing	1970

[1] Carter coordinate locations are enclosed in parentheses.

[2] Stopped flowing about 1966.

6. The faults at the northern and southern limits of the aquifer and the lateral east-west abrupt lithologic change from sandstone to shale are hydrologic boundaries.

Computed and measured drawdowns are listed in the following table:

The computed drawdown was most accurate at Barnsley oil field where the transmissivity and storage coefficient used for the entire aquifer were measured. Variations in transmissivity in the aquifer probably account for computed drawdowns that are greater than measured in the southern

Owner of well	Computed drawdown (feet)	Date	Measured drawdown (feet)	Date	Error (feet)[1]
City of Mortons Gap	85	1965	119	1965	+34
	414	1970	365	1970	−49
Ames Oil & Gas Co. (Barnsley oil field)	376	1970	355	1970	−21
South Hopkins High School	378	1970	295	1970	−85

[1] −(minus) indicates computed drawdown less than measured; +(plus) indicates computed drawdown more than measured. Water level assumed to have been at an elevation of 405 feet before development of the aquifer.

area. The greatest observed errors are in an area where transmissivity is probably about 1,500 gallons per day per foot and drawdown should be less than computed.

The model could be modified to obtain responses that more closely match the measured data; however, considering the crudeness of historical pumpage data, the authors consider the model to closely simulate the hydrologic properties of the aquifer.

Apparently low transmissivity is responsible for the large drawdown throughout the aquifer. An attempted computer run was made with transmissivity of 1,500 gallons per day per foot. This program exceeded the "permitted number of iterations" and stopped after 3.7 years of simulated pumping. Drawdown at a point near the pumped well at Mortons Gap was 28.1 feet compared with 39.7 feet using a transmissivity of 800 gallons per day per foot. The difference in drawdown of 11.6 feet in 3.7 years indicates that if the higher transmissivity were used, drawdown at Mortons Gap in 1965 would have been significantly less than measured.

The computer simulation verifies the approximate range of transmissivity and storage coefficient. It also tends to verify the concept of no recharge to the aquifer.

GROUND-WATER MOVEMENT

Ground-water movement is toward the centers of pumping in the aquifers that are developed and is virtually static in the undeveloped aquifers.

Since the principal aquifers do not crop out, recharge to the aquifers could occur: (1) by movement of water through shales from other aquifers, (2) by expulsion of water from compaction of clays, or (3) by movement of water downward along fault planes. Recharge by these methods is considered unlikely or insignificant for the following reasons. (a) Most adjacent aquifers, above or below the principal aquifers, contain brackish or saline water, and there is no evidence of changing water quality. However, it theoretically is possible (Bredehoeft and others, 1963, p. 260) for the shales between adjacent saline- and fresh-water aquifers to act as micro-filtration membranes through which water could move without producing notable changes in water quality in the aquifer being recharged. The saline water would be diluted as it moved through the shale. Thus the aquifer being recharged would receive fresh water, and the saline water on the other side of the shale membrane would become more saline. The rate of recharge, for practical water-development purposes, would probably be insignificant. (b) The shales are already compacted and have lost all natural plasticity needed to derive water by compaction. (c) The major faults are filled with gouge where exposed, and most of them are impermeable to the movement of oil; they commonly form structural traps for oil accumulation. Similarly the faults are impermeable to the movement of water as shown near Nortonville. Water levels across the faults at Nortonville differ markedly in elevation. The static water levels of the wells at Nortonville, a relatively large user of water, were 220 feet higher in 1970 than at South Hopkins County High School, a relatively small user of water. The two wells are 14,000 feet apart and are separated by several faults.

SUMMARY

To appraise the ground-water potential in aquifers of Pennsylvanian age in part of the Western Coal Field region, hydrologic data from wells tapping the aquifers were collected and studied, and data from oil-test drilling were used to outline the geometry and areas of fresh water in the aquifers.

The study shows that the developed aquifers have low transmissivity and storage properties, and no perceptible recharge from the surface, and that water levels are declining in the vicinity of centers of pumping. One channel-filling-sandstone aquifer not presently developed may yield as much as 300 gpm to individual wells and probably can receive recharge from the surface. However, hydrologic data are lacking to predict its performance.

In summation, the study area is underlain by fresh-water aquifers with low-yield characteristics. Utilization of these aquifers to supply water for large-scale economic development of the region is doubtful and, except for the Rochester valley sandstone aquifer, is not recommended unless additional data should show greater permanence of supply than is indicated by present data.

MANAGEMENT CONSIDERATIONS

The study suggests several factors to be considered in the management of ground water in all the aquifers in the study area. Water in overlying and underlying formations is under greater pressure than that in the developed Pennsylvanian fresh-water aquifers. Therefore, movement of water through improperly protected wells or test holes would be from formations containing poor-quality water to an aquifer containing fresh water. The result would be a deterioration of water quality in the fresh-water aquifer. Oil, gas, or other test holes that penetrate the aquifers should be cased securely through the aquifers or should be plugged properly to prevent contamination of the aquifers from the saline waters in the underlying older formations and the commonly brackish to saline water in overlying younger Pennsylvanian formations.

Similarly, the disposal of liquid wastes into an aquifer should be prohibited if the wastes are of poorer quality than the native water. The most common liquid waste that is disposed of underground in this area is saline water from separators in oil fields.

Brackish or saline water is present in the northern parts of the Rochester and Greenville valley aquifers. If these aquifers are developed, the fresh water-saline water interface will move toward the areas of development at an undetermined rate. Recharge in the Rochester valley aquifer may balance or closely balance discharge and prevent significant movement of the interface; however, in the Greenville valley aquifer, if the concept of no recharge is correct, the interface will move toward the area of pumping until the water being pumped becomes mixed with the more saline water.

In the 600-foot and 700-foot aquifers (Vienna datum), saline water is separated from fresh water by faults that probably are impermeable to the passage of significant amounts of saline water. The shallow aquifers near Richland and Sebree appear to receive sufficient recharge to prevent movement of any poorer quality water.

Of special interest to management are the declining water levels in the 600-foot aquifer (Vienna datum) north of the faults at Nortonville. The aquifer presently is used for public water supply and for waterflooding in oil fields where the primary pressure has diminished. Four possible courses of action for the aquifer can be taken:

1. Continue the present pumping regimen without consideration of the depletion of the source.
2. Limit withdrawal of water from the aquifer by reserving the use for either public supply or for oil-field waterflooding. This would extend the useful life of the aquifer.
3. Impound, treat, and inject surface water into the aquifer; however, although such recharge is technically feasible, it might not be economically practical.
4. Use the aquifer, or parts of it, for other purposes, such as the storage of natural gas.

REFERENCES CITED

Alger, R. P., 1966, Interpretation of electric logs in fresh water wells in unconsolidated formations: Soc. Prof. Analysts, 7th Ann. Logging Symposium, Tulsa, Okla., May 1966, Trans., p. CC1-CC25.

Atherton, Elwood, and others, 1960, Differentiation of Caseyville (Pennsylvanian) and Chester (Mississippian) sediments in the Illinois basin: Illinois Geol. Survey Circ. 306, 36 p.

Bredehoeft, J. D., Blyth, C. R., White, W. A., and Maxey, G. B., 1963, Possible mechanism for concentration of brines in subsurface formations: Am. Assoc. Petroleum Geologists Bull., v. 47, no. 2, p. 257-269.

Bristol, H. M., and Howard, R. H., 1971, Paleogeologic map of the sub-Pennsylvanian Chesterian (Upper Mississippian) surface in the Illinois basin: Illinois Geol. Survey Circ. 458, 14 p.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water (first edition): U. S. Geol. Survey Water-Supply Paper 1473, 269 p.

Hubbert, M. K., 1953, Entrapment of petroleum under hydrodynamic conditions: Am. Assoc. Petroleum Geologists Bull., v. 37, no. 8, p. 1954-2026.

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

McFarlan, A. C., 1943, Geology of Kentucky: Lexington, Univ. Kentucky Press, 531 p.

Palmer, J. E., 1967, Geologic map of the Saint Charles quadrangle, Hopkins and Christian Counties, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-674.

Payne, J. N., 1968, Hydrologic significance of the lithofacies of the Sparta Sand in Arkansas, Louisiana, Mississippi, and Texas: U. S. Geol. Survey Prof. Paper 569-A, p. A1-A17.

_______ 1970, Geohydrologic significance of lithofacies of the Cockfield Formation of Louisiana and Mississippi and of the Yegua Formation of Texas: U. S. Geol. Survey Prof. Paper 569-B, p. B1-B14.

Pinder, G. F., 1970, A digital model for aquifer evaluation: U. S. Geol. Survey Techniques of Water-Resources Inv. Book 7, Chap. C1, 18 p.

Rose, W. D., 1963, Oil and gas geology of Muhlenberg County, Kentucky: Kentucky Geol. Survey, ser. 10, Bull. 1, 118 p.

Shawe, F. R., and Gildersleeve, Benjamin, 1969, An anastomosing channel complex at the base of the Pennsylvanian System in western Kentucky: U. S. Geol. Survey Prof. Paper 650-D, p. D206-D209.

Sutton, D. G., 1953, Geological review of Rough Creek fault system, *in* Proceedings of the technical session, Kentucky Oil and Gas Association annual mid-year meeting, June 5, 1953: Kentucky Geol. Survey, ser. 9, Spec. Pub. 3, p. 17-20.

Turcan, A. N., Jr., 1966, Calculation of water quality from electrical logs—theory and practice: Louisiana Dept. Public Works, Water Resources Pamph. 19, 23 p.

Wilson, E. N., and Van Couvering, J. A., 1965, A deep fresh water aquifer in New Cypress pool, Muhlenberg County, Kentucky, corroborated by geophysical logs: Kentucky Geol. Survey, ser. 10, Inf. Circ. 12, 25 p.

APPENDIX

SOURCES USED TO COMPILE GEOLOGIC MAP (PLATE 1)[1]

Quadrangle name and source of data

Allegre – Klemic, Harry, 1965, Geologic map of the Allegre quadrangle, Todd County, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-446.

Beech Grove – Modified from: Tennessee Valley Authority, 1969, Coal reserves of western Kentucky: Tenn. Valley Authority, Fuels Plan. Staff, Chattanooga.

Calhoun – Modified from: TVA, 1969, cited above.

Central City East – Geology drawn to match adjacent quadrangles.

Central City West – Palmer, J. E., 1969, Geologic map of the Central City West quadrangle, Muhlenberg and Ohio Counties, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-831.

Coiltown – Franklin, G. J., 1967, Geologic map of the Coiltown quadrangle, Hopkins County, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-629.

Crofton – Modified from: Sutton, A. H., 1928, Map of areal and structural geology of Christian County, Kentucky: Kentucky Geol. Survey, ser. 6, *and*
Rose, W. D., 1964, Oil, gas, and structure map of northern Christian County, Kentucky: Kentucky Geol. Survey Oil and Gas Map, ser. 10.

Cromwell – Modified from: Mullins, A. T., Hodgson, D. L., Avery, G. G., and Wilson, E. N., 1963, Coal reserves in portions of Butler, Edmonson, Grayson, Muhlenberg, Ohio, and Warren Counties, Kentucky: Kentucky Geol. Survey, ser. 10, Inf. Circ. 11, 29 p.

Dalton – Palmer, J. E., 1966, Geologic map of the Dalton quadrangle, western Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-490.

Dawson Springs – Kehn, T. M., 1966, Geologic map of the Dawson Springs quadrangle, western Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-573.

Dawson Springs, S. E. – Modified from: Sutton, A. H., 1928, cited above, *and*
Rose, W. D., 1964, cited above.

Dawson Springs, S. W. – Modified from: Sutton, A. H., 1928, cited above, *and*
Rose, W. D., 1964, cited above.

Drakesboro – Hansen, D. E., 1972, Geologic map of the Drakesboro quadrangle, Muhlenberg County, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-934.

Dundee – Goudarzi, G. H., and Smith, A. E., 1968, Geologic map of the Dundee quadrangle, Ohio County, Kentucky: U. S. Geol. Survey Geol. Quad Map GQ-688.

Dunmor – Modified to match Drakesboro quadrangle from: Miller, T. P., 1964, Geology of the Dunmore quadrangle, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-290.

Equality – Goudarzi, G. H., 1969, Geologic map of the Equality quadrangle, western Kentucky: U. S. Geol. Survey Geol. Quad Map GQ-815.

Flener – Modified from: Mullins, A. T., and others, 1963, cited above.

Glenville – Modified from: TVA, 1969, cited above.

Gracey – Nelson, W. H., and Seeland, D. A., 1968, Geologic map of the Gracey quadrangle, Trigg and Christian Counties, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-753.

Graham – Kehn, T. M., 1968, Geologic map of the Graham quadrangle, western Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-765.

Greenville – Kehn, T. M., 1971, Geologic map of the Greenville quadrangle, Muhlenberg County, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-907.

Haleys Mill – Modified from: Sutton, A. H., 1928, cited above, *and*
Rose, W. D., 1964, cited above.

Hanson – Franklin, G. J., 1965, Geology of the Hanson quadrangle, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-365.

Hartford – Goudarzi, G. H., 1968, Geologic map of the Hartford quadrangle, Ohio County, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-741.

Honey Grove – Klemic, Harry, 1965, Geology of the Honey Grove quadrangle, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-376.

Horton – Modified from: Mullins, A. T., and others, 1963, cited above.

Kelly – Miller, T. P., 1964, Geology of the Kelly quadrangle, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-307.

Kirkmansville – Drillers' logs, field reconnaissance, and modified to match Greenville quadrangle from: Devaul, R. W., and Maxwell, B. W., 1962, Availability of ground water in McLean and Muhlenberg Counties, Kentucky: U. S. Geol. Survey Hydrol. Inv. Atlas HA-29.

Livermore – Modified from: TVA, 1969, cited above.

Madisonville East – Kehn, T. M., 1963, Geology of the Madisonville East quadrangle, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-252.

Madisonville West – Kehn, T. M., 1964, Geology of the Madisonville West quadrangle, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-346.

Millport – Geology drawn to match adjacent quadrangles.

Morgantown – Modified from: Mullins, A. T., and others, 1963, cited above.

Nebo – Franklin, G. J., 1969, Geologic map of the Nebo quadrangle, Webster and Hopkins Counties, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-777.

Nortonville – Palmer, J. E., 1968, Geologic map of the Nortonville quadrangle, Hopkins and Christian Counties, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-762.

Olney – Trace, R. D., and Kehn, T. M., 1968, Geologic

[1] Additional geological quadrangle maps have been published since time of map compilation (1970); therefore, this is not a current listing of geological quadrangle maps.

map of the Olney quadrangle, Caldwell and Hopkins Counties, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-742.

Paradise – Modified from: Mullins, A. T., and others, 1963, cited above.

Pleasant Green Hill – Nelson, W. H., 1964, Geology of the Pleasant Green Hill quadrangle, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-321.

Pleasant Ridge – Goudarzi, G. H., and Smith, A. E., 1968, Geologic map of the Pleasant Ridge quadrangle, Ohio and Daviess Counties, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-766.

Princeton East – Modified to match Olney quadrangle from: Sutton, A. H., 1928, cited above.

Providence – Kehn, T. M., 1966, Geologic map of the Providence quadrangle, western Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-491.

Quality – Gildersleeve, Benjamin, 1968, Geologic map of the Quality quadrangle, Butler and Logan Counties, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-673.

Rochester – Modified to match Drakesboro quadrangle from: Mullins, A. T., and others, 1963, cited above.

Rosewood – Drillers' logs, field reconnaissance, and modified to match Drakesboro quadrangle from: Devaul, R. W., and Maxwell, B. W., 1962, cited above.

Rosine – Modified from: Mullins, A. T., and others, 1963, cited above.

Sacramento – Modified from: TVA, 1969, cited above.

Saint Charles – Palmer, J. E., 1967, Geologic map of the Saint Charles quadrangle, Hopkins and Christian Counties, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-674.

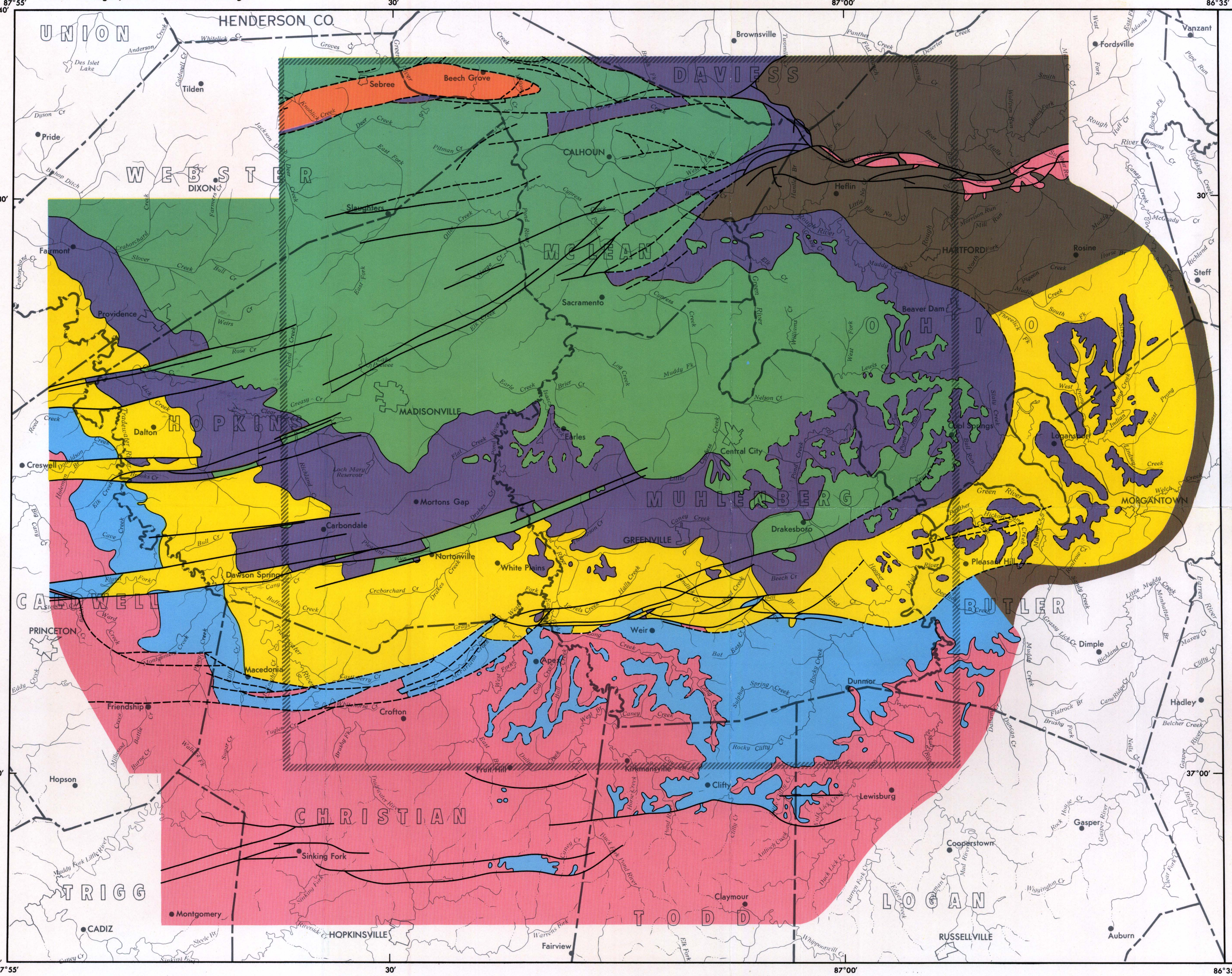
Sebree – Modified from: TVA, 1969, cited above.

Sharon Grove – Ulrich, G. E., 1966, Geologic map of the Sharon Grove quadrangle, Todd and Logan Counties, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-482.

Slaughters – Kehn, T. M., 1964, Geology of the Slaughters quadrangle, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-360.

South Hill – Modified from: Mullins, A. T., and others, 1963, cited above.

Utica – Johnson, W. D., Jr., and Smith, A. E., 1972, Geologic map of the Utica quadrangle, western Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-995.



EXPLANATION

PENNSYLVANIAN

- Henshaw and Lisman Formations, undifferentiated
- Carbondale Formation
- Tradewater Formation
- Tradewater and Caseyville Formations, undifferentiated (May include outliers of Carbondale Formation)
- Caseyville Formation (May include some Tradewater Formation in southeast part of map)

PENNSYLVANIAN AND MISSISSIPPIAN

- Pennsylvanian and Mississippian formations (Shown only in western part of Rough Creek fault zone; generally includes Caseyville through Carbondale Formations, and several outcrops of Mississippian rocks near Sebree)

MISSISSIPPIAN

- Mississippian rocks: Chesterian Series where overlain by or adjacent to Pennsylvanian rocks; not shown in eastern part of map

Contact
Dashed where inferred from structural maps of coal beds or other data in areas where geology has not been mapped on 7.5-minute quadrangles; dashed where inferred in Utica quadrangle

Fault
Dashed where data taken from structural maps of coal beds or from old county geologic maps

Outline of study area

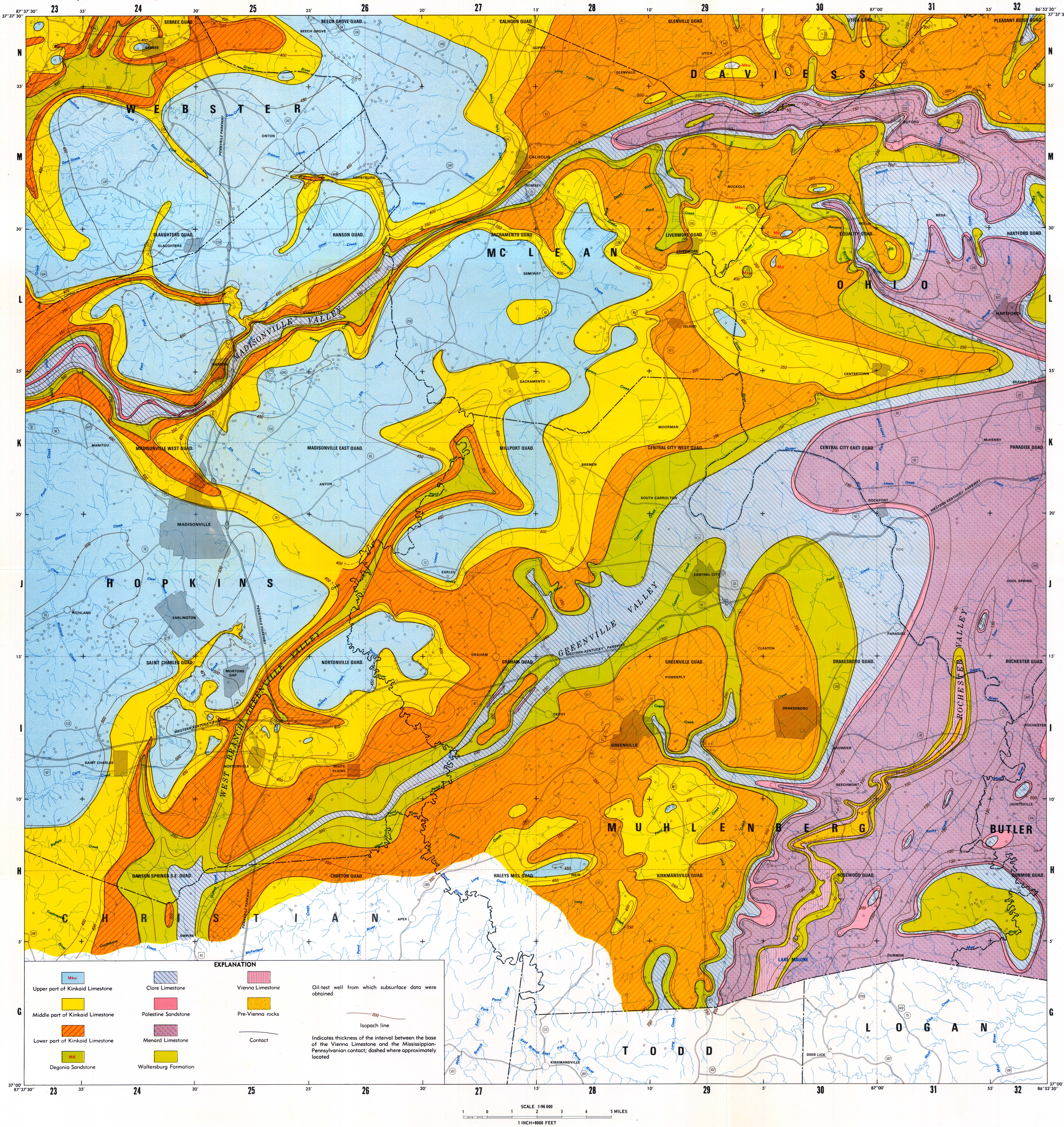
See appendix in text for sources used to compile map

Scale 1:250,000

5 0 5 10 15 20 Statute Miles

GENERALIZED GEOLOGIC MAP OF PART OF THE WESTERN COAL FIELD AND ADJACENT AREAS, KENTUCKY

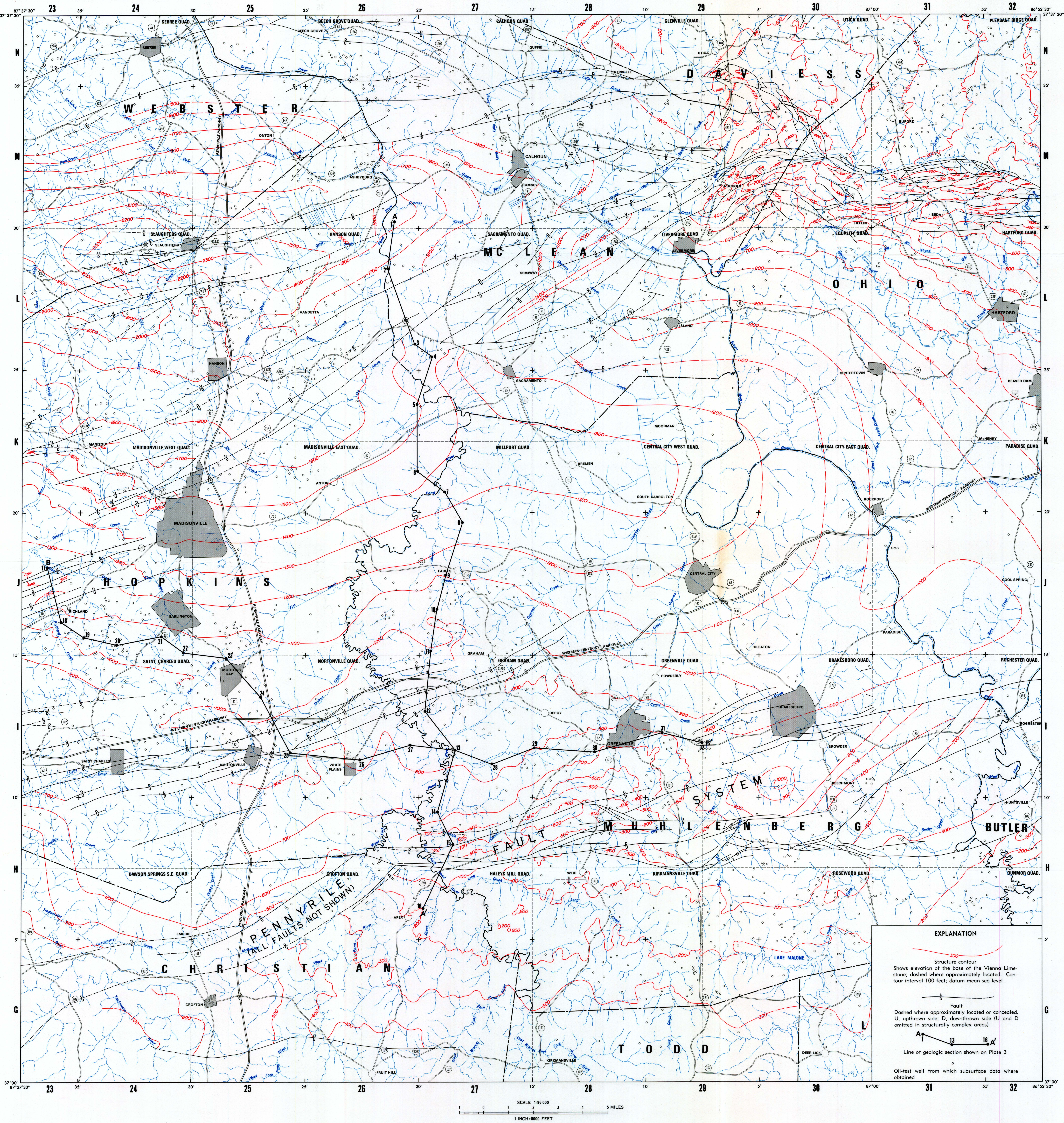
Cartography By Terry Hounshell



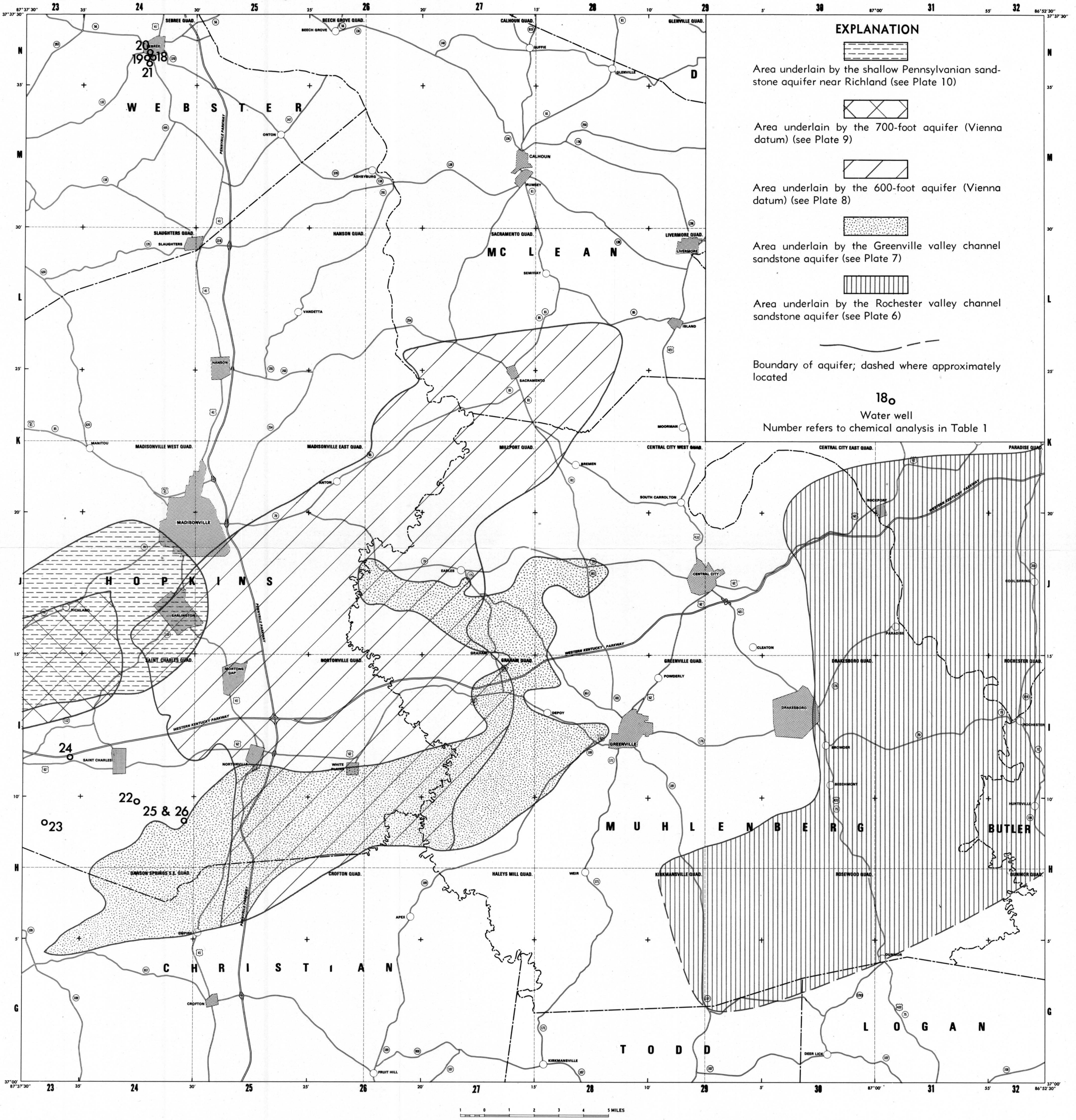
GEOLOGY AND RELIEF OF THE PRE-PENNSYLVANIAN SURFACE

Cartography By Terry Hounshell

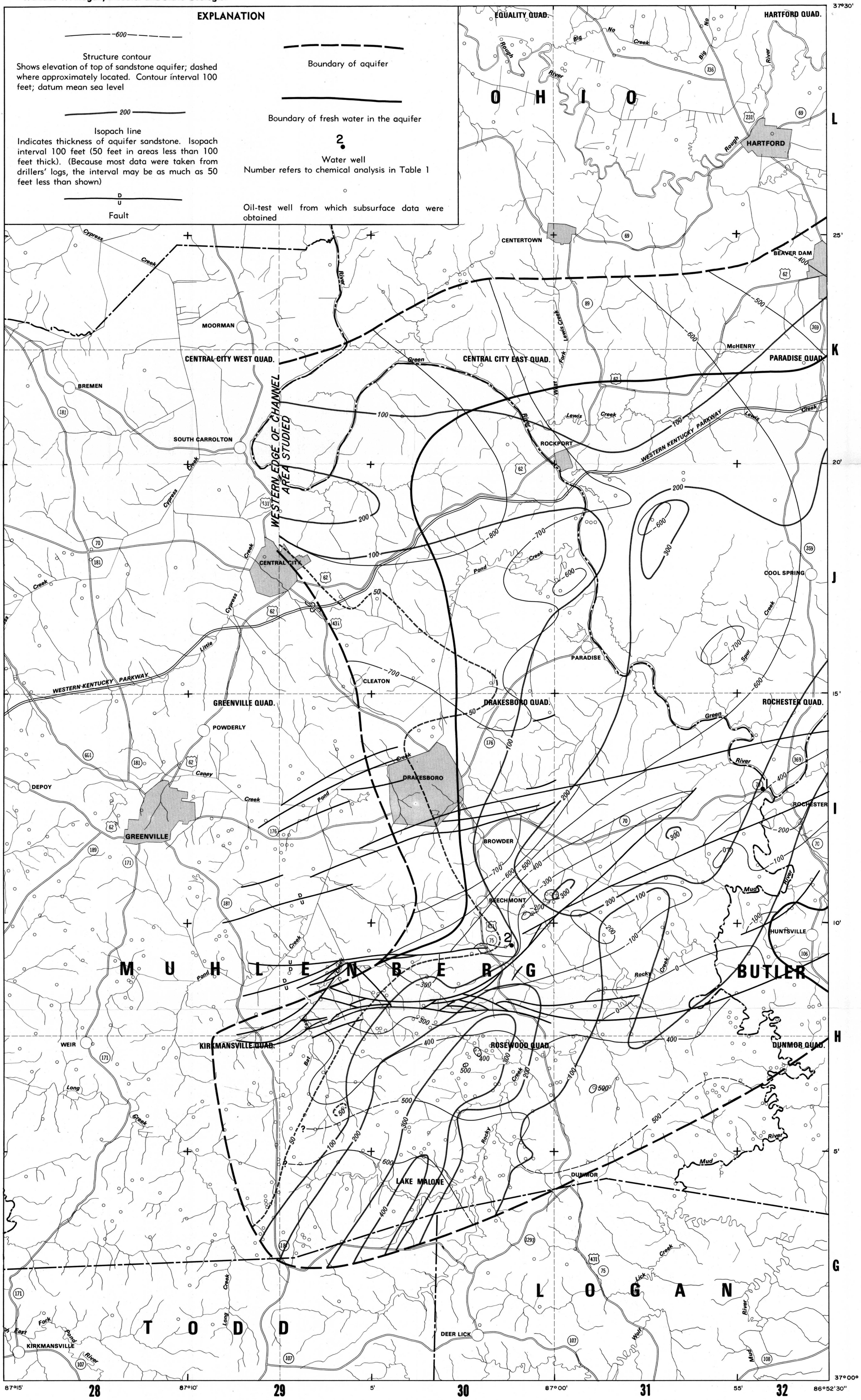
GEOLOGIC SECTIONS SHOWING THE PENNSYLVANIAN AQUIFERS



STRUCTURE MAP CONTOURED ON THE BASE OF THE VIENNA LIMESTONE



AREAS OF OCCURRENCE OF THE VARIOUS PENNSYLVANIAN AQUIFERS

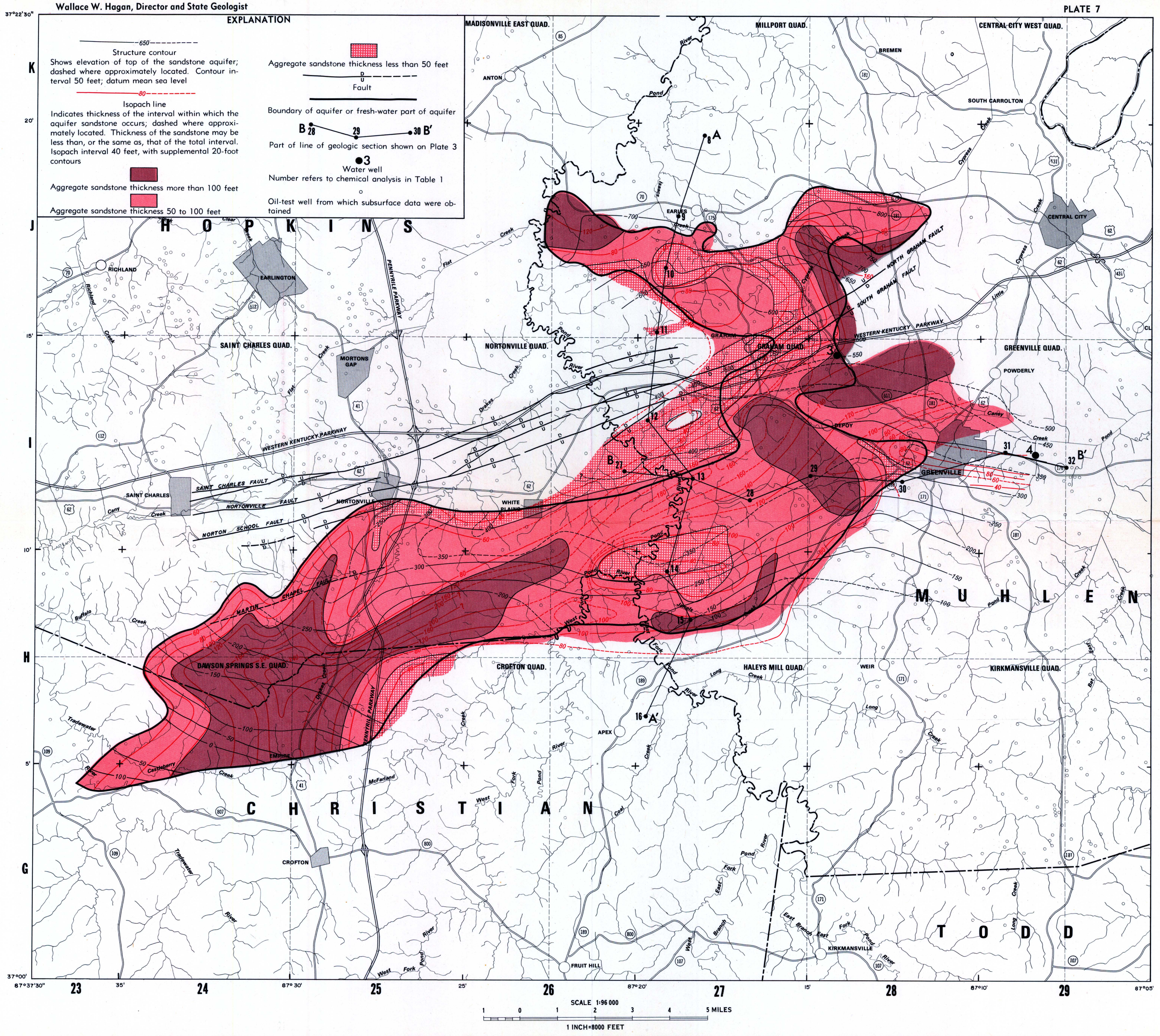


SCALE 1:96 000

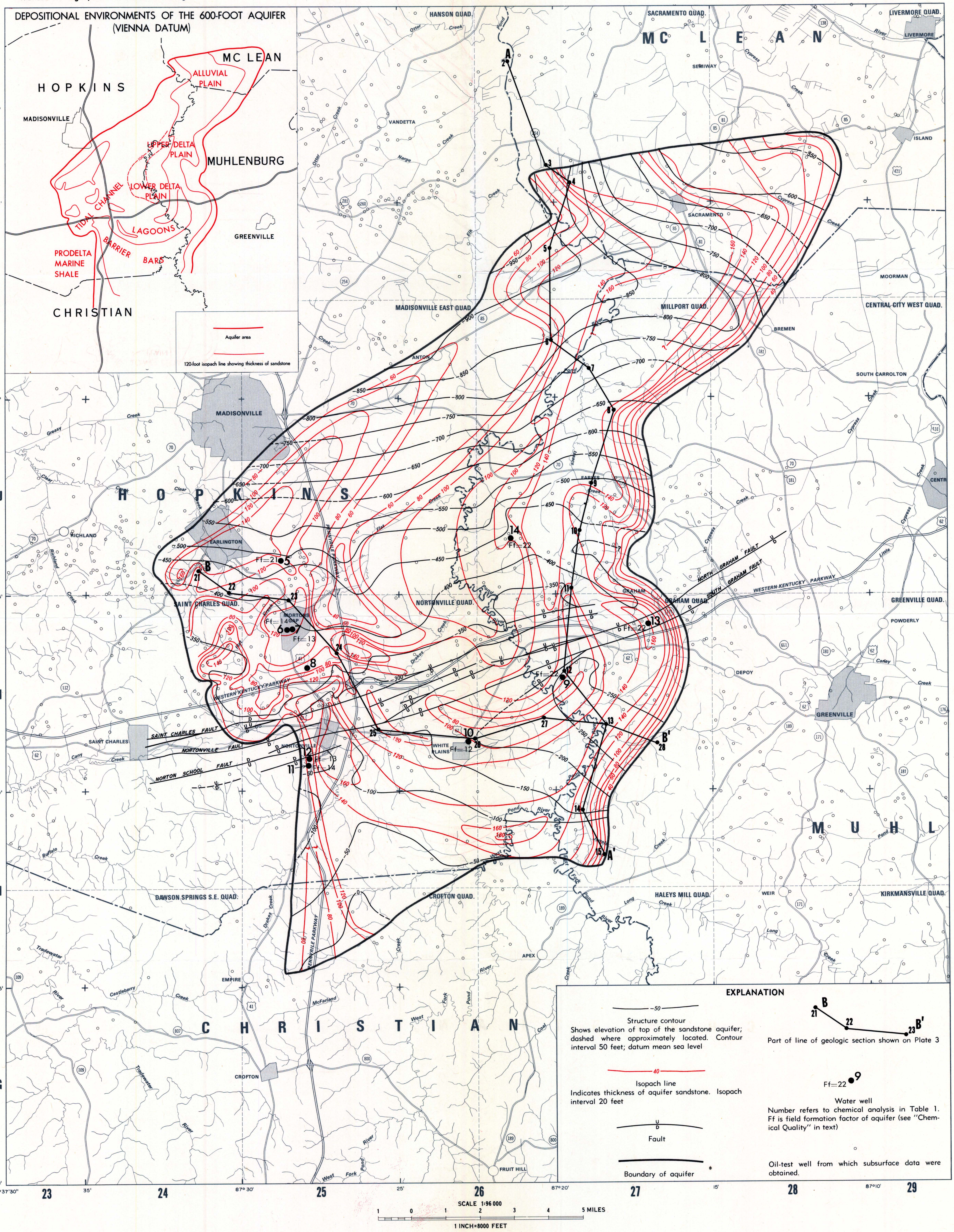
1 0 1 2 3 4 5 MILES

1 INCH = 8000 FEET

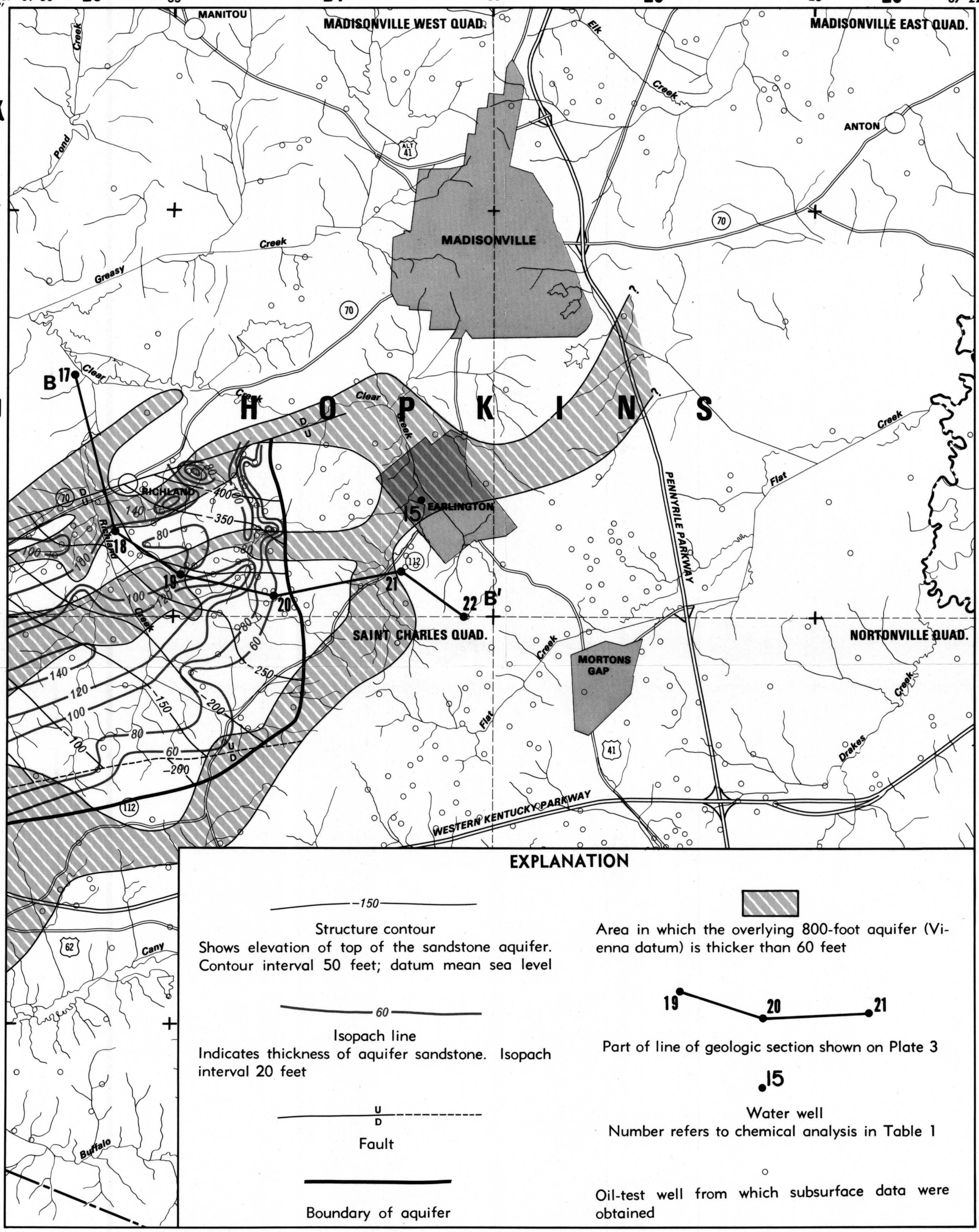
DISTRIBUTION, THICKNESS, AND STRUCTURE ON TOP OF THE ROCHESTER VALLEY CHANNEL SANDSTONE AQUIFER



DISTRIBUTION, THICKNESS, AND STRUCTURE ON TOP OF THE GREENVILLE VALLEY CHANNEL SANDSTONE AQUIFER



DISTRIBUTION, THICKNESS, AND STRUCTURE ON TOP OF THE 600-FOOT AQUIFER (VIENNA DATUM)

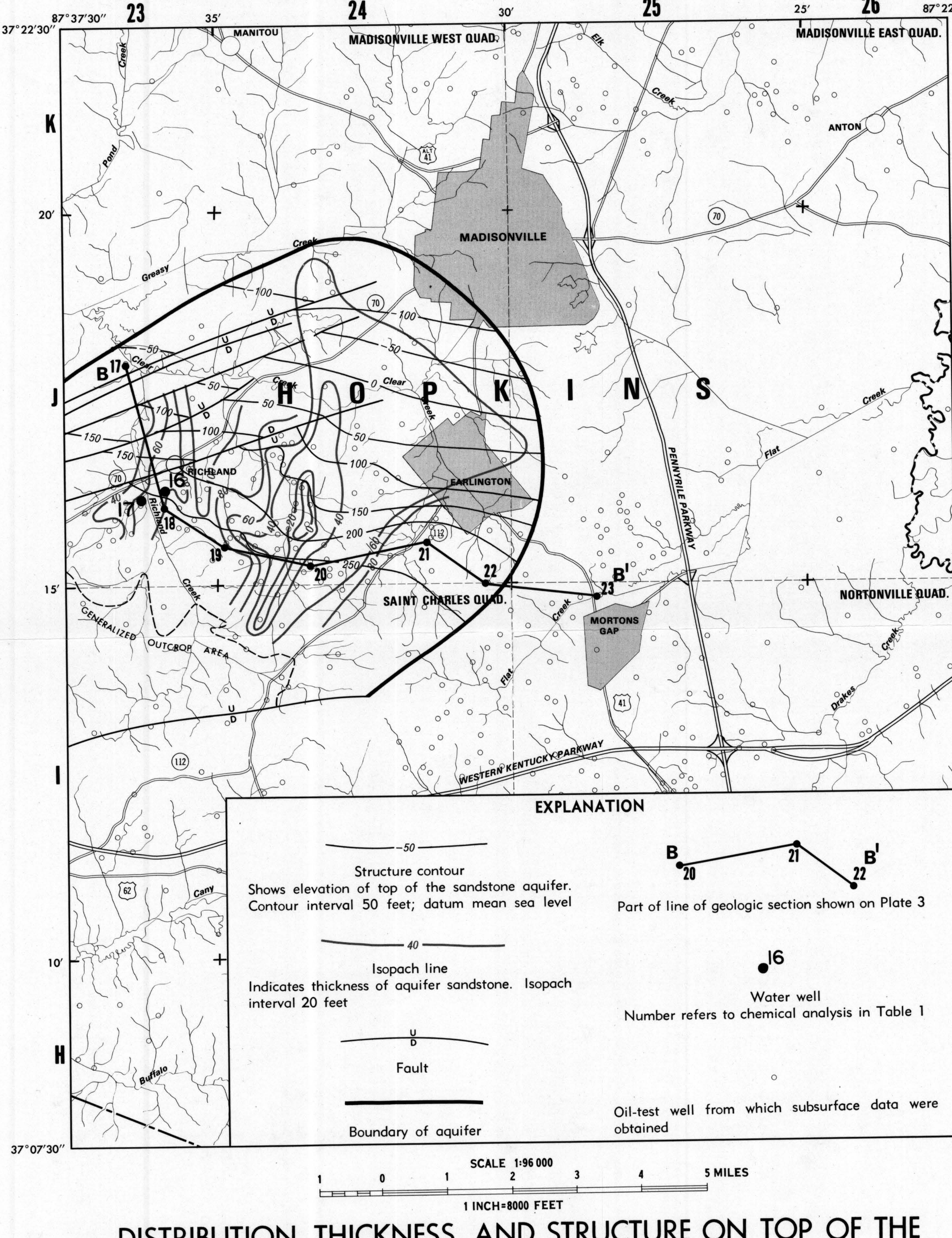


SCALE 1:96 000

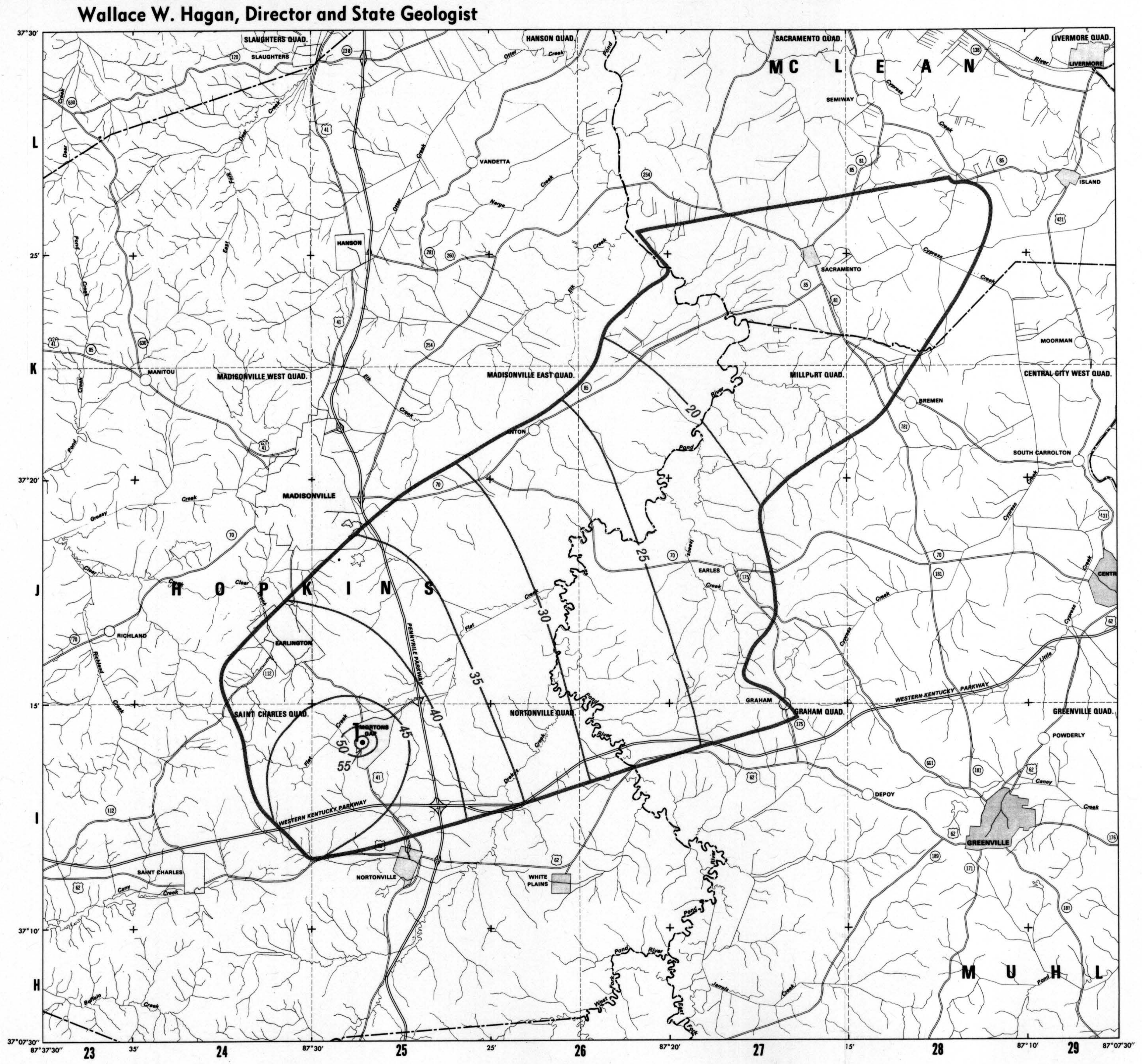
1 0 1 2 3 4 5 MILES

1 INCH=8000 FEET

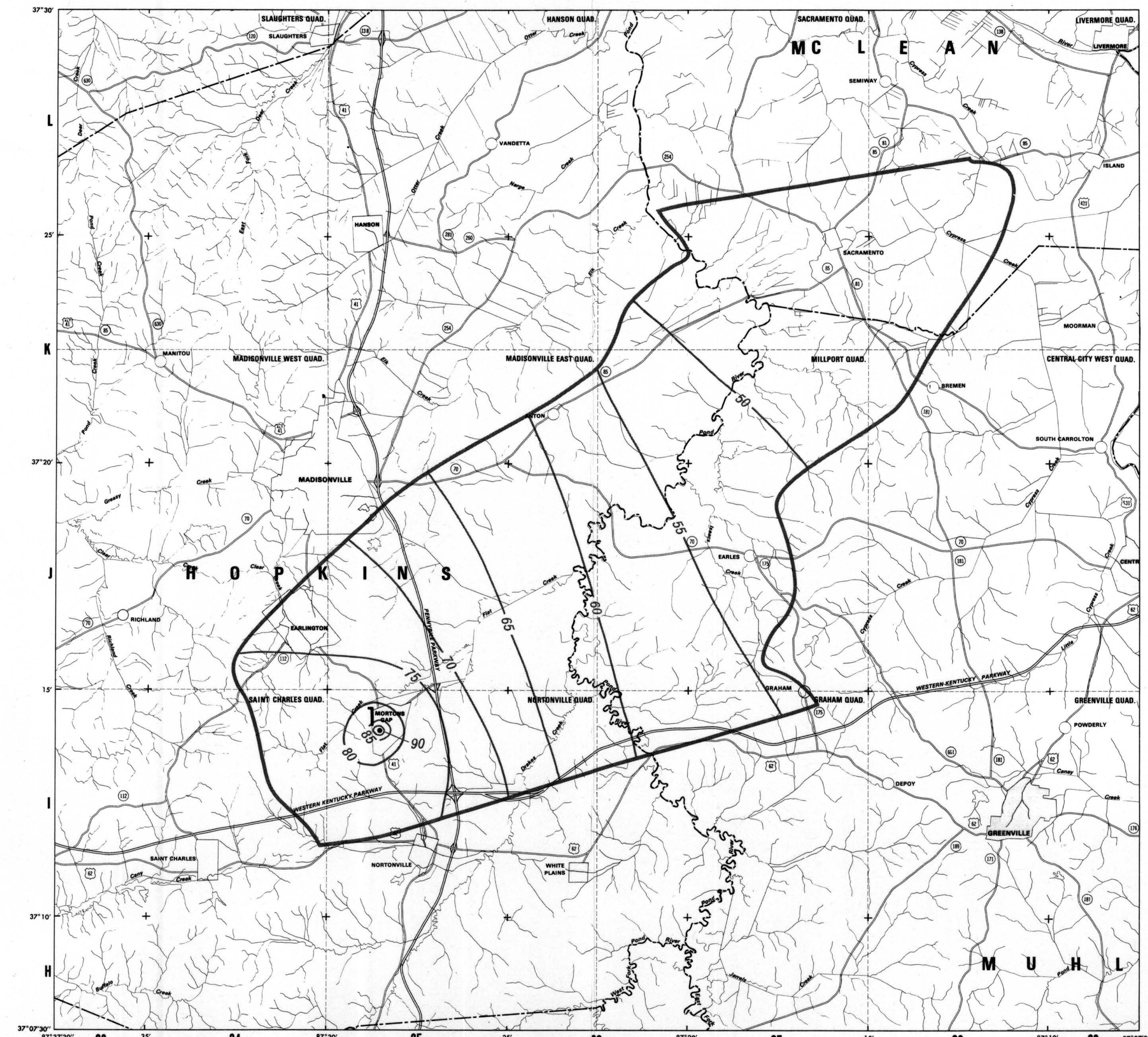
DISTRIBUTION, THICKNESS, AND STRUCTURE ON TOP OF THE 700- AND 800-FOOT AQUIFERS (VIENNA DATUM)



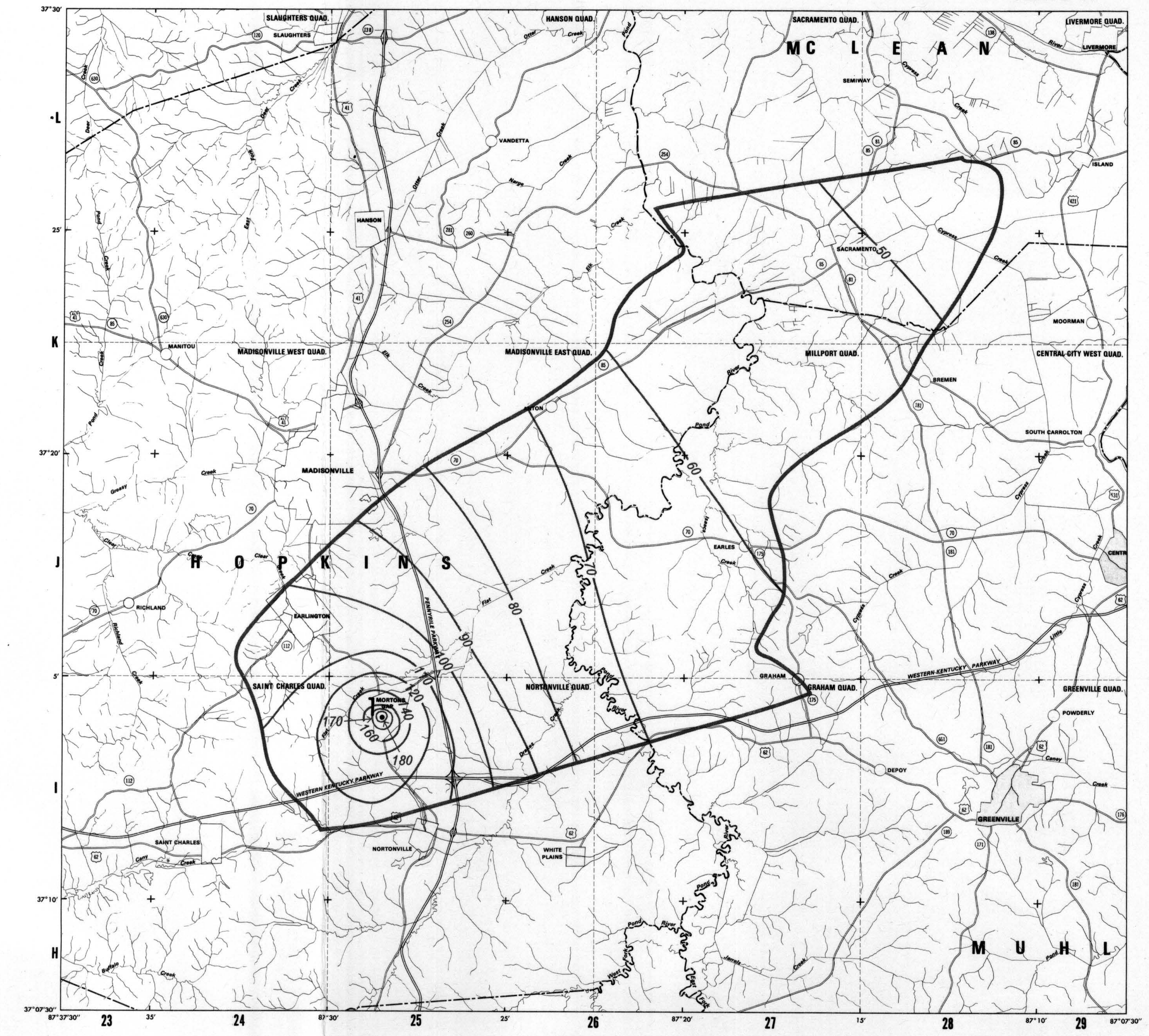
DISTRIBUTION, THICKNESS, AND STRUCTURE ON TOP OF THE SHALLOW PENNSYLVANIAN SANDSTONE AQUIFER NEAR RICHLAND



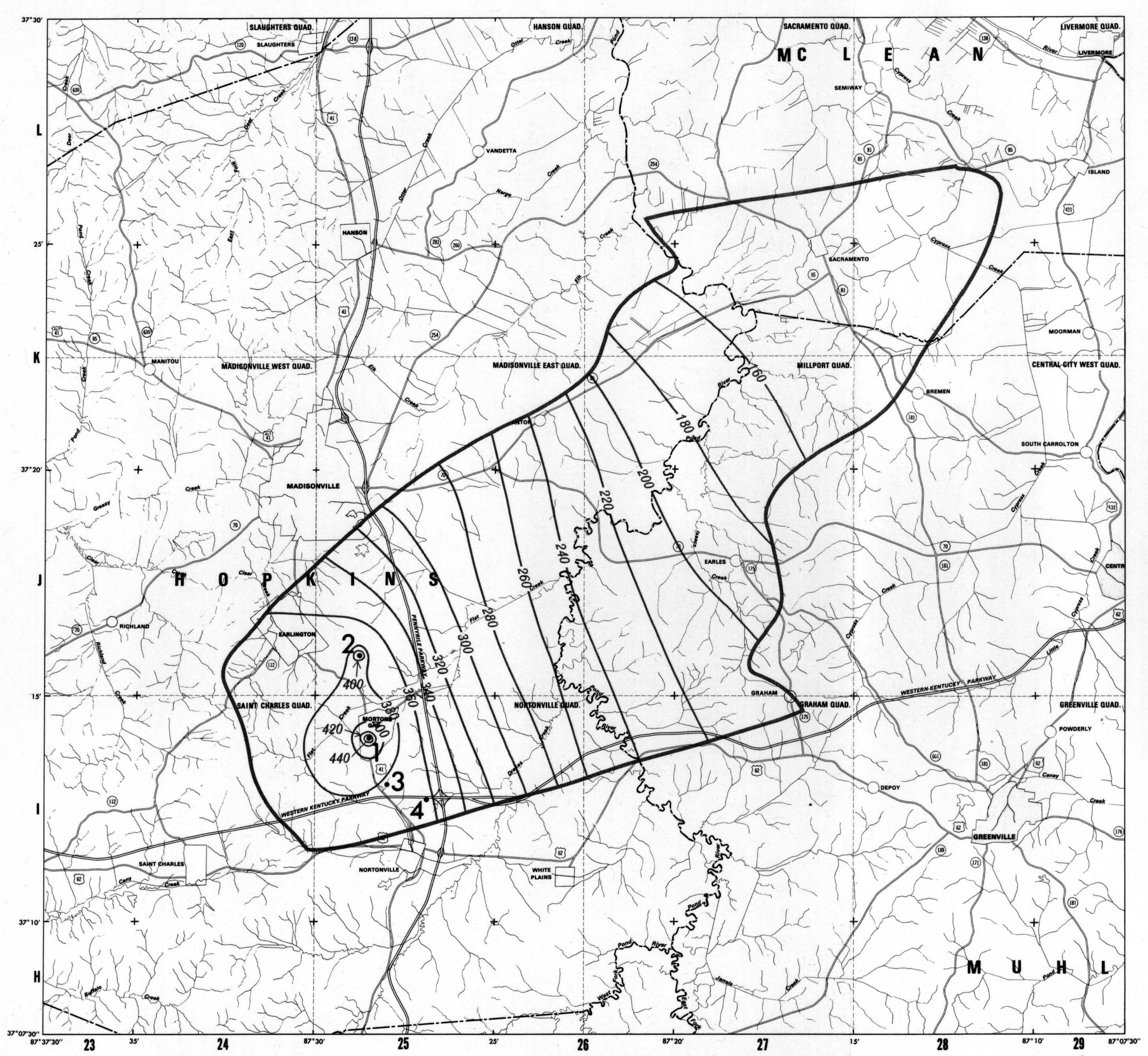
1959



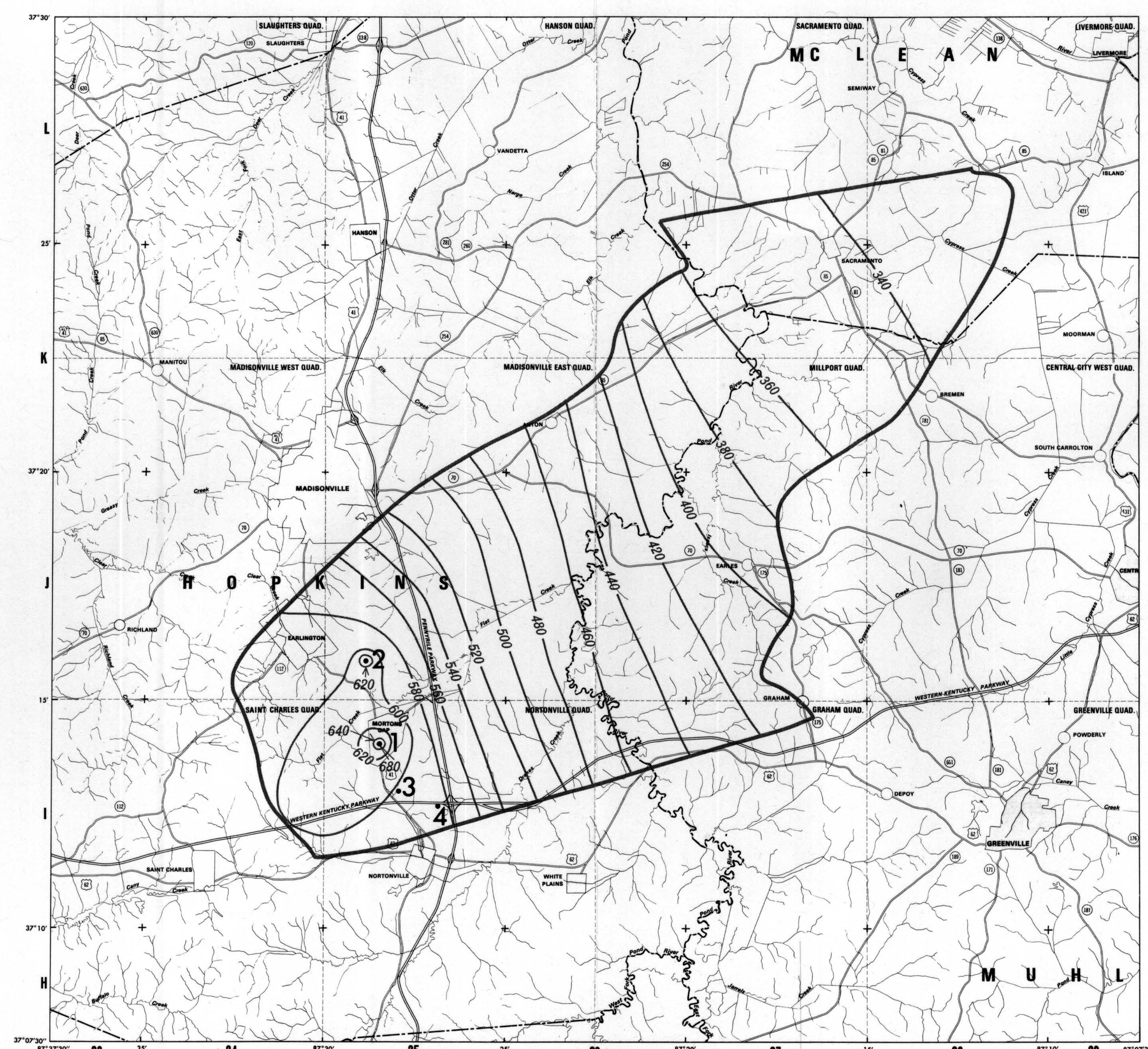
1965



1966



1970



1974

EXPLANATION

1959

—30— Contour

Shows decline of water level since 1954. Contour interval 5 feet

Assumed pumping rate:
Well at Mortons Gap pumping at an average daily rate of 12 gpm since 1954

Water well •1
1 City of Mortons Gap pump well

1965

—50— Contour

Shows decline of water level since 1954. Contour interval 5 feet

Assumed pumping rate:
Well at Mortons Gap pumping at an average daily rate of 12 gpm since 1954

Water well •1
1 City of Mortons Gap pump well

1966

—90— Contour

Shows decline of water level since 1954. Contour interval 10 feet

Assumed pumping rates:
Well at Mortons Gap pumping at an average daily rate of 12 gpm from 1954 to 1965 and 59 gpm from 1965 to 1966

Water well •1
1 City of Mortons Gap pump well

1970

—280— Contour

Shows decline of water level since 1954. Contour interval 20 feet

Assumed pumping rates:
Well at Mortons Gap pumping at an average daily rate of 12 gpm from 1954 to 1965 and 59 gpm from 1966 to 1970

Well at Barnsley oil field pumping at an average daily rate of 41 gpm from 1966 to 1970

Well at Oak Hill oil field pumping at an average daily rate of 9 gpm from 1966 to 1970

1• Water well

Key to well location numbers:
1 City of Mortons Gap pump well. Observation well nearby
2 Barnsley oil field pump well. Observation well nearby
3 South Hopkins County High School well
4 Oak Hill oil field pump well

1974

—460— Contour

Shows decline of water level since 1954. Contour interval 20 feet, except near pumped well at Mortons Gap

Assumed pumping rates:
Well at Mortons Gap pumping at an average daily rate of 12 gpm from 1954 to 1965, and 59 gpm from 1965 to 1974

Well at Barnsley oil field pumping at an average daily rate of 41 gpm from 1966 to 1974

Well at Oak Hill oil field pumping at an average daily rate of 9 gpm from 1966 to 1974

1• Water well

Key to well location numbers:
1 City of Mortons Gap pump well
2 Barnsley oil field pump well
3 South Hopkins County High School well
4 Oak Hill oil field pump well

1 0 1 2 3 4 5 MILES
SCALE

WATER-LEVEL DRAWDOWNS BASED ON DIGITAL COMPUTER SIMULATION OF THE NORTHERN PART OF THE 600-FOOT AQUIFER [VIENNA DATUM]