UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER RESOURCES OF THE BLACK HAND SANDSTONE MEMBER OF THE CUYAHOGA FORMATION AND ASSOCIATED AQUIFERS OF MISSISSIPPIAN AGE IN SOUTHEASTERN OHIO

by Stanley E. Norris and Gregory C. Mayer

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CONVERSION FACTORS

For those readers who may prefer to use metric (SI) units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

To convert from	To	Multiply by
inch (in)	millimeter (mm)	25.4
foot (ft)	meter (m)	0.3048
mile (mi)	kilometer (km)	1.609
mile (mi^2)	kilometer (km^2)	2.590
foot (ft^2)	meter (m^2)	0.02832
gallons (gal)	liters (L)	3.785

National Geodetic Vertical Datum of 1929 (NGVD OF 1929):

A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level." NGVD of 1929 refers to "Sea Level" in this report.

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ABSTRACT

The Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers of Mississippian age, including the Allensville Conglomerate, Member of the Logan Formation, were investigated in a 1,500-square-mile area, parts of five counties in southeastern Ohio. The aquifers crop out in western Vinton, western Hocking, and southwestern Fairfield Counties. They dip southeastward about 35 feet per mile, becoming progressively more deeply buried until at Lake Hope, in northeastern Vinton County, the aquifers are the deepest sources of potable ground water in Ohio, occurring at depths locally exceeding 700 feet.

These aquifers are the chief sources of water beneath the coal-bearing rocks of the Pennsylvanian System and are widely used for farm and home requirements. Specific capacities of wells are low, exceeding 1 gallon per minute per foot of drawdown only in scattered areas.

At McArthur, in Vinton County, the aquifers yield about 300,000 gallons per day for municipal and industrial use, but withdrawal has been accompanied by declining ground-water levels during the past 10 years in a 10-square-mile area. Transmissivity, determined from wells open to both the Black Hand Sandstone Member and Allensville Conglomerate Member at McArthur's west municipal well field, is about 135 square feet per day.

The ground water is predominately of the sodium bicarbonate or calcium bicarbonate type in the central part of the area and changes, as it moves downdip, to a sodium chloride bicarbonate type. Along the eastern boundaries of Hocking and Vinton Counties, the aquifers are below the common depth of wells and are presumed to be potable but contain water too salty for ordinary use. Locally, the aquifers are contaminated by brine from oil and gas wells.

INTRODUCTION

The purpose of this report is to describe the water resources of the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers in a southeastern Ohio area of about 1,500 square miles that includes most of Hocking and Vinton Counties and smaller parts of adjoining Fairfield, Perry, and Jackson Counties (fig. 1). These units constitute a relatively thin sequence of permeable coarse-grained sedimentary rocks within the upper and lower parts, respectively, of the generally shaly Cuyahoga and Logan Formations of Mississippian age. (See table 1.) In a region of increasingly active strip mining, these aquifers are the chief sources of ground water beneath the coal-bearing rocks of the Pennsylvanian System.

The investigation was funded by the U.S. Geological Survey as part of a program to identify and describe aquifers associated with the coal deposits. The report is intended to be useful to coal mine operators in applying for mining permits and to regulatory authorities in evaluating permit applications.

The report is based largely on drillers' logs of domestic water wells in the files of the Division of Water, Ohio Department of Natural Resources. Approximately 350 logs were field located, of which 160 were selected as a data base. The selected wells are listed in table 3, and the logs are presented graphically in figure 18. The approximate locations of the wells are shown in figure 17. More precise locations can be obtained from Ohio Division of Water files, by reference to the State log number given in table 3.

The authors are indebted to local drillers for well information, especially Kenneth Ellis, Lucius Kessler, Carl Loomis, Ralph Michel, Carl Peck, Lowell Reinschell, George Turner, and Steve Warthman.

Information on the quality of the ground water is based on 30 samples collected from wells and analysed by the U.S. Geological Survey. Robert Fawcett, of the U.S. Geological Survey, helped collect the water samples and prepared them in the field for shipment to the laboratory.

Thanks are given also to Jeffrey Risner, graduate student, Ohio University, Athens, Ohio, for information on wells at the village of McArthur and at the Austin Powder Company, which he collected as part of a thesis problem at the University. Joseph Klingshirn, graduate student, Iowa State University, helped to field locate wells and compiled well tables and maps while employed by the U.S. Geological Survey in the summer of 1980.

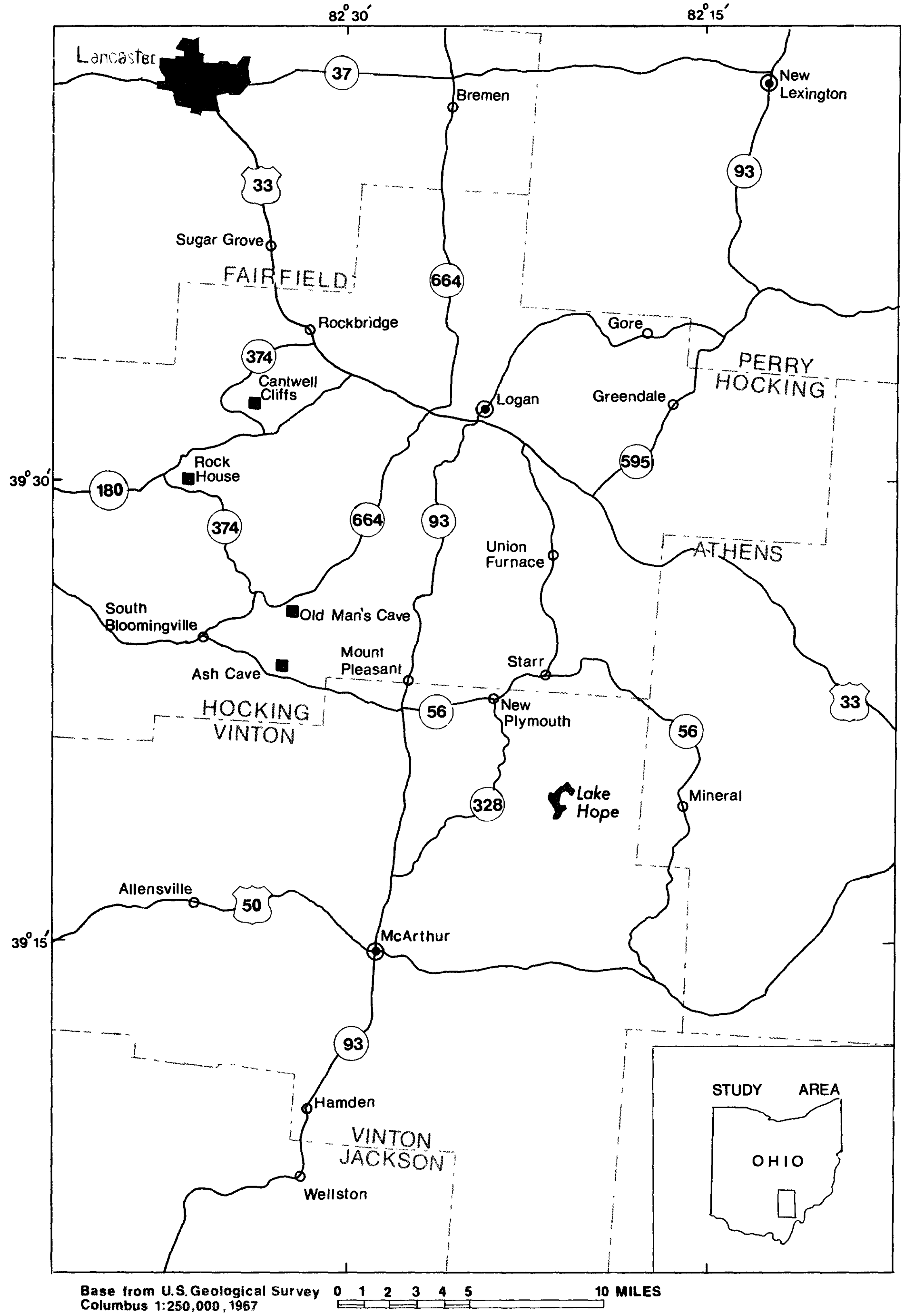


Figure 1. --Area of investigation in southeastern Ohio.

Table 1.--Stratigraphy and water-yielding properties of the Mississippian sequence of the Hocking Valley facies. (Modified from Hyde, 1953, table 1; Holden, 1942; and nomenclature in use by the Division of Geological Survey, Ohio Department of Natural Resources).

Formation	Member [1]	Thickness range, feet	Lithology	Water-yielding properties
Logan Formation	Vinton Sandstone Member	Varies due to erosion plane	Fine-grained sandstone or sandy shale	Not important as a source of water.
	Allensville Conglomerate Member	15-25	Coarse sandstone	Good source of water locally, as at McArthur, where it has been called the "McArthur aquifer." Generally, municipal and industrial wells that penetrate the Allensville Conglomerate Member also tap the Black Hand Sandstone Member and both units are considered parts of a single aquifer system.
	Byer Sandstone Member	20-80	Fine-grained shaly sandstone or sandy shale	Not important as a source of water.
	Berne Conglomerate Member	0-10	Conglomerate or coarse sandstone	Typically 2 feet or less in thickness; not distinguishable from Black Hand Sandstone in well logs.
Cuyahoga Formation	Black Hand Sandstone Member	100-150	Massive, coarse-grained sandstone; locally conglomeratic.	Principal aquifer of this report; yields abundant water for farm and domestic use; source of municipal and industrial supply at McArthur.
	Fairfield Member Lithopolis Member (Fairfield and Lithopolis Members are called the "Cuyahoga Shales" in some reports)	200-330 118-330	Fairfield and Lithopolis Members occur in northern and central parts of area of investigation and consist of shales interbedded with fine-grained sandstones. Some sandstone units in Fairfield Member are up to 60 feet thick. In southern part of area strata consist chiefly of shale with minor beds of sandstone	Generally reported as shales by well drillers; locally, the sandstone beds are sources of water to farm and domestic wells, chiefly in the northwestern part of area of investigation.
Sunbury Shale				Not an aquifer.
Berea Sandstone				Yields brine; source of oil and gas in places.
Bedford Shale				Not an aquifer.

1. The member names are local usage and follow the usage of the Ohio Geological Survey.

Geographic and Economic Setting

The study area is part of the unglaciated Appalachian Plateau, the principal physiographic feature of eastern Ohio. The topography consists of prominent hills and ridges separated by narrow valleys. The region slopes very slightly from west to east. Hilltops in the western part of the area attain altitudes of 1,250 feet, in southern Fairfield County, and more than 1,100 feet in western Hocking and western Vinton Counties. Hilltops in the eastern part of the area, in eastern Hocking and eastern Vinton Counties, are commonly 1,000 feet or less in altitude. Local relief, between the valleys and nearby hills, commonly ranges from 300 to 400 feet and is characterized by short, steep tributary valleys.

The principal stream is the Hocking River, which drains most of Fairfield, Perry, and Hocking Counties, and whose southeastward course past Lancaster and Logan, through Athens County to the Ohio River, is closely paralleled by State Route 33 (fig. 1). Western Hocking and western Vinton Counties are drained by southwestward-flowing tributaries to the Scioto River, and eastern Vinton County is drained by southeastward-flowing Raccoon Creek and its tributaries. All streams are tributary to the Ohio River.

The climate is characterized by an annual average temperature of 53^{o}F (12^{o}C) and nearly 40 inches of precipitation. About 60 percent of the rain falls during the growing season, from March through August, mainly from convection storms of high intensity and short duration. Precipitation during the remainder of the year is usually related to cyclonic storms and frontal systems and is typically of low intensity and long duration. About 70 percent of the annual runoff occurs during the nongrowing season. Annual precipitation at Athens and its distribution throughout the year are given as follows:

Mean monthly precipitation, in inches, 1941-1970 (National Oceanic and Atmospheric Administration, U.S. Department of Commerce: Annual Summaries, Ohio)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
3.15	2.70	4.07	3.68	4.07	3.56	4.70	3.09
Sept	Oct	Nov	Dec	----------	----------	----------	TOTAL
2.92	2.02	2.82	2.77	----------	----------	----------	39.56

Soils derived from sandstone and shale are thin and cause serious erosion problems, forcing local land abandonment. Agriculture is generally confined to valley bottoms and the gentler slopes, and most farms are small and poorly productive. Many rural residents work in nearby towns and only farm part time. Forest products are commercially important in many parts of the area.

The U.S. Government owns much land, though not necessarily its accompanying mineral rights, in southern Perry and eastern Hocking Counties in the Wayne National Forest. In addition, state forests are extensive in eastern Hocking County and parts of Vinton and Jackson Counties.

Coal mining is an important industry in southeast Ohio, but, within the study area, much of the readily available coal has been removed. Nevertheless, in 1978, 2.4 million tons was mined in Vinton County, nearly three-fourths of which was by stripping. In Hocking County, in the same year, 0.8 million tons was mined, all by strip mining.

Oil and gas drilling has been going on in southeastern Ohio for more than a century. Gas fields have been developed in eastern Fairfield, western Hocking, and central Vinton Counties, and an extensive underground gas storage area has been developed in eastern Hocking County. The gas is obtained from sandstone of the Silurian Clinton Formation equivalent at depths ranging from 2,100 to 2,550 feet. Farther east, in southern Perry and eastern Hocking Counties, small oil pools have also been discovered in the Clinton Formation equivalent at depths ranging from 2,650 to 3,000 feet. In southeastern Hocking County, a small oil pool has been developed in the Berea Sandstone at a depth of 1,100 feet.

Drilling is not currently active. In 1979, 63 wells were drilled in Hocking and Vinton Counties, most of them for gas. They produced about 3,000 million cubic feet of gas and about 1,000 barrels of oil.

Water supplies are generally meager, and problems of drinking water quality are widespread. A report by the Appalachian Regional Commission (Water Supply Improvement Project 1970-72: Final Report, Appalachian Regional Commission, Ohio Department of Health, Columbus, Ohio) states that of 11,000 water supplies in southeast Ohio, sampled during 1970-72, 48 percent were unsafe for human consumption because of boliform bacteria. Unsafe water was found in only 25 percent of the drilled wells, but the water from 60 to 80 percent of cisterns, dug wells, and springs was unsafe.

AQUIFER FRAMEWORK

Mississippian rocks crop out in Ohio in a band 20 to 60 miles wide that, beginning at the Ohio River near Portsmouth, extends northward past Columbus and Newark to Lake Erie and thence northeastward along the Lake shore, through Cleveland to the Pennsylvania line. Because of the southeastward regional dip of 30 to 50 feet per mile, Mississippian rocks in eastern Ohio occur beneath an increasingly thick cover of coal-bearing rocks of the Pennsylvanian System.

Mississippian rocks vary significantly in thickness, texture, and water-yielding properties from place to place. To aid in their classification, the Mississippian sedimentary rocks have been subdivided into lithologic units, or facies, corresponding to depositional areas, or provinces. In each province, the sedimentary rocks are generally uniform in texture and composition. Generally, the facies alternate between fine-and coarse-grained sedimentary rocks. However, their boundaries are gradational and not agreed upon by all investigators. Hyde (1915, 1921) recognized five facies of the Cuyahoga Formation. Holden (1942), expanding on Hyde's classification, dropped two and added four names, thus dividing the Cuyahoga Formation into seven facies. (For general overviews of the work of Hyde and Holden see Wolfe and others, 1962, and Collins, 1979.)

The Black Hand Sandstone Member of the Cuyahoga Formation occurs in three of Hyde's and Holden's depositional provinces, the Hocking Valley, Toboso, and River Styx. The distribution of the principal masses of the Black Hand Sandstone Member, based largely on work by Ver Steeg (1947) and Root and others (1961), is shown in figure 2.

Table 1 presents a generalized stratigraphic sequence of Mississippian rocks in the area of investigation, essentially that of the Hocking Valley province, and describes their lithologic and water-yielding properties.

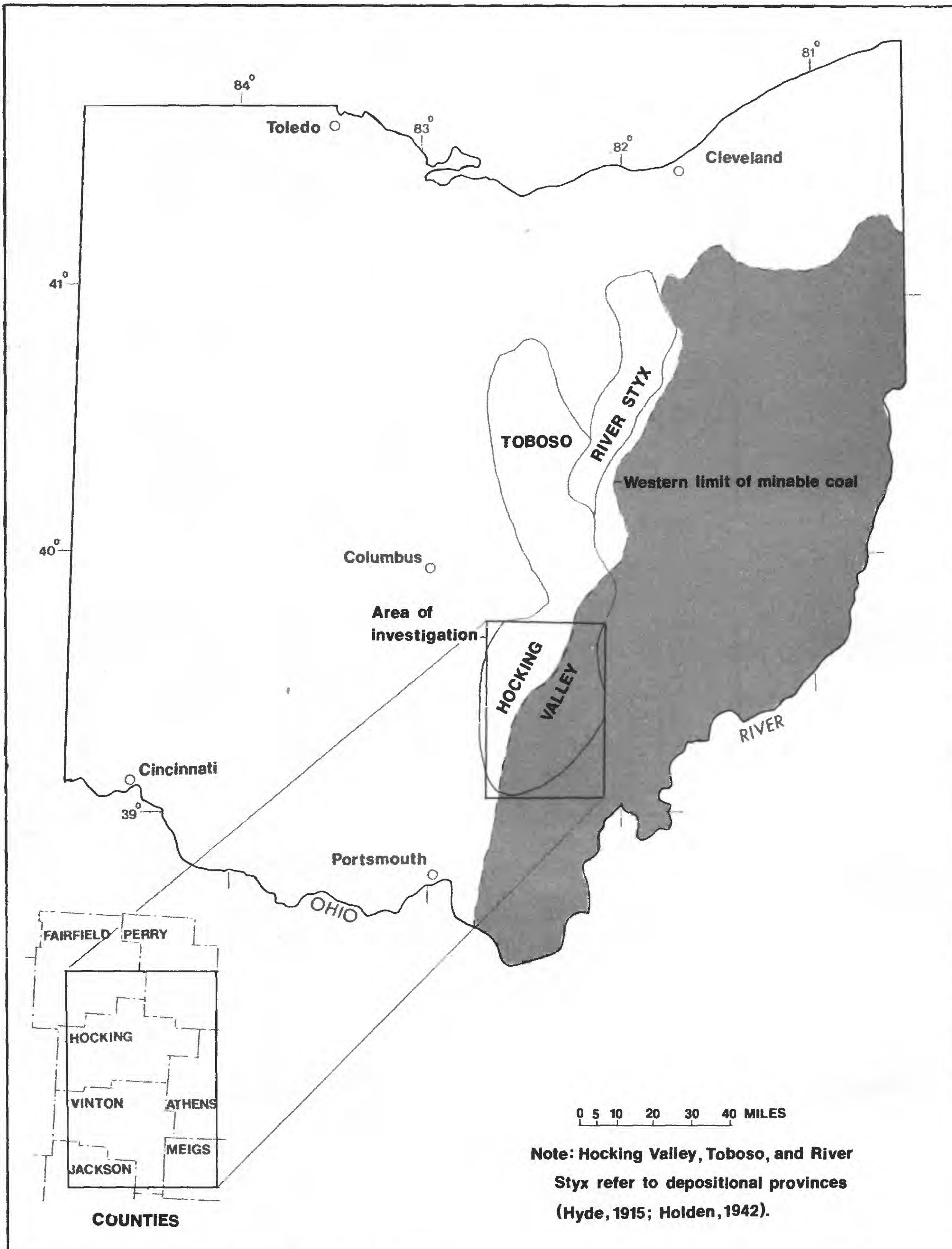


Figure 2. --Distribution of principal masses of Black Hand Sandstone Member in Ohio (after Ver Steeg, 1947, fig.3; Root and others, 1961).

Black Hand Sandstone Member of the Cuyahoga Formation

The Black Hand Sandstone Member crops out or lies beneath a relatively thin cover of younger sedimentary rocks, in a north-south-trending, wedge-shaped area that extends southward from southern Fairfield County, at the widest part, through western Hocking and western Vinton Counties, terminating in northwestern Jackson County (Hyde, 1953, fig. 1). Figure 3 shows the area in which the Black Hand Sandstone Member is commonly exposed and also where it is a principal aquifer.

The Black Hand Sandstone Member was deposited in shallow, near-shore marine waters, either as beaches, bars, or spits, according to Ver Steeg (1947), or as deltaic deposits, according to Holden (1941). The deposits are cross bedded, and the cross beds dip northward, indicating a current flow from the south. From exposures, Hyde (1915) described the Black Hand Sandstone Member as a "coarse pebbly sandstone with occasional beds of conglomerate." Hyde (1953, p. 79) also stated: "As a conglomerate it is usually about 100 or 125 feet or even perhaps 150 feet thick; as the bed becomes finer grained in character this may decrease to 60 feet or even less."

The Black Hand Sandstone Member in western Hocking County forms some of Ohio's most popular scenic features, including the Rock House, Cantwell Cliffs, Ash Cave, and Old Man's Cave (fig. 1). Carman (1946,p. 264) states: "The most important unit in the development of scenic features is the Black Hand Sandstone, a thick-bedded, massive, resistant, pebbly sandstone 100 to 150 feet thick. It forms the walls of the gorges, causes most of the waterfalls, and in it the valley-side caves are developed. The upper 15 to 20 feet of the sandstone is horizontally-bedded and quite firmly cemented. This results in more rapid disintegration of the middle part of the Black Hand and the development of a somewhat projecting upper part of the cliff."

Figure 4 is a contour map of the upper surface of the Black Hand based on the altitude of exposures and of the top of the unit as reported in well logs. The upper surface descends from 1,200 feet above sea level in southern Fairfield and western Hocking Counties to 300 feet in eastern Hocking and eastern Vinton Counties, over a distance of about 25 miles. The regional dip is southeast at approximately 35 feet per mile.

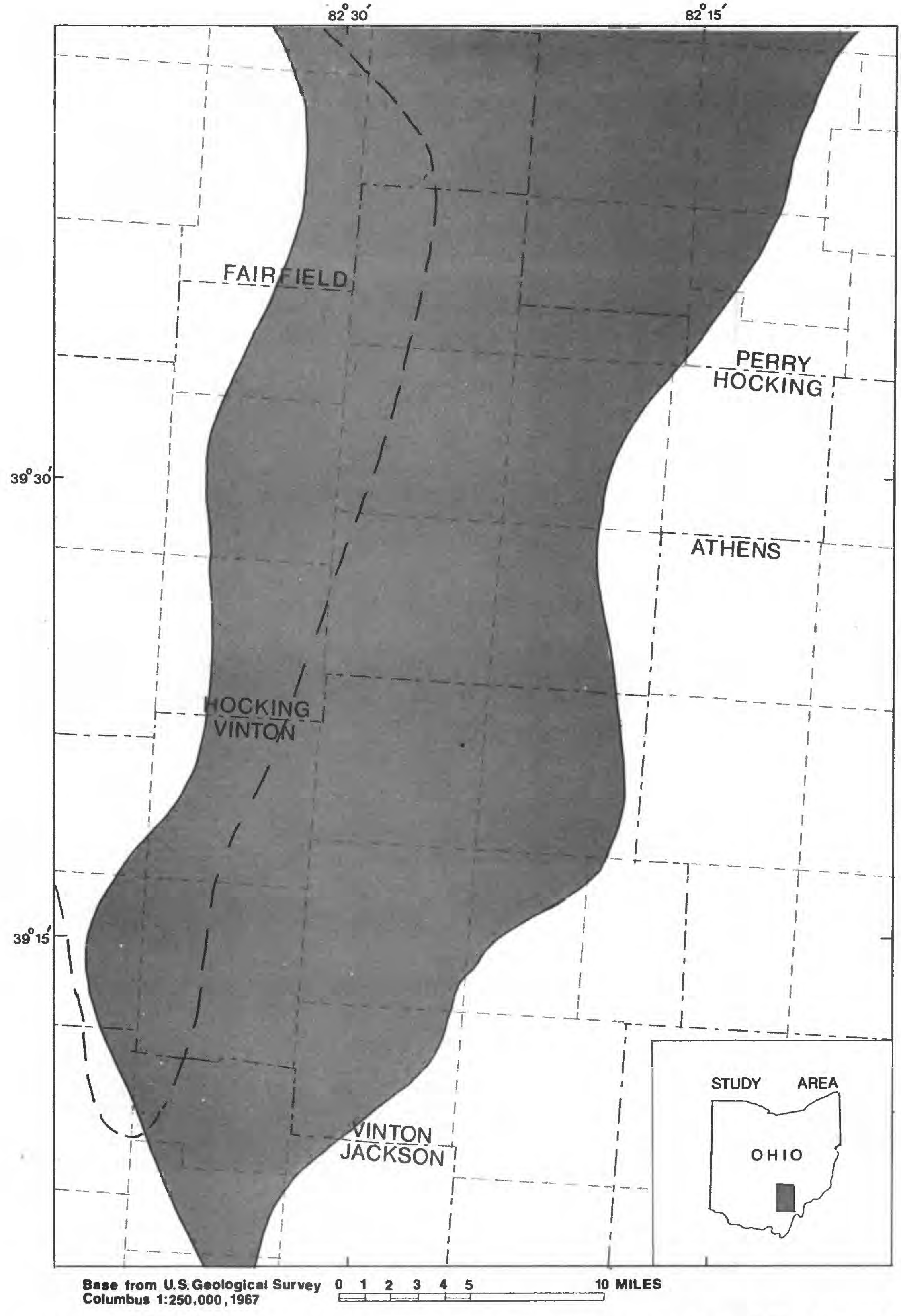


Figure 3. --Area in which the Black Hand Sandstone Member of the Cuyahoga Formation is commonly exposed at the surface (enclosed by dashed line), and area in which it is a principal aquifer (shaded).

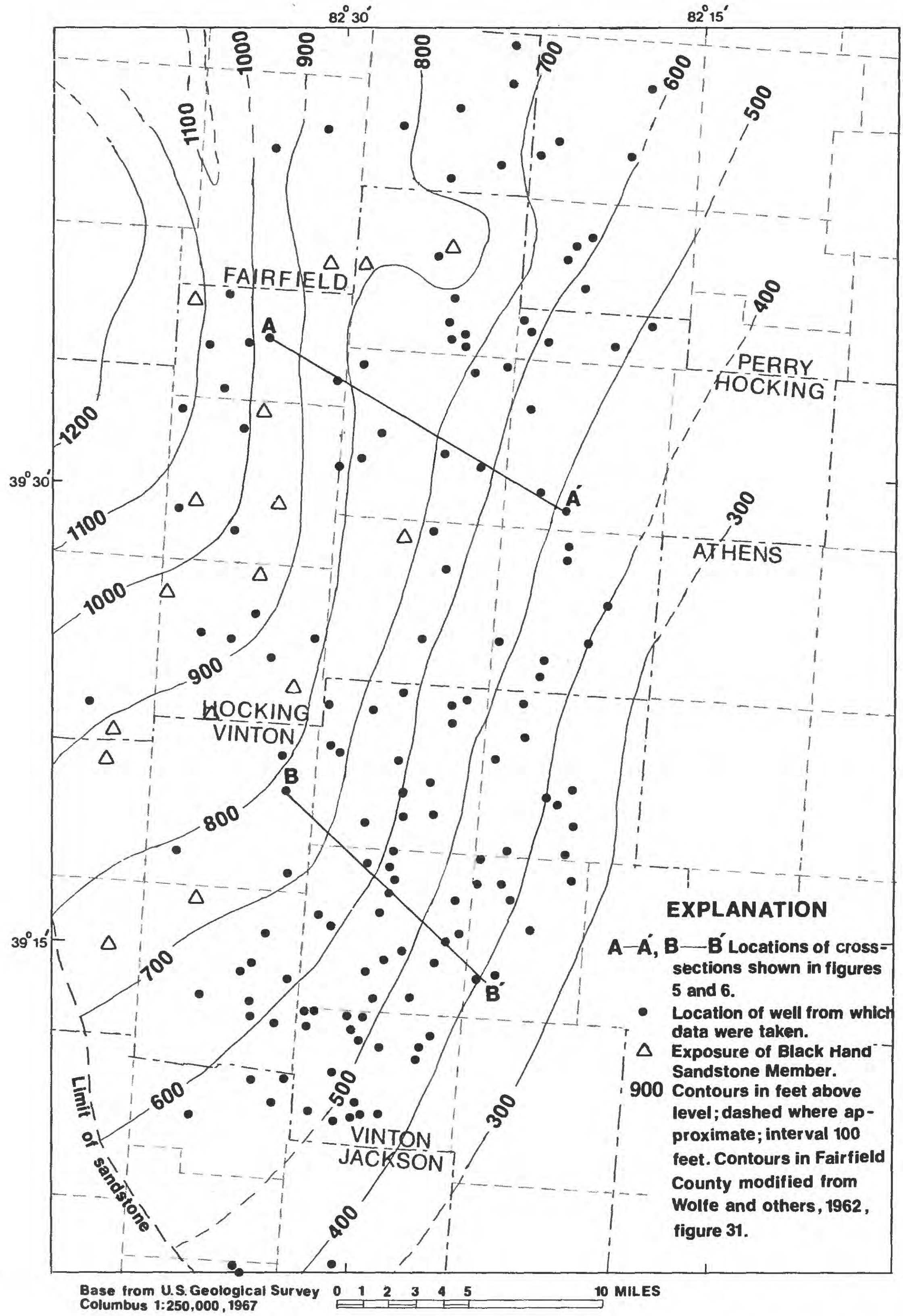


Figure 4. --Contours on Black Hand Sandstone Member of the Cuyahoga Formation.

The Black Hand Sandstone Member is an important aquifer in the eastern part of its outcrop area and 10 to 20 miles east of its outcrop area, where it occurs at progressively greater depths beneath the coal-bearing rocks (fig. 3). At Lake Hope, in northeastern Vinton County, where it is tapped to provide water to the State-owned lodge and camping facilities, the Black Hand is the deepest source of potable ground water in Ohio, occurring at depths exceeding 700 feet in places. The Black Hand yields water of good to acceptable quality in and near its outcrop area, but the water becomes increasingly mineralized downdip, where wells become progressively deeper. East of an irregular, north-south line in eastern Hocking and eastern Vinton Counties, the water becomes too mineralized for ordinary use. Eastward of this line, the aquifer is known primarily from records of oil and gas wells, in which the water it contains is reported as brine.

The Black Hand Sandstone Member differs from place to place in its water-yielding properties, largely reflecting changes in lithology and thickness. Generally, water occurs in the top of the aquifer or, where the top part is relatively hard and dense, a few feet below the top. Although the aquifer is generally permeable, in places it yields little water. For example, drillers report that south of Union Furnace, in southeastern Hocking County, they get no water from the Black Hand except near the base, where the water is too salty for ordinary use.

Aquifers above the Black Hand Sandstone Member of the Cuyahoga Formation

Where the Black Hand Sandstone Member is relatively deeply buried, as in the central and eastern parts of Hocking and Vinton Counties, not all wells reach it but, instead, tap overlying aquifers. For example, in northern Vinton and southern Hocking Counties, in an area about the size of a township, many wells are completed in what the drillers term the "white sandstone", 20 to 35 feet thick, the top of which occurs 100 or more feet above the Black Hand. This stratigraphically higher sandstone, at the base of the Pennsylvanian System, may represent the Massillon Sandstone Member of the Pottsville Formation or its equivalent.

In central Vinton County, the Allensville Conglomerate Member of the Logan Formation, called the "McArthur aquifer" by some drillers, is an important source of water (Stout, 1943, p. 625). At McArthur, the Allensville occurs 15 to 20 feet above the Black Hand, the two units being separated by shale. The town wells and some industrial wells are open to both sandstones, which function essentially as a single aquifer system. Figures 5 and 6, respectively, are diagrammatic sections showing the relationship of the Black Hand to the Allensville in Hocking and Vinton Counties. The locations of the sections are shown in figure 4, lines A-A' and B-B'.

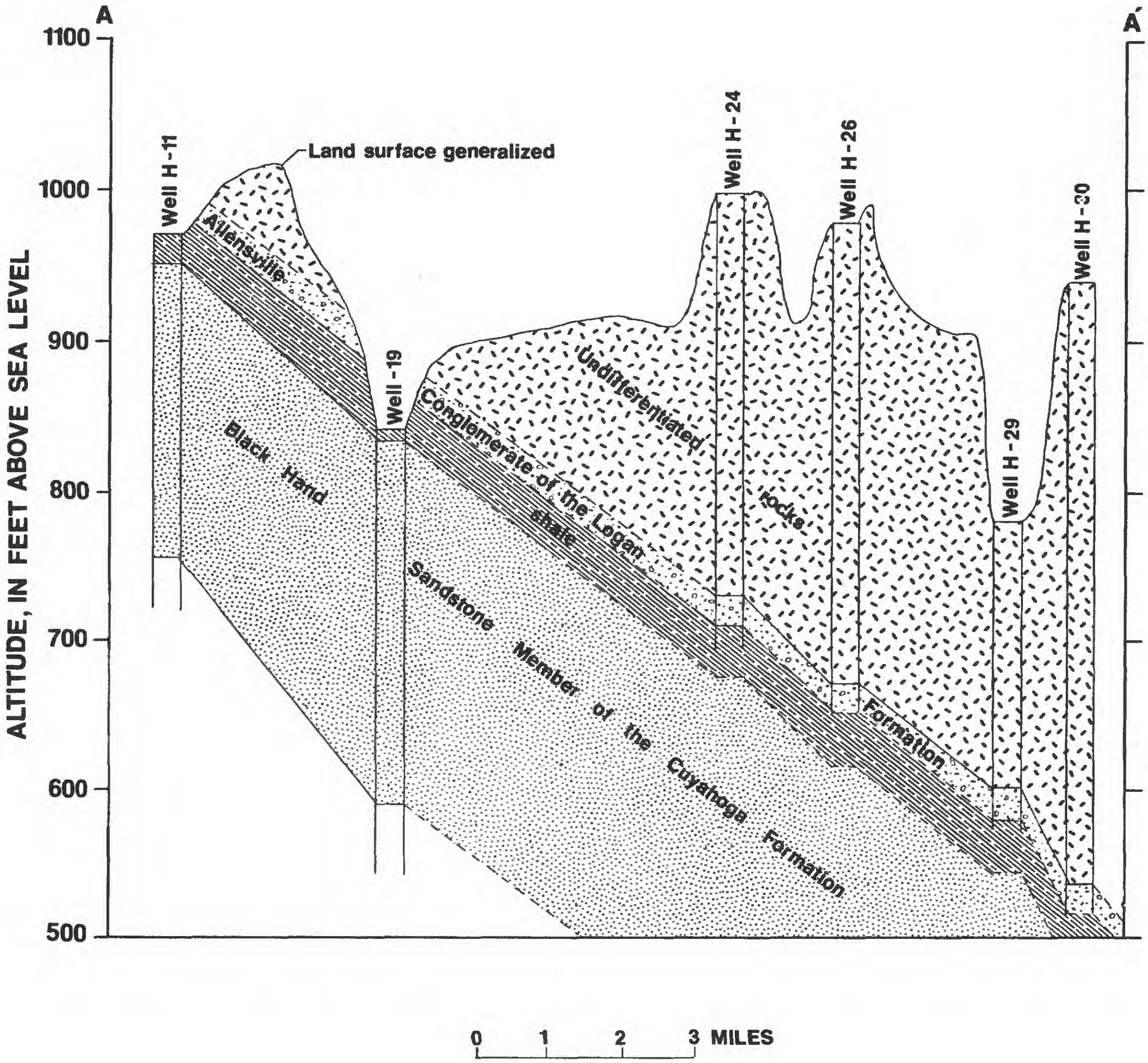


Figure 5. --Diagrammatic section in Hocking County, along line A-A', (figure 4), showing relation between Black Hand Sandstone Member of the Cuyahoga Formation and Allensville Conglomerate Member of the Logan Formation.

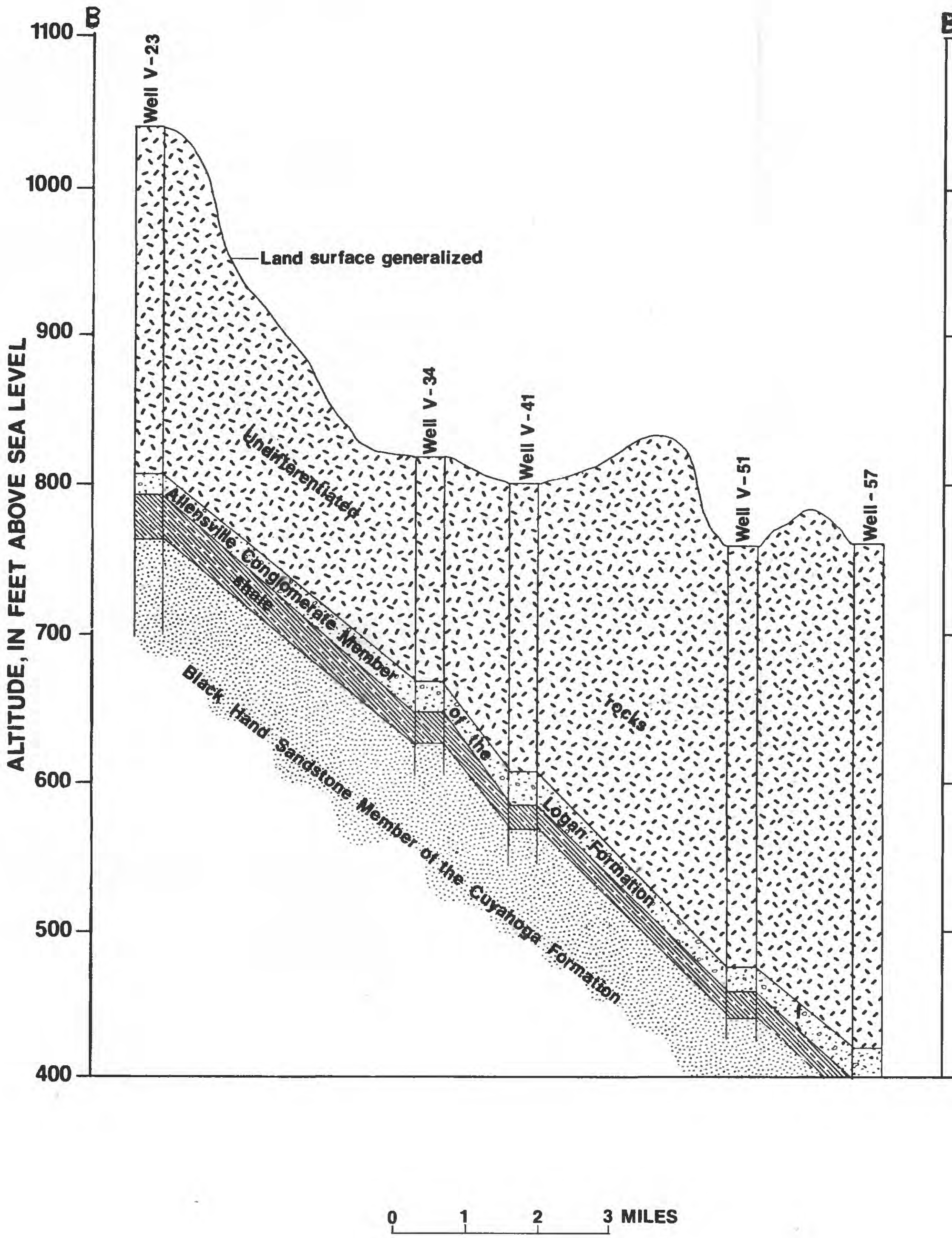


Figure 6. --Diagrammatic section in Vinton County along line B-B', (figure 4), showing relation between Black Hand Sandstone Member of the Cuyahoga Formation and Allensville Conglomerate Member of the Logan Formation.

Aquifers below the Black Hand Sandstone Member of the Cuyahoga Formation

In southwestern Fairfield, western Hocking, and northwestern Vinton Counties, in the outcrop area of the Black Hand Sandstone Member, wells tap sandstone aquifers stratigraphically lower than the Black Hand. These belong to the lower part of the Cuyahoga Formation (table 1). In the vicinity of Rockbridge and Sugar Grove, in northern Hocking and southern Fairfield Counties, respectively, where the Black Hand is exposed in the hills bordering the Hocking River, the chief aquifer is a sandstone that lies about 300 feet below the Black Hand. At Rockbridge, this deeper aquifer is about 240 feet below the flood plain of the Hocking River.

Near Lancaster, in southern Fairfield County, a coarse sandstone occurs in the upper part of the Fairfield Member of the Cuyahoga Formation, underlying the Black Hand Sandstone Member. The two sandstones, indistinguishable from each other to the well driller, form a single aquifer system.

Eastward of its outcrop area, where the Black Hand is deeply buried, sedimentary rocks that directly underlie the Black Hand consist chiefly of shale, with minor beds of sandstone. These underlying beds are consistently reported as "shale" by well drillers.

In much of Hocking and Vinton Counties, the Black Hand Sandstone is commonly called by well drillers the "Injun" or "Big Injun" sandstone. Use of this term, which has been borrowed from the oil-and-gas-well driller, is unfortunate in that often it is applied also to other sandstone aquifers, some of which are below and others above the Black Hand Sandstone Member. For example, the deep sandstone aquifer in the Rockbridge area is called the "Injun sandstone" on many drillers' logs, and so, commonly, is the "white sandstone", which lies above the Black Hand in southern Hocking and Northern Vinton Counties. On many logs, the Allensville Conglomerate Member is termed the "Little Injun sandstone" to distinguish it from the underlying "Injun" or "Big Injun" sandstone, used to designate the Black Hand Sandstone Member.

YIELDS OF WELLS

Yields are reported on drillers' logs for about 145 wells. Most of these wells are open to both the Black Hand Sandstone Member of the Cuyahoga Formation and Allensville Conglomerate Member of the Logan Formation; some terminate in the Allensville the Black Hand not having been reached. A few wells are cased to the principal aquifers, but others are cased to depths of only a few feet, and the yields are augmented by water from aquifers above those in which the wells are terminated. Reported yields were nearly all based on bailer tests lasting 1 to 4 hours, but in one or two instances lasting 6 to 8 hours.

For 22 percent of the wells, the reported yield was less than 10 gal/min; it was from 10 to 19 gal/min for 37 percent of the wells, from 20 to 29 gal/min for 27 percent, and over 29 gal/min for 13 percent. These values may be significantly overstated, however. In many instances, bailing was stopped after the water level had declined significantly and was approaching the bottom of the well, indicating that the "safe" or sustained yield of the well was less, perhaps much less, than the yield reported in the driller's log.

The highest yield reported was 192 gal/min for a pumping test of 16 hours, from a well drilled in 1966 in McArthur's north well field. That well, one of two actively used wells in the north well field, yields between 30 and 40 gal/min when it and its companion well are both being pumped. Experience has shown that sustained yields in the 30 to 40 gal/min range are near the maximum that can be obtained. Most municipal and industrial wells tapping these aquifers yield no more than 10 to 20 gal/min on a sustained basis.

A measure of a well's productivity is termed its specific capacity, or yield per unit of drawdown, commonly expressed as gallons per minute per foot of drawdown (gal/min)/ft). The specific capacity of wells in the sandstone aquifers, calculated from drillers' reports of bailer tests and the records of a few pumped wells, was generally less than 0.5 (gal/min)/ft. Specific capacities exceeded 1.0 (gal/min)/ft only in the small areas shown in figure 7. For only six wells was the computed specific capacity 2.0 (gal/min)/ft or greater, and the highest calculated value was 5.0 (gal/min)/ft, for a domestic well in northern Vinton County. The specific capacity data are mainly useful in determining location of the more productive areas and for comparing relative well performance, not as indicators of sustained yield.

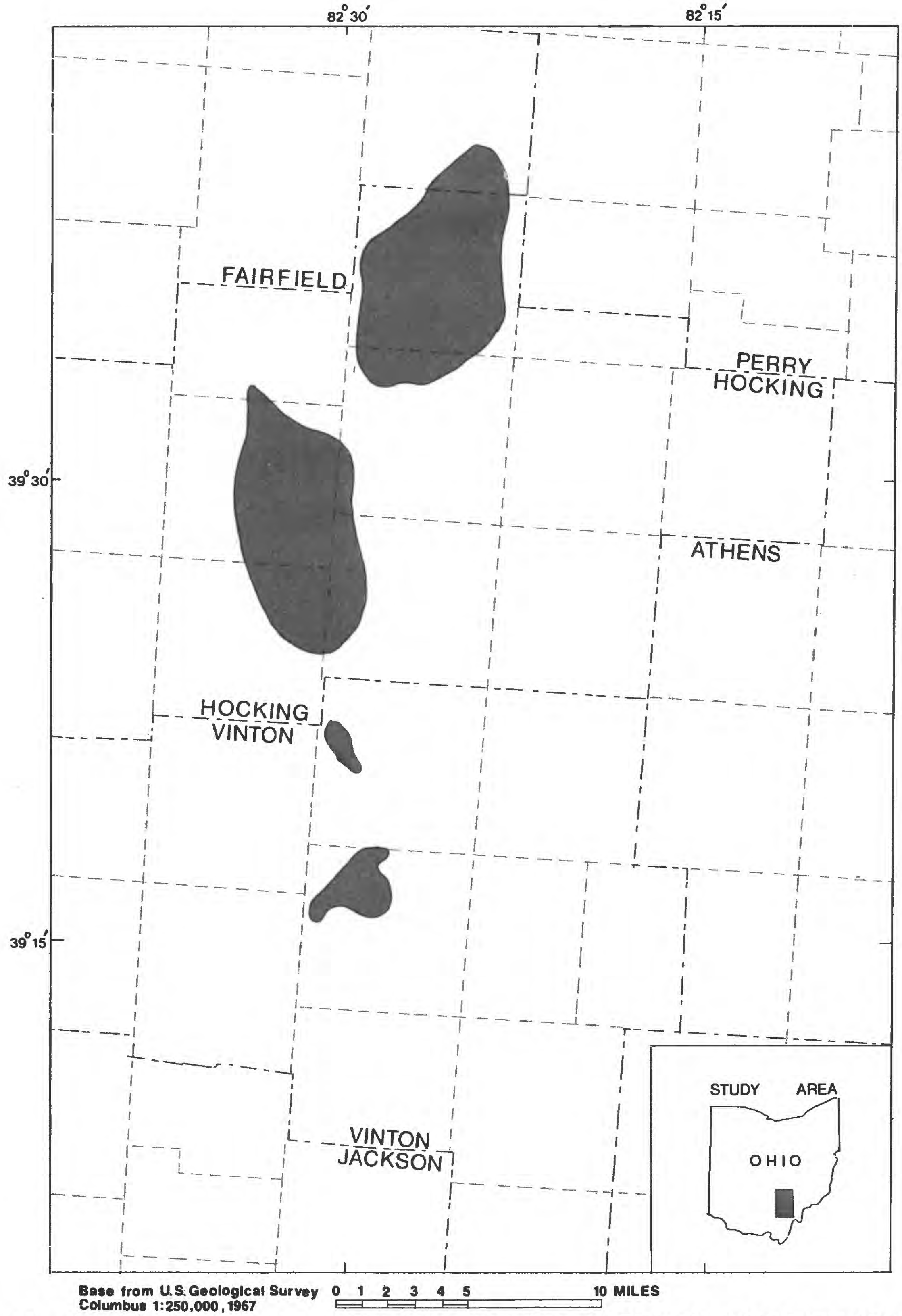


Figure 7. --Areas (shaded) where specific capacity of wells in the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers exceeds 1 (gal/min)/ft. of drawdown.

MOVEMENT OF GROUND WATER AND SOURCES OF RECHARGE TO THE AQUIFERS

Figure 8 is a map of the potentiometric surface in wells open to the Black Hand Sandstone Member, based on water levels reported by the drillers. Typically, well casings terminate above the Black Hand, and most wells are open to the overlying Allensville Conglomerate Member as well as the Black Hand. Some wells having only a few feet of casing are also open to aquifers above the Allensville. The contours show that the potentiometric surface slopes generally eastward 10 to 20 feet per mile, somewhat less than the southeastward dip of the Black Hand of about 35 feet per mile.

Ground water moves in long arcuate paths normal to the potentiometric contours, flowing generally downdip from the outcrop to points of natural discharge, possibly as far distant as the Ohio River valley. Water enters not only at the outcrop, but also in areas east of the outcrop, by infiltration through the overlying sedimentary rocks.

Evidence that water moves downward to the aquifers from the surface is shown by a progressive decline in the water level in wells being drilled, a condition commonly reported by the drillers. This head loss indicates that one component of the hydraulic gradient is vertically downward. The phenomenon is illustrated in figure 9 by the record of well V-15, drilled in northeastern Vinton County by C. G. Greathouse, deceased of Lancaster, Ohio, whose highly detailed well records were especially valuable in this investigation. Well V-15 is open to the Black Hand between depths of 205 and 229 feet, having passed through both the drillers' "white sandstone" and the Allensville. As shown in the diagram, the water level dropped incrementally from 33 to 180 feet below the surface as the well was deepened from 50 to 229 feet. The completed well was cased to the top of the Black Hand, and the last reported water level, of 180 feet, presumably represents the head only in the Black Hand.

The potentiometric contours show an unclosed depression in south-central Vinton County (fig. 8), prominently marked by the 650-foot contour, which appears to have been drawn westward to encompass an irregular area of about 10 square miles. This depression in the potentiometric surface is the result of municipal and industrial pumpage in the vicinity of McArthur, which represents the only significant withdrawals from the sandstone aquifers.

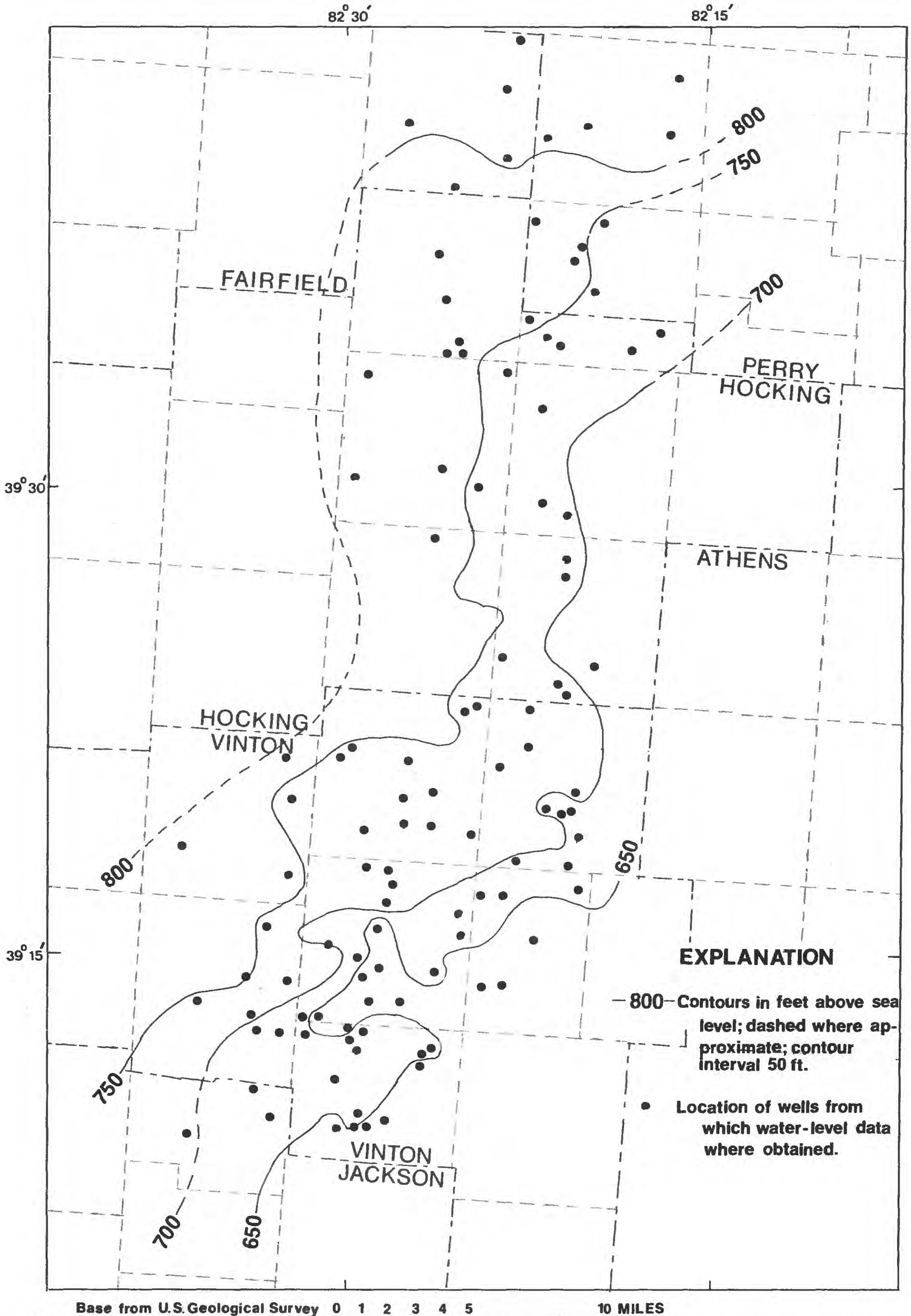


Figure 8. --Potentiometric surface in wells open to the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers.

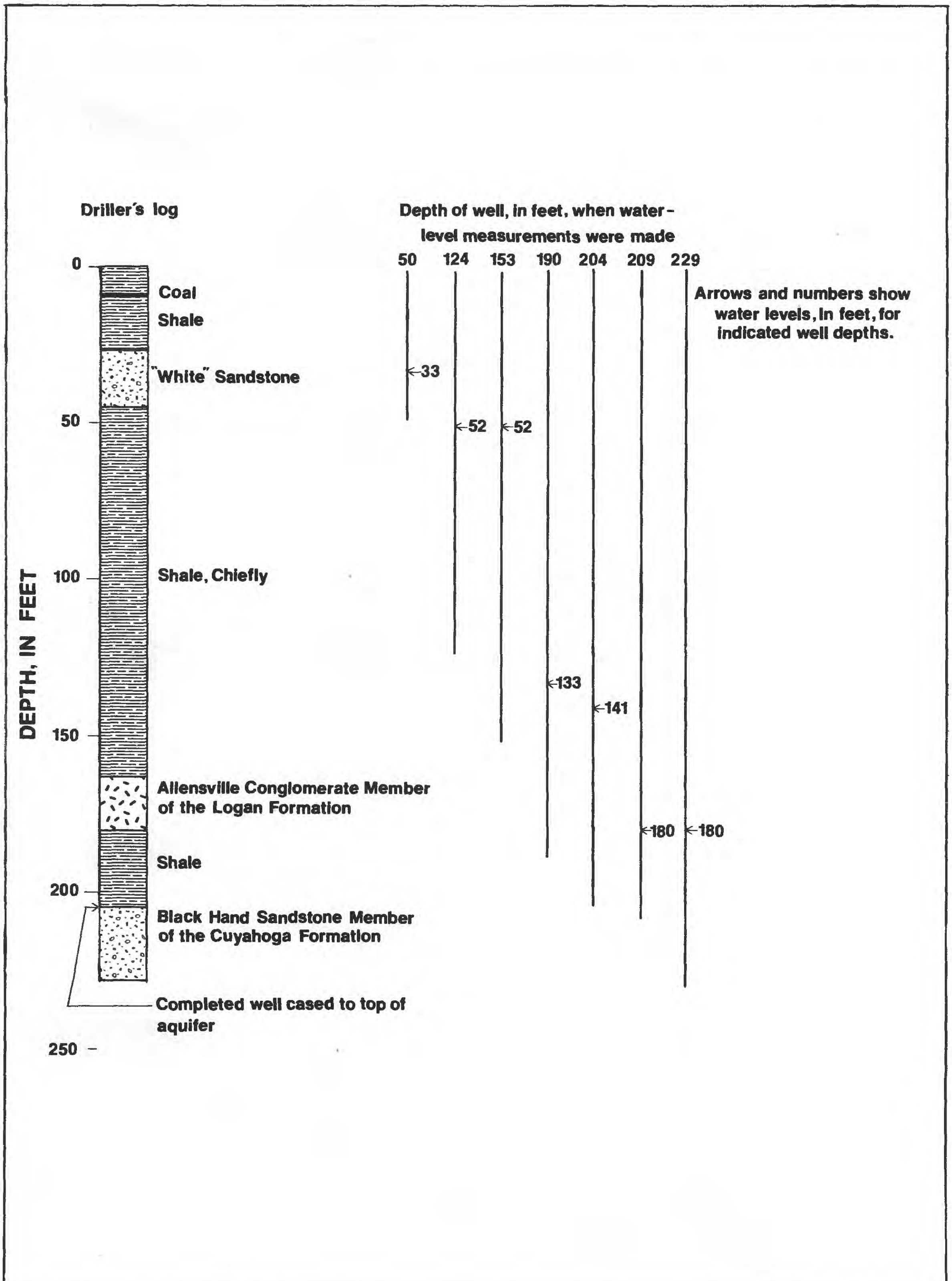


Figure 9.--Log of well V-15, in northeastern Vinton County, showing how the water level became progressively lower as the well was deepened.

GROUND-WATER SITUATION AT MCARTHUR

Ground water is withdrawn principally at three pumping centers at McArthur, shown in figure 10; they are the Austin Powder Company plant, 3 miles east of town, and two village well fields, termed here the west and north well fields. Wells at all three pumping centers tap the Black Hand Sandstone Member and Allensville Conglomerate Member. Increasing pumpage has resulted in a notable lowering of the regional potentiometric surface. Moreover, the rate of water-level decline has accelerated in the past few years.

The situation is illustrated in figure 11 by the hydrograph of State observation well V-1, at the State Highway garage near the center of town. Well V-1 is about 17,000 feet from the Austin Powder plant, and 3,200 feet and 6,500 feet, respectively, from the west and north village well fields (fig. 10). Observation well V-1 is 220 feet deep, too shallow by about 5 feet to reach the Black Hand. Originally, the well probably did penetrate the Black Hand, but over the years probably has become partly filled with sediment. Well V-1 is open to the Allensville between depths of 184 and 206 feet, based on interpretation of a gamma log made by the U.S. Geological Survey.

In 1980, the water level in well V-1 ranged between 80 and 90 feet below the surface, having declined 35 feet in the previous 10 years. The 10-year decline followed an equally long period during which the water level maintained a generally level trend, fluctuating between 50 and 60 feet below the surface. . As the hydrograph shows, the decline was halted and the well partly recovered in mid 1979. The upturn was the result of a temporary halt in pumping at the Austin Powder plant, because of a strike, and the repair of a leak in the McArthur distribution system, which allowed pumping from the village wells to be reduced. The water level began to decline again in late 1979, with resumption of pumping at the Austin Powder plant. By December 1980, it was still a few feet above the 1979 low.

At the Austin Powder Company, pumpage from seven wells, distributed over about 200 acres, is estimated by plant engineers at between 100,000 and 160,000 gal/d. Owing to the strong surface relief, the wells range widely in depth, from 337 to 475 feet, and penetrate the Black Hand Sandstone Member to an average depth of 23 feet. The overlying Allensville Conglomerate Member averages 12 feet in thickness and is separated from the Black Hand by about 25 feet of shale.

No systematic records are available of the growth in pumpage or changes in ground-water levels at the Austin Powder plant over the years. Only one well has been measured recently; it is an unpumped well, called by plant engineers the "fuseline" well.

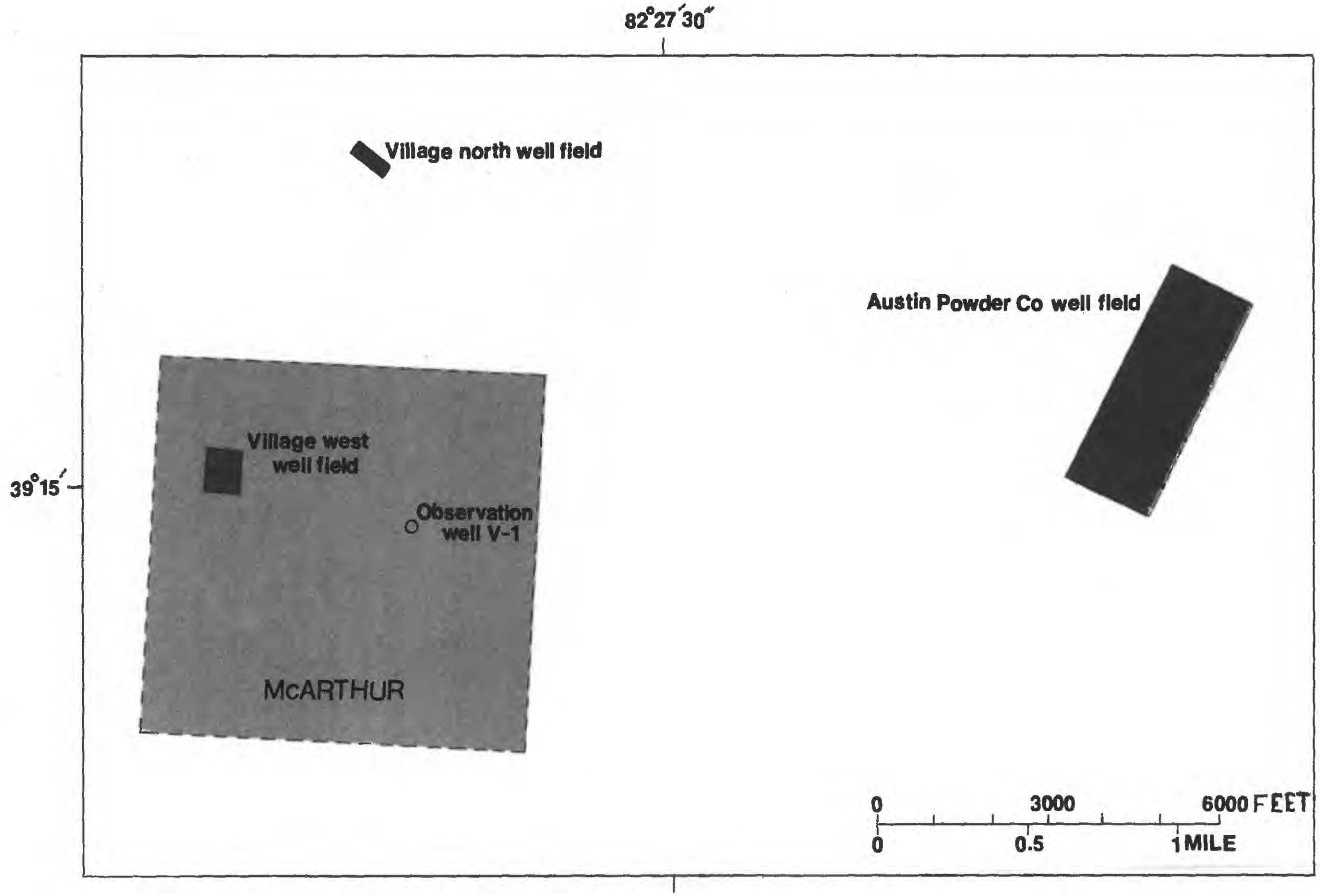


Figure 10.--Location of observation well V-1 and pumping centers in the McArther area.

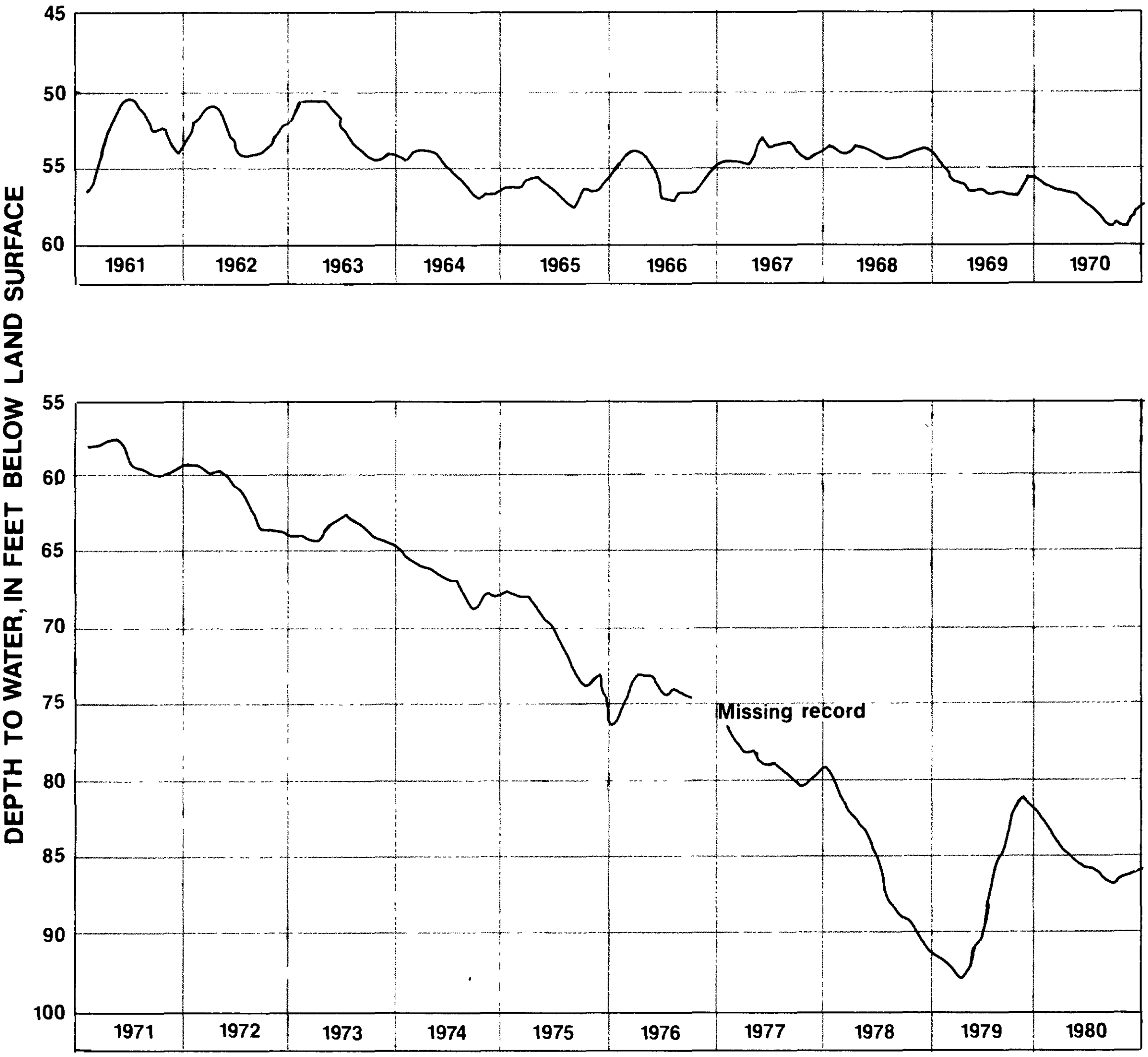


Figure 11. --Hydrograph of State observation well V-1, McArthur, Ohio, 1961- 1980.

The water level, taken by airline measurement in September 1980, was 156 feet below the surface, which corresponds to an altitude of 655 feet, or 235 feet above the Black Hand. The water level in the same well in 1969 was 150 feet below the surface, as reported by the driller. There is no record of how the water level may have been affected by nearby pumping at the time of either measurement.

Two well fields of the village of McArthur are also major centers of ground-water withdrawal, yielding an average of about 160,000 gal/d from six wells. Four of the pumping wells are in the west well field, in the west part of town near the ball park, and the other two are in the north well field, approximately 4,000 feet north of town and west of State Highway 93 (fig. 10).

Records of pumpage, other than recent, at the village well fields are not avilable. In 1952, an engineering firm estimated village water use at 110,000 gal/d, and the same estimate was given again 10 years later. Before the middle 1960's, all water came from the west well field, but, since then, most pumping has been from the north well field. At present, 70 percent of the total average pumpage of 160,000 gal/d, or 112,000 gal/d, comes from the north well field, and the remainder, 48,000 gal/d, comes from the west well field.

Wells at McArthur's west well field range in depth from 265 to 271 feet and penetrate 11 to 35 feet of Black Hand Sandstone Member, whose thickness is estimated at 100 feet. The overlying Allensville Conglomerate Member, about 16 feet thick, is separated from the Black Hand by 12 feet of shale.

No record is available to indicate the original depth to water at the west field, where the first village-owned wells were drilled in the 1930's. In 1956, the water level in a newly drilled well was reported as 105 feet below the surface, or about 130 feet above the Black Hand. This is about the same as it is today. However, pumpage has declined more than 50 percent since 1956, from 110,000 gal/d to 48,000 gal/d.

At McArthur's north well field, the wells are 255 feet deep and penetrate nearly 100 feet of the Black Hand, essentially its full estimated thickness. The overlying Allensville, 20 feet thick, is separated from the Black Hand by 20 feet of shale.

The water level in 1966, in the first well drilled at the north well field, was 27 feet below the surface. In 1974, when an observation well was drilled, the reported water level was 55 feet below the surface. In late 1980, the water level, now measured regularly in an unpumped well, fluctuated between 75 and 85 feet below the surface. The net decline during 1966-80, therefore, could be as much as 58 feet.

Specific capacity tests, relating yield to drawdown, made when some of the wells were drilled, offer a basis for estimating pumping levels. At the Austin Powder Company plant, specific capacities reported by drillers range from 0.15 to 0.55 (gal/min)/ft and average 0.36 (gal/min)/ft. Specific capacities of the village wells average 0.5 (gal/min)/ft at the west field, and 1.0 (gal/min)/ft at the north well field. Using average values of specific capacities for wells at the respective well fields (assuming that pumpage is evenly distributed among the wells), average drawdowns were computed for the Austin plant (44 ft) and for McArthur's west and north well fields (22 and 39 ft, respectively). The computed average drawdowns are not excessive compared to the available depth of water above the Black Hand, 235 feet at Austin Powder Company and 130 feet and 75 feet, respectively, at McArthur's west and north well fields. Of course, the averages do not necessarily apply to individual wells, and pumping levels are probably much lower in some wells than in others.

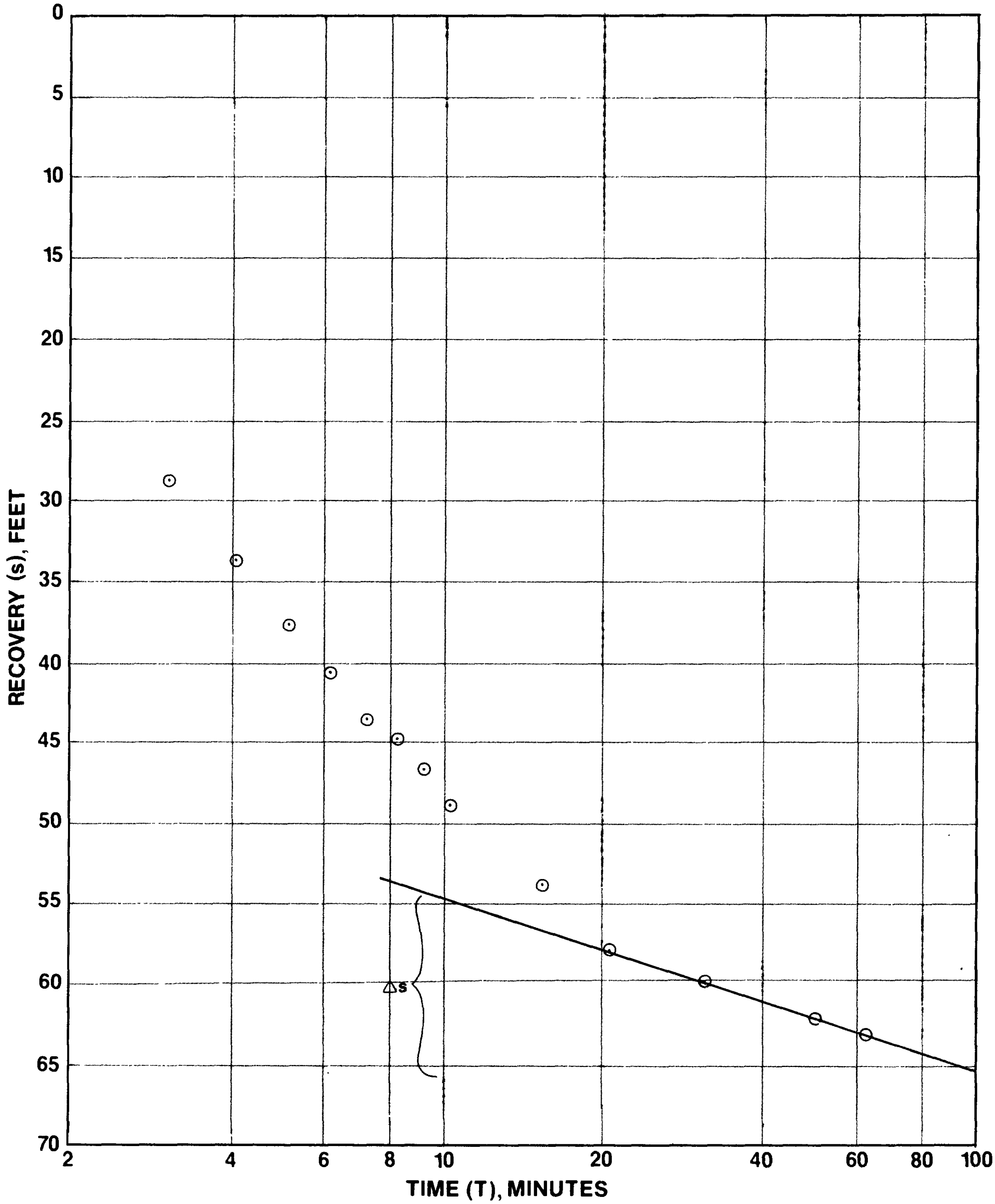
The amount of water available from the aquifer is determined not by well characteristics but by aquifer characteristics and the quantity of recharge that can be induced to the wells. When wells are pumped, ground-water levels decline, and the cone of influence created by the wells spreads until discharge is balanced by recharge and water levels reach equilibrium. Equilibrium will not be reached, however, as long as pumpage continues to increase, as has happened in the McArthur area in the past several years. If the trend continues, it may be necessary, eventually, either to reduce pumpage, perhaps in favor of a surface water source, or spread the pumpage over a much larger area.

Village of McArthur Test

In 1950, an engineering firm made separate 24-hour tests of village wells 3 and 4, in the west well field. The wells are 265 feet deep, and their respective driller's logs are nearly identical. Beneath a thick cover of shale and minor beds of sandstone, clay, and coal, the wells are open to the Allensville Conglomerate Member between depths of 195 and 215 feet and penetrate the underlying Black Hand Sandstone Member to a depth of 30 feet. About 20 feet of shale separates the Allensville and the Black Hand. Both wells are constructed with 10-inch-diameter casing that extends from the surface to 110 feet, below which the wells consist of uncased holes approximately 8 inches in diameter. The pumping rate for each well in the 24-hour tests averaged 39 gal/min. The specific capacity was the same for both wells, 0.55 (gal/min)/ft of drawdown. Periodic water-level measurements were made during drawdown and early recovery in each test, but only in the well being pumped.

Instantaneous values of recovery for selected times during the first hour after pump shut off were plotted for both wells as semilogarithmic graphs, as shown by the example in figure 12, for well 4. Aquifer transmissivity determined from the graphs by the "straight line" method described by Cooper and Jacob (1946), through the use of data collected after 20 minutes of recovery, averaged 135 ft^2/d (square feet per day). Data collected within the first 20 minutes of recovery were not used in the computations because of partial penetration effects (Hantush 1964, p. 355). The coefficient of storage was not determined from the test data but an estimated value for the confined aquifer is 0.0001.

Through the use of the value for transmissivity determined from the tests (135 ft^2/d) and the assumed value for the coefficient of storage (0.0001), calculations were made to determine hypothetical drawdowns for selected pumping rates in an aquifer system analogous to that in the McArthur area. Specifically, an attempt was made to simulate the drawdown observed in observation well V-1 caused by withdrawals at the three pumping centers. Total pumpage from the three well fields currently is estimated at 320,000 gal/d, or 220 gal/min. For this analysis, it was assumed that average pumpage over the past 10 years was 200 gal/min or 288,000 gal/d. It was further assumed that the Austin Powder Company pumps half the water withdrawn; of the other half, 70 percent comes from McArthur's north well field and 30 percent from the west well field.



$$\text{Transmissivity (T)} = \frac{264\ Q\ \text{(pumping rate)}}{\Delta s\ \text{(change/log cycle)}} \qquad T = \frac{264 \times 39.2}{10.2 \times 7.48} = 135\ \text{ft}^2\text{/day}$$

Figure 12.--Semilogarithmic plot of recovery versus time in well 4, December 1950.

Figure 13 shows graphs of drawdown versus distance for selected pumping rates after 3,600 days, or about 10 years. The assumptions are that the aquifer is infinite in extent and that all water pumped is derived from storage in the aquifer. The convergence of the drawdown lines to a point about 114,000 feet (21.5 miles) from the point of origin shows the hypothetical extent of the radijs of the cone of depression at the end of the 10-year pumping period. On the drawdown graphs, average distances between the well fields and observation well V-1 are indicated.

If all water had come from storage in the aquifer, the graphs indicate the cumulative drawdown at observation well V-1 would have been as follows:

Drawdown caused by the north well field	(70 gal/min)	44.5 ft
Drawdown caused by the west well field	(30 gal/min)	24.0 ft
Drawdown caused by the Austin Powder plant	(100 gal/min)	42.5 ft
Total --		111.0 ft

The total computed drawdown, 111 feet, is about three times the observed drawdown, 35 feet, in well V-1 over the past 10 years. It is assumed, therefore, that, of the total quantity of water pumped at the three well fields, only aboujt one-third is being taken from storage in the aquifer and the remaining two-thirds represents recharge. To show how ground-water levels may have declined over the years, the time-drawdown graphs in figure 14 are presented. These graphs show hypothetical effects on well V-1 caused by pumping at the three well fields at rates equal to about one-third their estimated rural average pumping rates in the past 10 years.

The selected pumping rates, 10 gal/min for the west well field, 25 gal/min for the north well field, and 35 gal/min for the Austin Powder Company wells, represent those parts of the respective total withdrawals assumed to have come from storage in the aquifer. The graphs show that in 10 years the drawdown at well V-1 would have been as follows:

Drawdown caused by the north well field	(25 gal/min)	15.8 ft
Drawdown caused by the west field	(10 gal/min)	8.0 ft
Drawdown caused by Austin Powder Company wells	(35 gal/min	14.6 ft
Total drawdown --------------------------------------		38.4 ft

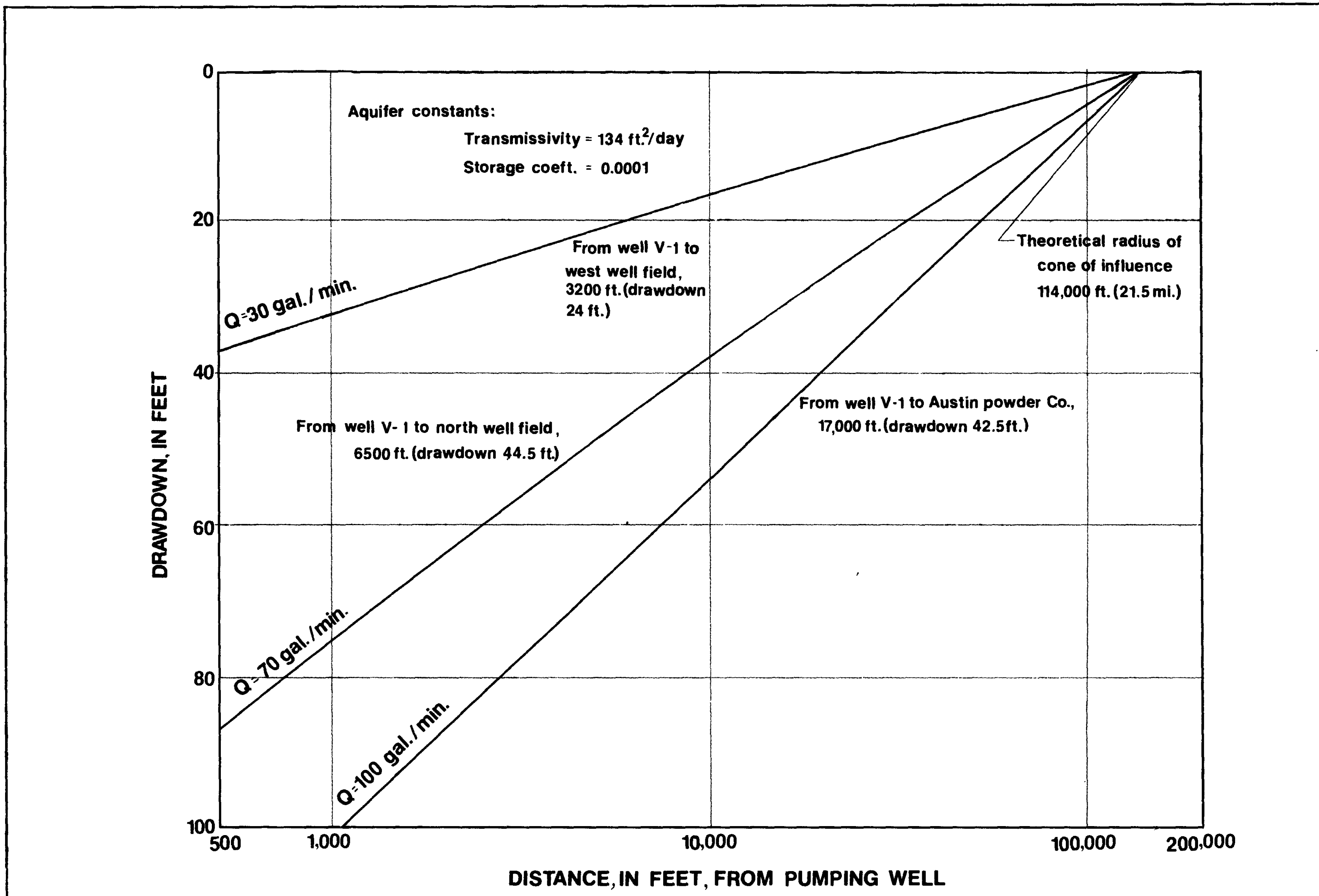


Figure 13. --Semilogarithmic graphs of drawdown versus distance for selected pumping rates for a pumping period of 3600 days (9.8 years).

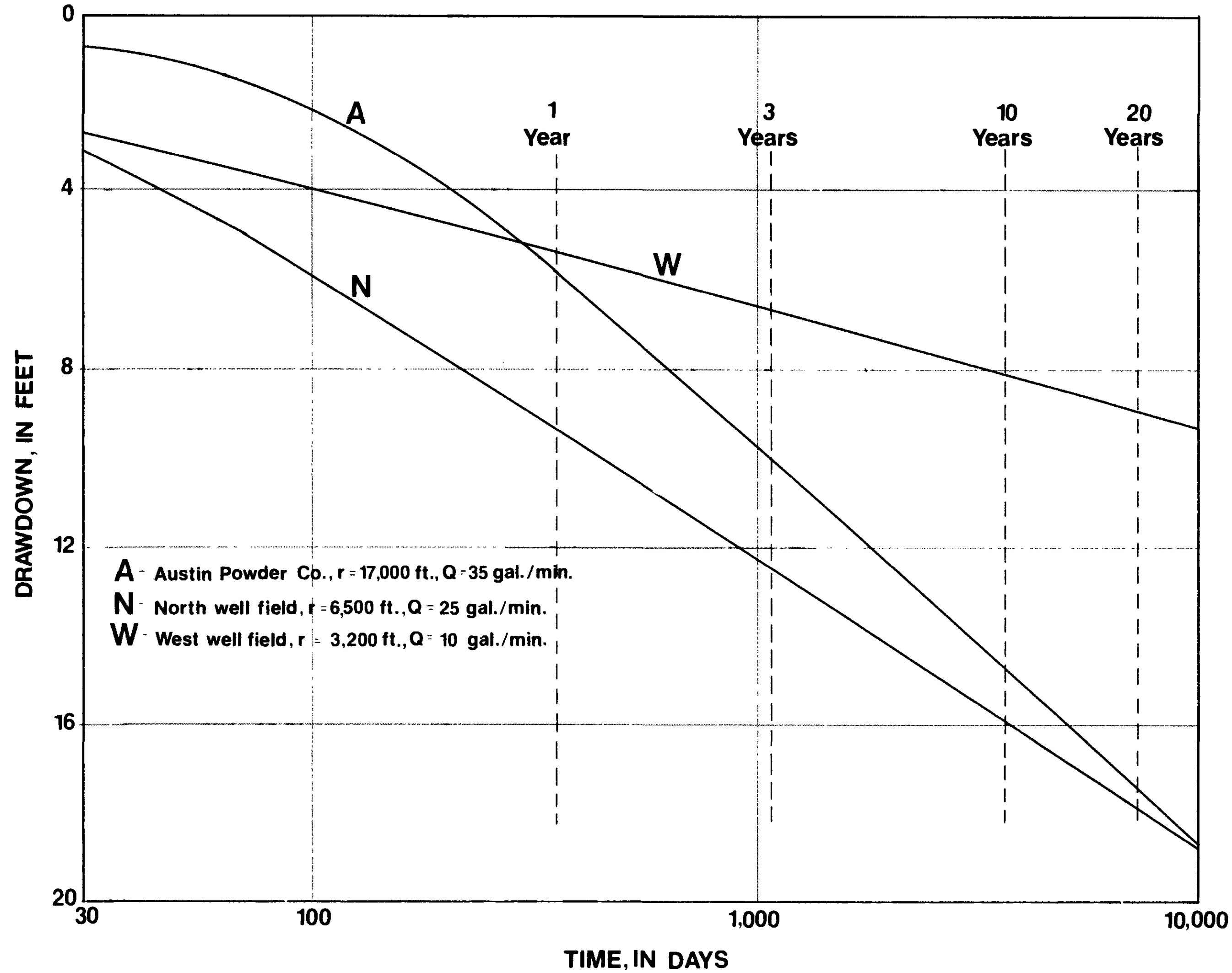


Figure 14. -Semilogarithmic graphs of drawdown versus time for selected pumping rates at three pumping centers.

Total computed drawdown, 38 feet, is fairly close to the observed drawdown at well V-1 in the past 10 years. If pumping rates were to remain the same in the next 10 years as in the past 10 years, the graphs indicate that drawdown at well V-1 will increase by an additional 6 feet. However, the anlaysis is hypothetical, and probably does not accurately simulate real conditions in the McArthur area, no matter how closely the cumulative drawdown values determined from the graphs may approximate the observed drawdown at well V-1. The future effect of continued pumping may be greater than that indicated by the graphs. Indeed, the rate of decline in well V-1, as shown by the hydrograph in figure 11, has clearly accelerated in the past 3 or 4 years, far more than would have been predicted by the graphs in figure 14. On the other hand, the graphs indicate more drawdown in the first few years than was observed in well V-1. The chief defect in this simulation is probably the fact that the graphs in figure 14 are based on constant pumping rates, whereas the rates have been increasing year by year. Moreover, the sources of recharge to the aquifer are not clearly understood, nor can it be predicted how much additional recharge might be induced by a further lowering of the potentiometric surface.

Recharge may originate locally, in saturated surface and near-surface deposits, with the water entering the aquifer by induced downward leakage, or recharge may have a more distant source, in the outcrop area of the aquifer, with the water moving laterally into the cone of depression. At the outcrop, water can enter the aquifer directly by infiltration of rain and snow melt. It seems likely that recharge is derived in some measure from both sources. Evidence is insufficient to suggest which source may be the more important. For recharge to occur by downward leakage, water must move through 150 to 200 or more feet of coal formation clay and shale beds of relatively low permeability to reach the aquifer. Nevertheless, because of the large cone of depression, no doubt some water can be induced to move through these poorly permeable deposits under a comparatively small head differential. On the other hand, water doubtlessly moves laterally within the aquifer to the wells.

The map, figure 8, shows that the regional slope of the potentiometric surface in the Black Hand Sandstone Member is on the order of 10 feet per mile in Vinton County. Through a value for aquifer transmissivity of 135 ft^2/d, a simple calculation shows that approximately 10,000 gal/d, or 7 gal/min would move through each mile-wide strip of the aquifer under the prevailing gradient. If the cone of depression formed by the three pumping centers intercepts water from a 10-mile-wide strip of aquifer, then about 70 gal/min may reach the wells by lateral movement from the outcrop area. This estimate does not seem excessive, based on evidence in figure 13, indicating that the radius of the cone may extend as far as 21 miles.

The decline in ground-water levels in the past 10 years in the McArthur area is significant, and the accelerated downward trend in the past 2 or 3 years may portend a serious water shortage in the future. Clearly, the situation bears close watching and underscores the necessity of gathering additional data to more clearly understand the hydrologic system. At the very least it would seem prudent for operators of the principal well fields to know and record the depth to water in their wells and to relate those levels and their long-term trends to the regional situation, as indicated by the hydrograph of well V-1.

CHEMICAL QUALITY OF THE GROUND WATER

Concentrations of selected chemical constituents in samples collected in late summer 1980 from 30 wells and analysed by the U.S. Geological Survey are shown in table 2. The map, figure 15, shows the locations of the sampled wells, whose depths and other physical characteristics are given in table 3 (p. 42). Water moving in the ground dissolves constituent minerals that reflect the lithologic character of the aquifers. Water in limestone, for example, tends to have dominant ions of calcium and bicarbonate and sulfate, especially where gypsum is present. Water moving through marine sandstone and shale typically contains a high proportion of sodium, generally in combination with carbonate and chloride. Calcium, magnesium, and sulfate ions are also typically present. Of the analyses in table 2, about three-fourths represent sodium bicarbonate or sodium chloride bicarbonate type waters, and the rest are calcium sulfate and calcium sulfate bicarbonate types.

As shown by figure 15, an areal difference in water type is evident. Water in the central part of the area is predominantly a sodium bicarbonate or calcium bicarbonate type; that in the eastern part, which is downdip and downgradient from the central part, is a sodium chloride bicarbonate type. Typically, water picks up much of its mineral content from the rocks with which it first comes in contact. As it moves through the rocks, the initial composition changes as a result of contact with rocks of different mineral content, by ion exchange, and changes in pressure and equilibrium conditions. In the central part, the aquifers are relatively close to the surface; in the eastern part they are more deeply buried beneath an increasingly thick cover of shale, sandstone, coal, and clay. Most water in the aquifers probably originates in the western part, on and near the outcrops, but some water enters the aquifers in all parts. Thus, water moving downgradient and downdip, in the aquifers, while subject to chemical change in its movement, is being augmented continuously by water of different initial composition, resulting from longer and longer contact with the overlying sediments. The result, in the downgradient direction, is a constantly changing mixture of water types, trending toward a sodium chloride type. Generally, dissolved constituents increase, and, ultimately, the water becomes too mineralized for ordinary use. It is unlikely, for example, that water from the Allensville Conglomerate Member or the Black Hand Sandstone Member is potable in the extreme eastern part of Vinton County, east of Lake Hope.

Table 2.--Chemical characteristics of water from selected wells

Well number	SPECIFIC CONDUCTANCE (UMHOS)*	PH (UNITS)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	SODIUM, DISSOLVED (MG/L AS NA)
F-3	710	7.9	65	0	15	6.6	110
F-5	155	6.1	99	45	29	6.5	5.1
P-3	670	7.3	300	4	90	19	39
P-6	1810	8.2	19	0	5.0	1.7	400
H-2	350	7.6	190	26	44	19	2.4
H-9	620	7.7	95	0	24	8.6	120
H-16	505	7.4	270	0	72	23	8.3
H-21	710	8.7	12	0	3.5	.8	170
H-29	1140	7.9	60	0	15	5.5	230
H-36	520	8.6	16	0	4.1	1.4	120
H-37	2550	8.1	44	0	11	4.1	580
H-42	540	7.9	89	0	20	9.5	93
H-46	1250	8.5	10	0	2.8	.8	300
H-48	370	7.6	190	0	50	17	5.1
V-1	465	8.0	10	0	3.0	.6	100
V-2	500	8.1	82	0	19	8.5	85
V-3	925	8.1	62	0	16	5.4	220
V-6	655	7.1	360	130	90	34	2.6
V-10	1060	8.8	8	0	2.1	.6	250
V-16	405	8.2	61	0	15	5.6	72
V-22	1790	8.5	10	0	2.6	.8	460
V-28	380	8.1	110	0	26	11	44
V-30	1100	8.2	10	0	2.5	.8	260
V-40	1300	8.6	11	0	2.8	.9	334
V-45	850	8.0	60	0	13	6.7	200
V-47	590	8.4	21	0	4.6	2.4	130
V-63	1180	8.6	12	0	3.0	1.0	280
V-68	1740	8.2	15	0	4.1	1.2	400
V-81	1430	8.6	12	0	3.2	.9	320
J-4	1880	6.6	1300	1060	260	150	34

* Micromhos per centimeter at 25^{o}C

Table 2.--Chemical characteristics of water from selected wells--Continued

Well number	POTASSIUM, DISSOLVED (MG/L AS K)	BICARBONATE FET-FLD (MG/L AS HCO3)	CARBONATE FET-FLD (MG/L AS CO3)	SULFATE DISSOLVED (MG/L AS SO4)	CHLORIDE, DISSOLVED (MG/L AS CL)	FLUORIDE, DISSOLVED (MG/L AS F)	SILICA, DISSOLVED (MG/L AS SIO2)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)
F-3	2.4	340	0	1.0	74	.3	12	378
F-5	.8	66	0	5.8	12	.1	21	139
P-3	3.2	360	0	81	6.5	.4	23	432
P-6	3.2	600	0	38	310	1.7	8.2	1060
H-2	1.1	200	0	34	1.1	.2	9.7	205
H-9	3.0	300	0	53	26	.6	10	384
H-16	1.4	330	0	24	2.2	.2	18	300
H-21	1.1	390	22	2.6	34	.4	8.5	432
H-29	3.3	370	0	29	210	.3	12	674
H-36	1.5	330	10	18	1.7	.3	9.6	315
H-37	4.2	660	0	61	550	1.9	9.5	1530
H-42	2.3	320	0	41	1.8	.6	14	333
H-46	2.1	550	16	43	140	1.5	8.3	780
H-48	1.9	250	0	13	1.0	.2	17	221
V-1	2.4	210	0	26	30	1.6	3.1	269
V-2	2.2	320	0	25	4.7	.4	10	305
V-3	2.2	540	0	39	32	2.0	8.8	590
V-6	2.3	280	0	150	1.0	.2	11	433
V-10	1.4	440	22	2.4	130	.7	8.6	635
V-16	1.8	240	0	23	5.9	.2	11	249
V-22	2.4	570	14	.3	300	1.8	7.1	1050
V-28	2.5	240	0	20	1.9	.2	7.7	231
V-30	1.7	490	0	2.3	129	1.3	8.5	648
V-40	1.8	430	28	5.3	190	1.4	7.6	785
V-45	2.6	310	0	39	110	.7	6.7	533
V-47	1.6	270	16	37	29	.7	8.5	363
V-63	2.5	460	18	48	170	1.1	8.5	743
V-68	3.7	650	0	43	280	2.6	8.3	1060
V-81	2.5	460	16	41	230	1.3	8.3	836
J-4	8.6	296	0	990	16	.3	19	1620

Table 2.--Chemical characteristics of water from selected wells--Continued

Well number	NITROGEN, NITRATE DISSOLVED (MG/L AS N)	NITROGEN, NITRITE DISSOLVED (MG/L AS N)	NITROGEN, AMMONIA DISSOLVED (MG/L AS N)	NITROGEN, ORGANIC DISSOLVED (MG/L AS N)	PHOSPHORUS, DISSOLVED (MG/L AS P)	IRON, DISSOLVED (UG/L AS FE)	MANGANESE, DISSOLVED (UG/L AS MN)	CARBON, ORGANIC DISSOLVED (MG/L AS C)
F-3	.09	.020	1.00	.00	.030	80	20	.8
F-5	5.70	.000	.010	.00	.020	60	10	.5
P-3	.28	.000	.040	.04	.020	120	10	.5
P-6	.00	.010	.840	.00	.020	40	10	1.2
H-2	.45	.000	.010	.00	.010	1100	50	.3
H-9	.02	.000	.330	.00	.010	80	30	.4
H-16	.11	.000	.020	.08	.010	50	30	.7
H-21	1.40	.010	.450	.00	.050	40	10	.6
H-29	.00	.000	.910	.07	.030	70	40	.5
H-36	.36	.020	.170	.00	.050	0	10	.3
H-37	.03	.010	1.10	.00	.030	110	20	.2
H-42	.01	.000	1.10	.00	.020	110	30	.3
H-46	.01	.010	.570	.03	.030	90	10	.3
H-48	.00	.120	.470	.00	.040	1100	30	.7
V-1	.07	.030	.360	.11	.010	30	10	2.9
V-2	.00	.000	.760	.00	.000	60	30	.3
V-3	.00	.000	.480	.00	.020	260	150	.4
V-6	.00	.000	.060	.00	.030	4000	140	.8
V-10	.00	.000	.550	.00	.060	40	10	.1
V-16	.00	.000	.590	.00	.000	60	10	.7
V-22	.02	.000	.690	.11	.020	30	3	1.3
V-28	.00	.000	.620	.00	.000	10	10	.8
V-30	.00	.000	.600	.00	.020	90	10	.1
V-40	.01	.000	.550	.00	.030	130	8	.4
V-45	.04	.000	.670	.00	.020	30	20	1.2
V-47	1.10	.000	.490	.08	.020	30	10	1.0
V-63	.01	.000	.810	.00	.020	30	10	.2
V-68	.29	.050	.850	.01	.020	10	10	.3
V-81	.01	.000	.780	.00	.020	40	10	.1
J-4	.77	.000	.020	.00	.040	100	20	.8

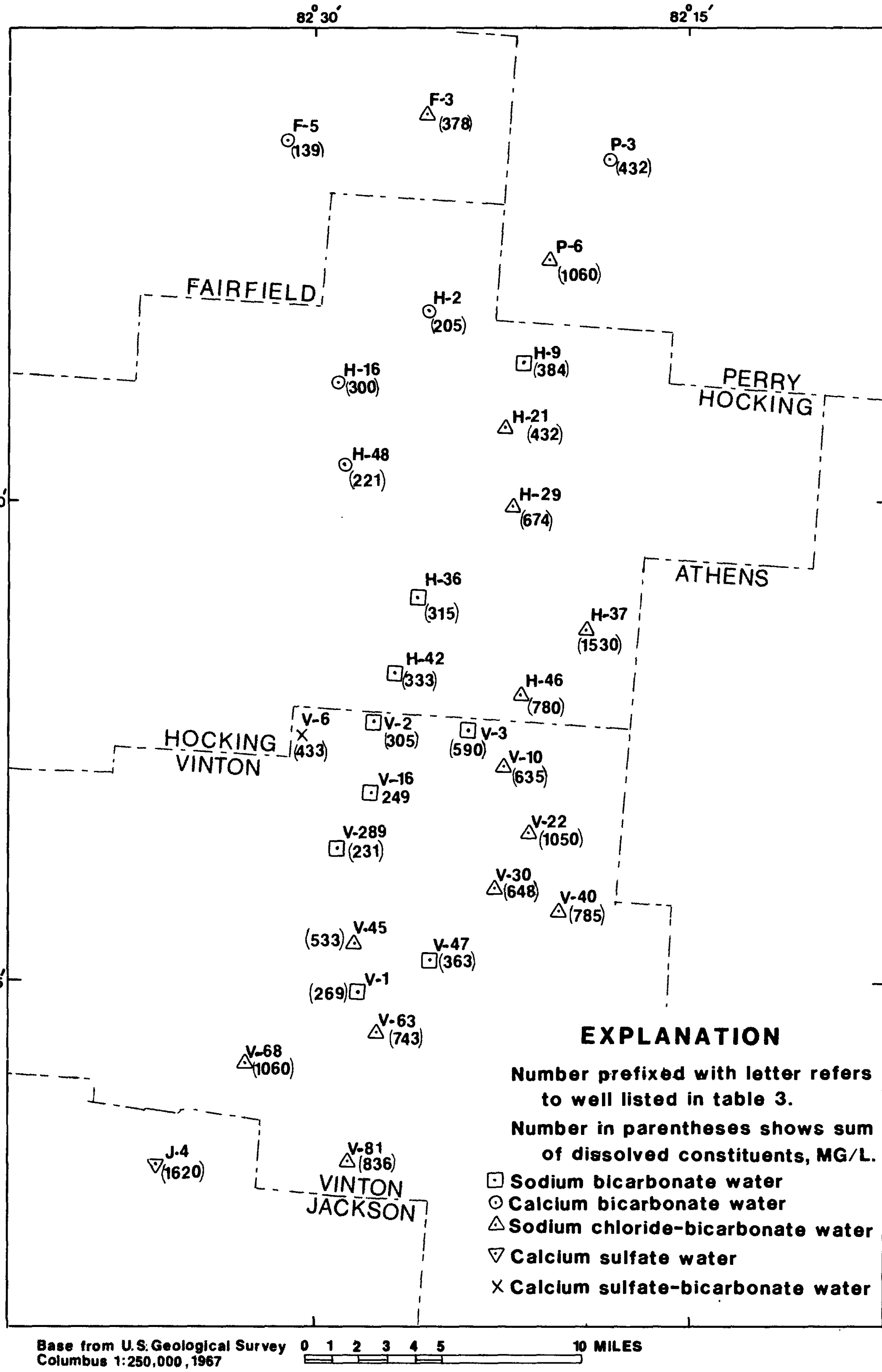


Figure 15. --Eastward change from sodium bicarbonate or calcium bicarbonate water to sodium chloride-bicarbonate water.

The model described applies chiefly to aquifers or extensive zones within aquifers where ground-water circulation is rapid and of more than local extent. With respect to the Black Hand, the model applies chiefly to the top few feet of the aquifer in which most wells are terminated. There is evidence that at many places in fresh water areas brine occurs at depth in the aquifer, indicating underlying zones of stagnant water. According to well drillers, if a well penetrates 50 or more feet into the Black Hand, chances are good the water will be too salty for use. Moreover, in some areas where most wells yield potable water, an atypical well, or a few such wells, may yield brine from the same depth zone tapped by all other wells.

Undoubtedly, in some areas, high levels of brine represent contamination by oil field wastes. Oil and gas have been exploited for a century or more in the area. Oil fields have patchy distribution in eastern Fairfield and western Perry Counties, in central and eastern Hocking County, and in northeastern Vinton County. The oil is pumped from what drillers term the "Clinton sand" a widespread, generally productive stratum in eastern Ohio. The "Clinton sand" lies 1,400 to 1,800 feet below sea level in central Hocking and central Vinton Counties, at depths ranging from about 2,100 to 2,800 feet. More brine than oil is produced; a study of a small area in Hocking County, near Logan, indicated an oil-brine ratio of 1:6 and production of 18 barrels of brine per well per day (Adams, 1980). Some brine is discharged to the ground, where it can infiltrate shallow aquifers, but a far larger amount is reportedly disposed of by direct discharge to aquifers through the well annulus or space between casing strings of different diameters. Adams (1980) found 25 water wells contaminated by chloride in the area he studied and stated that it would take years for the brine to be flushed from the aquifer after discharge is halted. Areas in which brine contamination of shallow ground-water supplies have been reported, probably by oil-well wastes, occur chiefly in Hocking County, at places near Logan, Gore, Greendale, and Union Furnace. (See fig. 1.)

Another potential source of contamination is acid drainage derived from the weathering of coal mine spoils or exposed coal deposits. Acid waters typically are characterized by low pH, high specific conductance, and high concentration of iron and sulfate. These effects result from exposure to air and subsequent oxidation of iron-sulfur minerals, chiefly pyrite and marcasite, commonly associated with the coal. Water from well J-4, in table 2, in northern Jackson County, has an unusually high sulfate content and low pH, conditions that may be related to acid drainage from coal deposits.

The anomalous chemical character of water from well J-4 is shown in figure 16, which shows the relationship between the specific conductance and sum of dissolved solids for all the sampled wells. The relationship is ordinarily linear, as shown by the plots for all sampled wells, except that for J-4. The plot for wsell J-4, first sampled in September 1980 with most of the other wells, deviates so far from the normal line that an error in sampling was suspected. The well was resampled in late February 1981, and that data plot, too, falls off the line but not as far as the earlier plot. The shift toward normal in the second sampling is probably caused by ground-water recharge in February, a month of above-normal precipitation that followed 5 consecutive months of below normal precipitation and generally declining ground-water levels.

There is no evidence of coal mining in the immediate vicinity of well J-4, and no coal beds are recorded in the driller's log. However, coal deposits are reported by Stout (1916, p. 62) to cropout in a ravine half a mile south of the well at an altitude that indicates that the well probably penetrated one or more thin coal seams. Well J-4 is 290 feet deep and is cased only to the depth of 14 feet. With a reported depth to water of 210 feet, a considerable thickness of rock is exposed to the air. Coal beds could be oxidized and high sulfate waters could be produced under these circumstances, which probably accounts for the anomalous relationship shown in figure 16.

The concentrations of dissolved mineral constituents in the samples indicated ground water of suitable quality for most uses. U.S. Environmental Protection Agency (1977) drinking water standards recommend that dissolved solids not exceed 500 mg/L. Water containing more than 1,000 mg/L is unsuitable for some purposes. About half the samples were below 500 mg/L in dissolved solids, and only five exceeded 1,000 mg/L.

The water is low in hardness, about half the samples being below 60 mg/L, which is considered soft. About one in five samples exceeded 180 mg/L in total hardness, which is considered very hard. Iron was low in most samples; in only three did the concentration exceed 0.3 mg/L, the recommended limit of the EPA. More than about 0.3 mg/L of iron stains laundry and utensils and is objectionable for use in food and other processing and beverages. The sodium content of drinking water can be an important factor for persons on medically restricted diet if the sodium concentration exceeds 20 mg/L (USEPA, 1977). The sodium concentration exceeded 20 mg/L in about 80 percent of the samples, and more than half had concentrations greater than 100 mg/L.

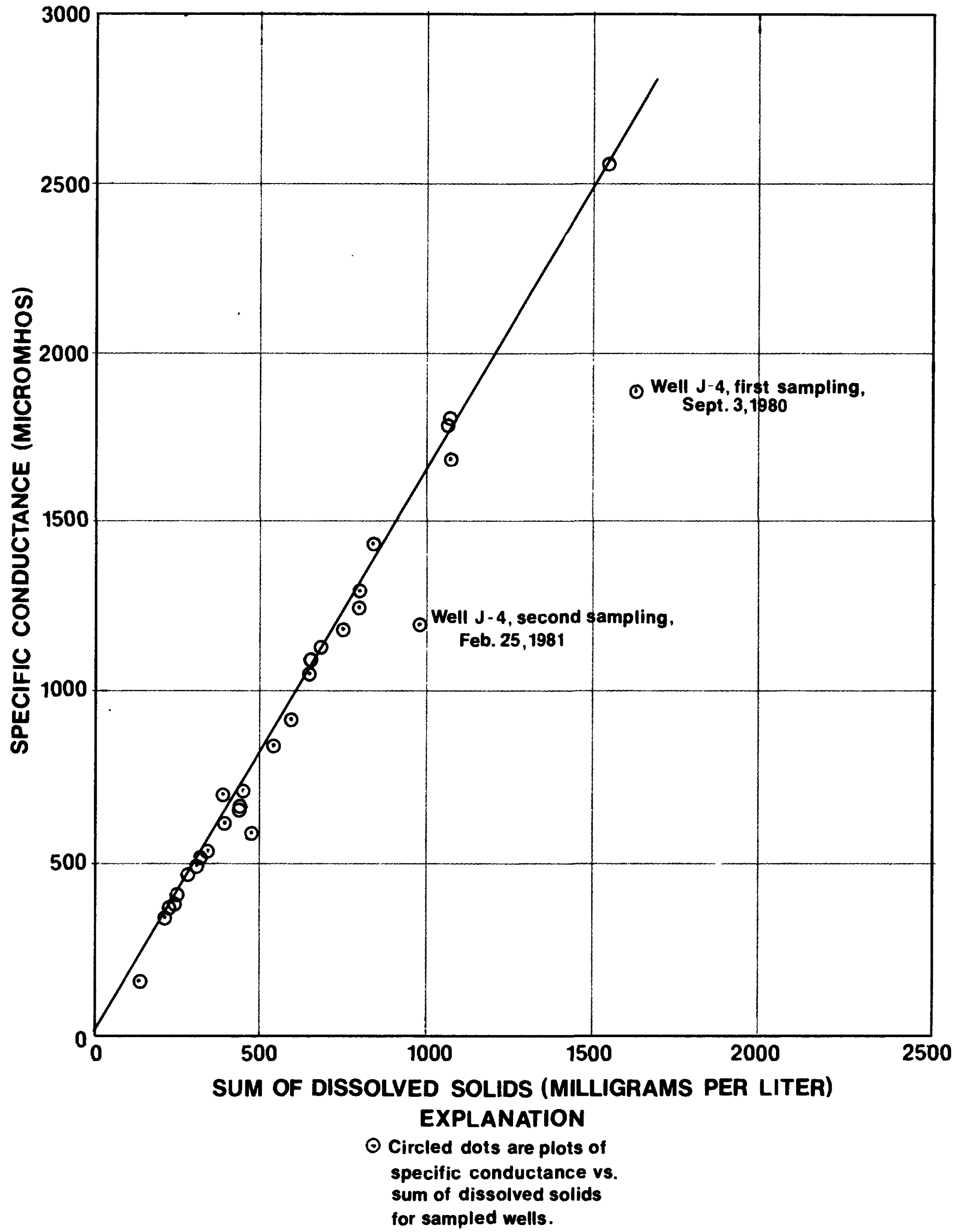


Figure 16.--Relation between specific conductance and sum of dissolved solids for sampled wells, showing anamolous character of water from well J-4.

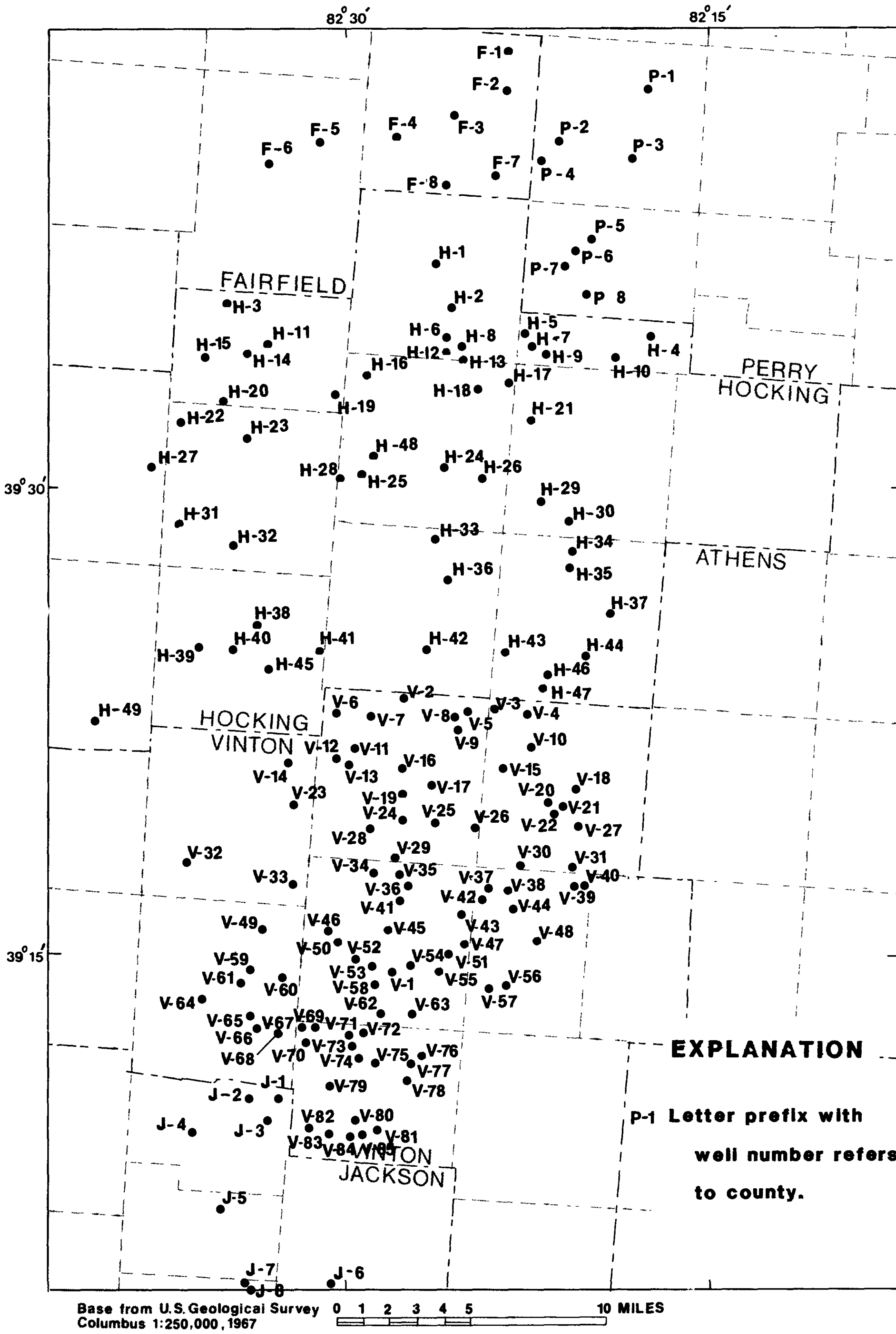


Figure 17. --Locations of wells listed in table 3.

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers.

Well number: Letter prefix refers to county in which well is located.

Altitude: In feet below National Geodetic Vertical Datum of 1929 (formerly Mean Sea Level).

Depth of well: Reported by driller.

Depth of casing: Reported by driller.

Well number	State well log number	Altitude (feet)	Depth of well (feet)	Depth of casing (feet)
F-1	504493	975	255	25
F-2	320151	870	188	47
F-3	533087	950	300	80
F-4	495000	890	150	25
F-5	450970	950	110	56
F-6	351259	1020	348	47
F-7	426542	840	109	104
F-8	459684	970	304	82
P-1	435681	882	251	65
P-2	362284	980	313	70
P-3	467683	980	380	37
P-4	173747	1005	372	61
P-5	455374	835	265	0
P-6	476647	923	290	106
P-7	30889994	1005	388	100
P-8	476645	792	167	45

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Aquifers: As interpreted from well logs: AL, Allensville Member of the Logan Formation; BH, Black Hand Sandstone Member of the Cuyahoga Formation.

Water level: Reported by driller.

Yield: Estimated by driller for short bailing test.

Well number	Aquifers			Water level		Yield	
	Depth (feet)	Thickness (feet)	Name	Depth (feet)	Date	Rate (gpm)	Drawdown (feet)
F-1	205	25	AL	180	4-28-77	8	45
	243	12+	BH				
F-2	155	5	AL	60	9-08-64	9	100
	165	23+	BH				
F-3	190	25	BH	200	8-20-78	15	25
	240	60+	BH				
F-4	25	10	AL	85	2-12-77	8	65
	75	70	BH				
F-5	72	30	BH	60	7-27-73	11	30
F-6	15	25	AL	204	7-09-66	10	100
	65	65	BH				
F-7	102	7	BH	37	5-05-72	20	15
F-8	225	75	BH	200	1-07-74	20	15
P-1	250	1+	BH	26	9-22-75	1	0
P-2	305	8+	BH	85	10-23-67	10	215
P-3	378	2+	BH	120	4-23-75	2.5	180
P-4	316	10	AL	200	12-05-59	5	70
	331	39	BH				
P-5	208	57+	BH	100	8-28-73	3	--
P-6	248	42+	BH	170	3-19-76	13	120
P-7	363	25+	BH	265	8-08-64	9	5
P-8	162	5+	AL	127	2-04-76	10	127

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Well number: Letter prefix refers to county in which well is located.

Altitude: In feet below National Geodetic Vertical Datum of 1929 (formerly Mean Sea Level).

Depth of well: Reported by driller.

Depth of casing: Reported by driller.

Well number	State well log number	Altitude (feet)	Depth of well (feet)	Depth of casing (feet)
H-1	325625	850	150	128
H-2	407415	1040	350	220
H-3	364459	1105	356	28
H-4	455394	790	265	140
H-5	369149	840	195	160
H-6	536413	1025	330	120
H-7	470570	800	180	153
H-8	92637	840	153	134
H-9	369101	895	285	70
H-10	92646	765	288	53
H-11	504476	970	255	21
H-12	92635	890	250	170
H-13	92639	840	161	135
H-14	530864	1115	345	30
H-15	543781	1130	350	40
H-16	407438	980	250	100

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Aquifers: As interpreted from well logs: AL, Allensville Member of the Logan Formation; BH, Black Hand Sandstone Member of the Cuyahoga Formation.

Water level: Reported by driller.

Yield: Estimated by driller for short bailing test.

Well number	Aquifers			Water level		Yield	
	Depth (feet)	Thickness (feet)	Name	Depth (feet)	Date	Rate (gpm)	Drawdown (feet)
H-1	8	142+	BH	84	9-13-66	25	15
H-2	165	15	AL	280	4-17-71	10	0
	248	102+	BH				
H-3	49	148	BH	307	9-07-67	10	15
H-4	261	4+	AL	50	8-20-74	15	210
H-5	175	20+	BH	95	5-24-70	20	0
H-6	200	20	AL	275	9-14-79	30	15
	247	83	BH				
H-7	125	16	AL	40	10-19-74	22	95
	164	16+	BH				
H-8	107	46+	BH	78	8-04-62	25	13
H-9	260	15+	AL	103	8-07-67	15	0
H-10	250	33+	BH	33	6-02-66	4	134
H-11	19	56	BH	200	12-14-76	12	25
H-12	148	102+	BH	132	6-21-62	12	23
H-13	119	42+	BH	81	9-04-62	25	10
H-14	105	240+	BH	280	6-19-78	10	11
H-15	51	299+	BH	275	1-29-79	10	30
H-16	160	12	AL	200	6-30-77	11	10
	215	35+	BH				

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Well number: Letter prefix refers to county in which well is located.

Altitude: In feet below National Geodetic Vertical Datum of 1929 (formerly Mean Sea Level).

Depth of well: Reported by driller.

Depth of casing: Reported by driller.

Well number	State well log number	Altitude (feet)	Depth of well (feet)	Depth of casing (feet)
H-17	326758	750	120	87
H-18	275632	900	225	55
H-19	92626	840	304	142
H-20	513594	1095	370	122
H-21	501011	930	318	183
H-22	550399	1160	315	34
H-23	233249	1082	342	30
H-24	400573	1000	305	258
H-25	473790	995	288	131
H-26	266283	980	326	20
H-27	551968	1120	275	39
H-28	531954	805	85	40
H-29	244665	780	211	38
H-30	300096	942	416	140
H-31	544017	1105	325	30
H-32	233234	1078	310	24

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Aquifers: As interpreted from well logs: AL, Allensville Member of the Logan Formation; BH, Black Hand Sandstone Member of the Cuyahoga Formation.

Water level: Reported by driller.

Yield: Estimated by driller for short bailing test.

Well number	Aquifers			Water level		Yield	
	Depth (feet)	Thickness (feet)	Name	Depth (feet)	Date	Rate (gpm)	Drawdown (feet)
H-17	90	30+	BH	15	4-30-65	10	58
H-18	188	29	AL	150	9-14-63	1.5	40
	219	6+	BH				
H-19	8	242	BH	35	10-12-60	12	100
H-20	8	197	BH	260	3-08-79	30	40
H-21	296	22+	AL	228	9-20-76	15	60
H-22	32	223	BH	235	6-27-79	7	35
H-23	90	150	BH	270	8-10-61	8	--
H-24	270	35+	AL	215	11-23-74	22	50
H-25	205	83+	BH	200	2-25-75	15	30
H-26	310	5	AL	250	7-30-63	--	25
H-27	2	273	BH	205	8-30-63	--	70
H-28	3	79	BH	40	---	20	10
H-29	179	32+	AL	47	11-14-61	25	24
H-30	406	10+	BH	240	6-01-68	25	--
H-31	30	295	BH	275	7-19-78	10	15
H-32	75	125	BH	260	9-21-60	N.R.	--

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Well number: Letter prefix refers to county in which well is located.

Altitude: In feet below National Geodetic Vertical Datum of 1929 (formerly Mean Sea Level).

Depth of well: Reported by driller.

Depth of casing: Reported by driller.

Well number	State well log number	Altitude (feet)	Depth of well (feet)	Depth of casing (feet)
H-33	92645	795	261	219
H-34	449477	760	253	67
H-35	275751	760	251	52
H-36	523735	1000	405	150
H-37	455377	1045	622	170
H-38	434301	1105	427	18
H-39	536421	1020	350	--
H-40	474697	930	235	31
H-41	362251	840	130	65
H-42	331932	1025	370	108
H-43	541036	990	410	179
H-44	449475	820	405	170
H-45	300063	1050	419	366
H-46	300077	800	309	197
H-47	375073	790	300	222
H-48	250797	920	224	41
H-49	233213	1070	325	28

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Aquifers: As interpreted from well logs: AL, Allensville Member of the Logan Formation; BH, Black Hand Sandstone Member of the Cuyahoga Formation.

Water level: Reported by driller.

Yield: Estimated by driller for short bailing test.

	Aquifers			Water level		Yield	
Well number	Depth (feet)	Thickness (feet)	Name	Depth (feet)	Date	Rate (gpm)	Drawdown (feet)
H-33	93	168+	BH	28	12-30-64	12	40
H-34	245	8+	AL	100	2-19-76	5	75
H-35	248	3+	AL	48	6-11-64	1.3	--
H-36	309	15+	BH	330	3-14-78	8	60
H-37	600	22+	AL	250	9-22-73	3	--
H-38	185	170	BH	389	10-18-74	--	0
H-39	73	102	BH	145	11-02-79	30	145
H-40	25	210	BH	175	7-01-76	12	50
H-41	8	122+	BH	93	2-03-67	20	10
H-42	360	10+	AL	210	10-30-65	8	150
H-43	388	22+	AL	275	9-26-79	15	30
H-44	380	25+	AL	160	11-08-75	5	50
H-45	360	59+	--	105	6-07-65	30	0
H-46	289	11+	AL	55	10-29-66	7	224
H-47	285	15+	AL	60	8-01-70	--	180
H-48	152	8	AL	98	5-05-61	10	15
	165	59+	BH				
H-49	125	60	BH	195	8-29-59	--	--

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Well number: Letter prefix refers to county in which well is located.

Altitude: In feet below National Geodetic Vertical Datum of 1929 (formerly Mean Sea Level).

Depth of well: Reported by driller.

Depth of casing: Reported by driller.

Well number	State well log number	Altitude (feet)	Depth of well (feet)	Depth of casing (feet)
V1		730	220	100
V-2	481543	975	370	174
V-3	122393	830	304	32
V-4	300065	1000	480	213
V-5	122385	785	240	127
V-6	363567	1060	345	164
V-7	447590	1000	325	154
V-8	300064	775	218	22
V-9	528773	920	375	150
V-10	331932	1025	370	108
V-11	375074	1025	338	184
V-12	92622	820	115	89
V-13	92629	762	345	310
V-14	522201	1040	336	204
V-15	325629	920	229	205
V-16	505909	800	210	151
V-17	411949	910	330	128

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Aquifer: As interpreted from well logs: AL, Allensville Member of the Logan Formation; BH, Black Hand Sandstone Member of the Cuyahoga Formation.

Water level: Reported by driller.

Yield: Estimated by driller for short bailing test.

Well number	Aquifers			Water level		Yield	
	Depth (feet)	Thickness (feet)	Name	Depth (feet)	Date	Rate (gpm)	Drawdown (feet)
V-1	184	22	AL	85	7-17-80	--	--
V-2	357	13+	BH	210	8-11-75	11	70
V-3	296	8+	AL	40	6-29-56	30	194
V-4	462	18+	AL	264	7-31-65	5	216
V-5	222	18+	AL	40	9-23-55	30	120
V-6	284	61+	BH	315	9-26-68	20	10
V-7	285	30	AL	338	9-29-73	11	32
V-8	203	15+	AL	30	6-24-65	30	123
V-9	355	18	AL	170	10-04-78	12	105
V-10	273	8+	AL	30	6-17-64	20	220
V-11	290	14	AL	278	8-24-70	--	298
	327	11+	BH				
V-12	45	15+	AL	69	6-20-58	25	5
	89	26+	BH				
V13	310	35+	BH	60	8-01-61	13	121
V14	230	100	BH	260	3-13-78	10	67
V15	205	24+	BH	180	9-11-67	13	5
V16	186	24+	BH	92	12-11-76	22	150
V17	308	20	AL	174	12-16-70	22	56

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Well number: Letter prefix refers to county in which well is located.

Altitude: In feet below National Geodetic Vertical Datum of 1929 (formerly Mean Sea Level).

Depth of well: Reported by driller.

Depth of casing: Reported by driller.

Well number	State well log number	Altitude (feet)	Depth of well (feet)	Depth of casing (feet)
V-18		970	720	600
V-19	92617	772	198	176
V-20		926	690	521
V-21		750	454	321
V-22		920	670	460
V-23	318559	1040	346	75
V-24	92621	755	185	167
V-25	375081	923	376	308
V-26	91886	753	280	139
V-27	410764	715	396	271
V-28	528774	800	135	64
V-29	92625	760	223	189
V-30	410786	720	275	217
V-31	318561	750	426	264
V-32	481528	990	280	44
V-33	239356	1030	328	260
V-34	92624	820	218	183

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Aquifers: As interpreted from well logs: AL, Allensville Member of the Logan Formation; BH, Black Hand Sandstone Member of the Cuyahoga Formation.

Water level: Reported by driller.

Yield: Estimated by driller for short bailing test.

Well number	Aquifers			Water level		yield	
	Depth (feet)	Thickness (feet)	Name	Depth (feet)	Date	Rate (gpm)	Drawdown (feet)
V-18	605	115+	BH	265	10-18-63	--	--
V-19	177	21+	BH	40	3-09-55	25	18
V-20	521	153	BH	260	1-07-60	22	254
V-21	359	16	AL	120	1-01-50	33	134
	404	50+	BH				
V-22	568	18	BH	230	8-12-59	20	137
V-23	233	14	AL	296	12-14-64	10	50
	277	69+	BH				
V-24	160	25+	BH	21	9-25-57	25	40
V-25	353	23+	BH	220	5-05-71	--	82
V-26	272	8+	BH	35	9-03-54	30	130
V-27	374	22+	BH	20	9-21-74	20	360
V-28	119	15	AL	85	10-06-78	30	100
V-29	147	23	AL	38	9-03-59	25	29
	189	34+	BH				
V-30	260	15+	AL	35	7-26-73	20	240
V-31	392	34+	AL	60	1-22-65	7	366
V-32	195	75	BH	206	5-29-75	35	74
V-33	311	17+	BH	248	10-14-60	9	80
V-34	192	26+	BH	107	8-12-58	25	13

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Well number: Letter prefix refers to county in which well is located.

Altitude: In feet below National Geodetic Vertical Datum of 1929 (formerly Mean Sea Level).

Depth of well: Reported by driller.

Depth of casing: Reported by driller.

Well number	State well log number	Altitude (feet)	Depth of well (feet)	Depth of casing (feet)
V-35	429749	795	255	130
V-36	400223	770	210	89
V-37	410787	920	420	320
V-38	481535	715	310	200
V-39	183399	1025	765	610
V-40	180739	1025	780	565
V-41	92623	802	260	234
V-42	491044	740	255	140
V-43	204316	750	290	197
V-44	318579	720	290	197
V-45	466889	720	255	70
V-46	431769	870	255	125
V-47	394876	840	430	268
V-48	410767	730	356	255
V-49	318574	990	360	190
V-50	429719	810	195	107
V-51	144886	760	337	210

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Aquifers: As interpreted from well logs: AL, Allensville Member of the Logan Formation; BH, Black Hand Sandstone Member of the Cuyahoga Formation.

Water level: Reported by driller.

Yield: Estimated by driller for short bailing test.

Well number	Aquifers			Water level		Yield	
	Depth (feet)	Thickness (feet)	Name	Depth (feet)	Date	Rate (gpm)	Drawdown (feet)
V-35	238	17+	BH	81	5-18-72	22	40
V-36	179	23	AL	67	12-10-69	24	3
V-37	395	25+	AL	235	8-27-73	6	175
V-38	278	32+	AL	51	7-03-75	33	42
V-39	695	70+	BH	345	4-08-58	20	[illegible]
V-40	682	57	BH	350	11-10-61	--	[illegible]
V-41	234	26+	BH	95	7-26-58	25	[illegible]
V-42	234	21+	AL	90	9-02-76	12	8[illegible]
V-43	245 280	20 10+	AL BH	60	10-13-58	35	9[illegible]
V-44	270	20+	AL	70	1-12-66	10	17[illegible]
V-45	120 160	20 95+	AL BH	81	9-24-80	100	105
V-46	230	20	BH	200	9-15-72	20	15
V-47	399	31+	BH	170	6-10-69	15	40
V-48	341	15+	AL	90	12-03-71	10	160
V-49	285 343	48 17+	AL BH	270	10-04-65	8	90
V-50	173	19	BH	110	8-31-71	22	40
V-51	286	51+	BH	120	6=14-57	25	45

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Well number: Letter prefix refers to county in which well is located.

Altitude: In feet below National Geodetic Vertical Datum of 1929 (formerly Mean Sea Level).

Depth of well: Reported by driller.

Depth of casing: Reported by driller.

Well number	State well log number	Altitude (feet)	Depth of well (feet)	Depth of casing (feet)
V-52	363558	780	223	110
V-53	155892	760	268	180
V-54	375099	705	206	198
V-55	318600	740	311	184
V-56	472104	795	385	205
V-57	178681	760	360	228
V-58	472120	740	231	120
V-59	359331	950	330	123
V-60	144883	950	356	30
V-61	411947	850	195	46
V-62	302513	738	215	85
V-63	528753	840	350	259
V-64	410755	842	348	11
V-65	429725	780	165	95
V-66	410765	820	255	130
V-67	431799	960	400	213
V-68	363570	740	194	94

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Aquifers: As interpreted from well logs: AL, Allensville Member of the Logan Formation; BH, Black Hand Sandstone Member of the Cuyahoga Formation.

Water level: Reported by driller.

Yield: Estimated by driller for short bailing test.

	Aquifers			Water level		Yield	
Well number	Depth (feet)	Thickness (feet)	Name	Depth (feet)	Date	Rate (gpm)	Drawdown (feet)
V-52	169	11	AL	80	12-07-67	12	40
	192	31+	BH				
V-53	177	4	AL	105	5-10-56	32	70
	194	74+	BH				
V-54	188	18+	BH	40	8-06-74	15	166
V-55	271	14	AL	60	11-06-67	20	60
	296	15+	BH				
V-56	373	12+	AL	90	8-01-74	10	135
V-57	340	20	AL	100	4-08-58	25	50
V-58	172	29	AL	80	8-22-75	15	110
	211	20+	BH				
V-59	260	18	AL	200	6-05-67	1	130
V-60	294	62+	BH	225	4-22-57	10	131
V-61	170	20	AL	99	12-03-70	1	96
V-62	196	19+	AL	28	2-08-65	10	--
V-63	335	15+	AL	220	6-08-78	12	105
V-64	330	18+	AL	155	5-28-71	20	85
V-65	129	21	AL	55	10-06-71	1	110
V-66	179	15	AL	165	10-08-71	30	90
V-67	360	40	AL	280	3-27-73	10	80
V-68	164	30+	BH	92	7-19-71	1	102

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Well number: Letter prefix refers to county in which well is located.

Altitude: In feet below National Geodetic Vertical Datum of 1929 (formerly Mean Sea Level).

Depth of well: Reported by driller.

Depth of casing: Reported by driller.

Well number	State well log number	Altitude (feet)	Depth of well (feet)	Depth of casing (feet)
V-69	528781	850	295	171
V-70	318588	948	385	210
V-71	410782	880	340	178
V-72	204329	753	236	109
V-73	144867	873	327	109
V-74	239398	762	233	113
V-75	410751	800	307	98
V-76	239388	780	323	208
V-77	368599	815	354	235
V-78	447592	805	350	147
V-79	363564	722	200	100
V-80	528755	960	290	127
V-81	491095	755	300	157
V-82	429701	720	210	14
V-83	466864	708	210	84
V-84	481510	740	240	128
V-85	375094	965	479	235

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Aquifers: As interpreted from well logs: AL, Allensville Member of the Logan Formation; BH, Black Hand Sandstone Member of the Cuyahoga Formation.

Water level: Reported by driller.

Yield: Estimated by driller for short bailing test.

	Aquifers			Water level		yield	
Well number	Depth (feet)	Thickness (feet)	Name	Depth (feet)	Date	Rate (gpm)	Drawdown (feet)
V-69	260	25	AL	210	3-21-79	12	30
V-70	358	27+	AL	286	12-03-66	10	100
V-71	324	16+	AL	240	3-30-73	20	60
V-72	213	13+	AL	74	5-07-59	20	160
V-73	303	24+	AL	180	7-31-56	35	120
V-74	218	15	AL	70	3-25-63	10	163
V-75	280	27+	AL	80	4-01-71	20	220
V-76	305	18+	AL	95	6-21-62	10	228
V-77	338	16+	AL	120	11-25-70	10	210
V-78	330	20+	AL	160	10-01-73	10	175
V-79	167	31	AL	46	3-30-68	40	124
V-80	260	25	AL	215	5-26-78	50	75
V-81	257	13	AL	120	9-09-76	10	180
	278	22+	BH				
V-82	158	16	AL	--	10-23-71	--	--
V-83	175	31	AL	70	3-19-74	22	70
V-84	220	20+	AL	75	1-21-75	15	155
V-85	458	20	AL	266	3-27-72	7	266

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Well number: Letter prefix refers to county in which well is located.

Altitude: In feet below National Geodetic Vertical Datum of 1929 (formerly Mean Sea Level).

Depth of well: Reported by driller.

Depth of casing: Reported by driller.

Well number	State well log number	Altitude (feet)	Depth of well (feet)	Depth of casing (feet)
J-1	410796	745	172	13
J-2	472101	845	262	53
J-3	544766	842	330	25
J-4	368553	922	290	14
J-5	318596	780	232	106
J-6	522206	820	351	116
J-7	91863	790	362	52
J-8	91864	780	267	50

Table 3.--Records of wells drilled into the Black Hand Sandstone Member of the Cuyahoga Formation and associated aquifers--Continued.

Aquifers: As interpreted from well logs: AL, Allensville Member of the Logan Formation; BH, Black Hand Sandstone Member of the Cuyahoga Formation.

Water level: Reported by driller.

Yield: Estimated by driller for short bailing test.

Well number	Aquifers			Water level		Yield	
	Depth (feet)	Thickness (feet)	Name	Depth (feet)	Date	Rate (gpm)	Drawdown (feet)
J-1	160	12+	AL	50	5-19-74	2	122
J-2	238	24+	AL	160	6-17-74	0.5	102
J-3	248 314	21 8	AL BH	160	11-12-79	1.5	170
J-4	271	19+	--	210	1-25-68	25	80
J-5	211	21+	BH	104	7-14-67	40	128
J-6	348	3+	AL	231	7-20-78	2	112
J-7	208	34	AL	40	11-06-53	10	120
J-8	246	14	AL	40	11-06-53	10	120

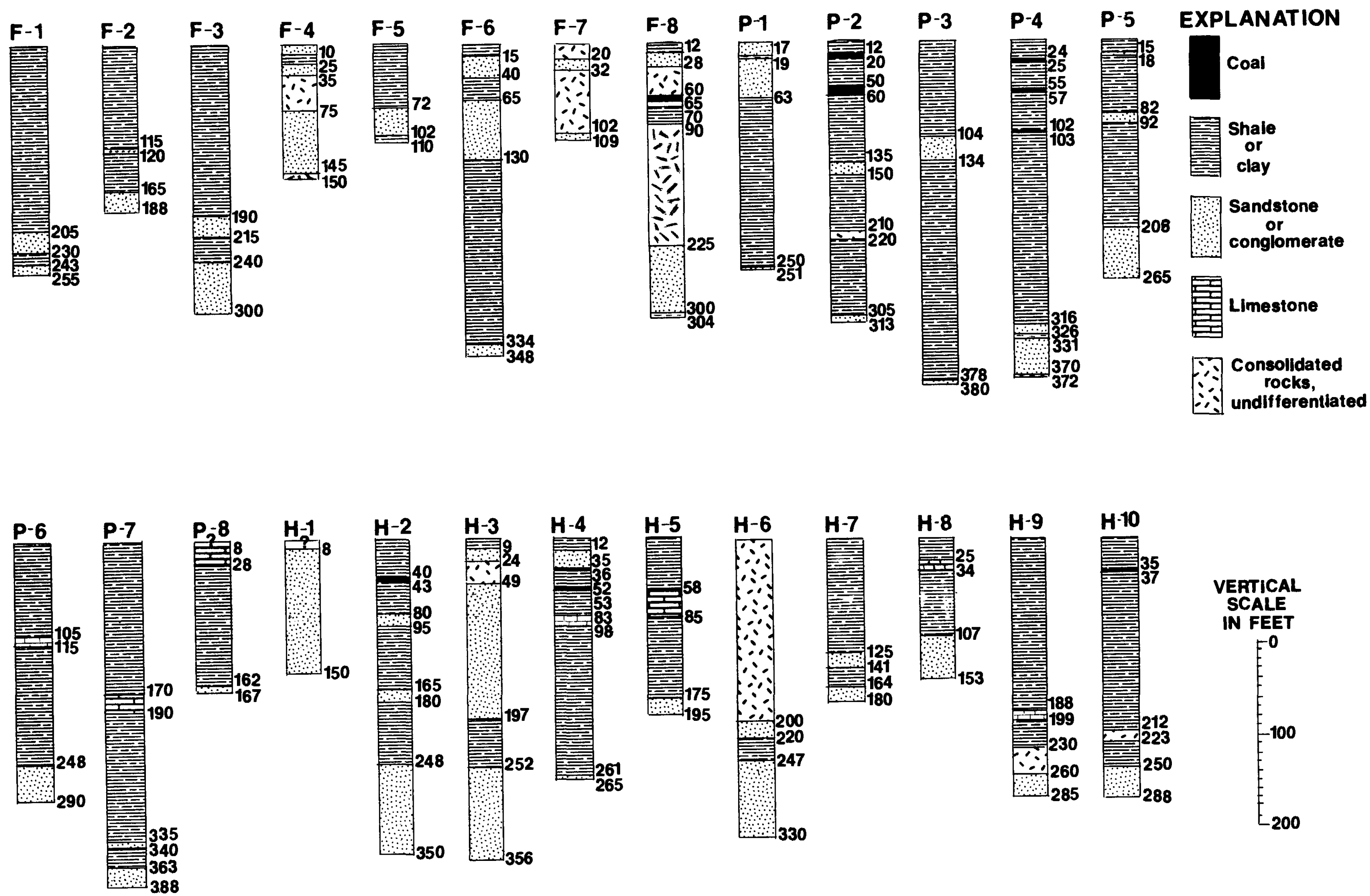


Figure 18. --Logs of wells listed in table 3 (continued).

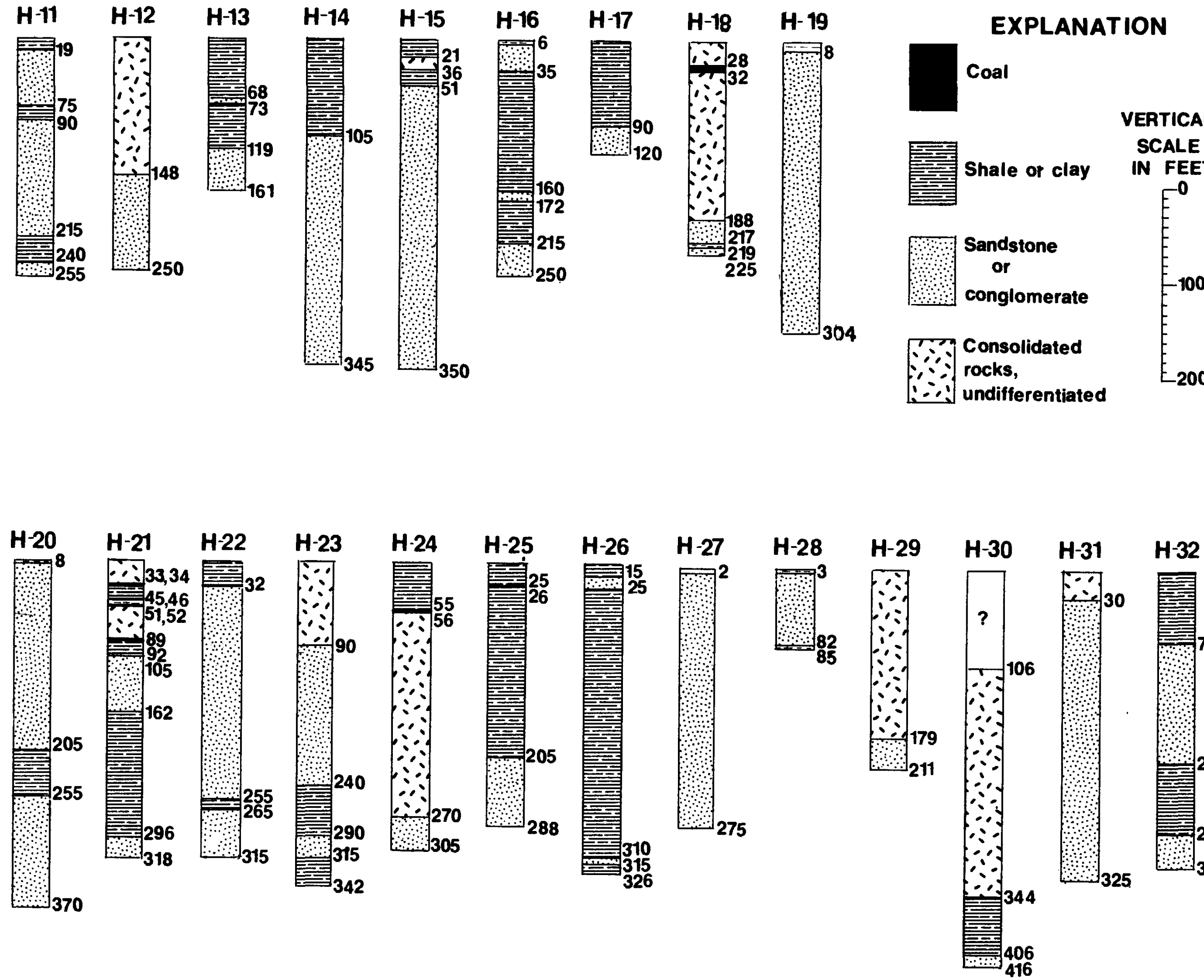


Figure 18. --Logs of wells listed in table 3 (continued).

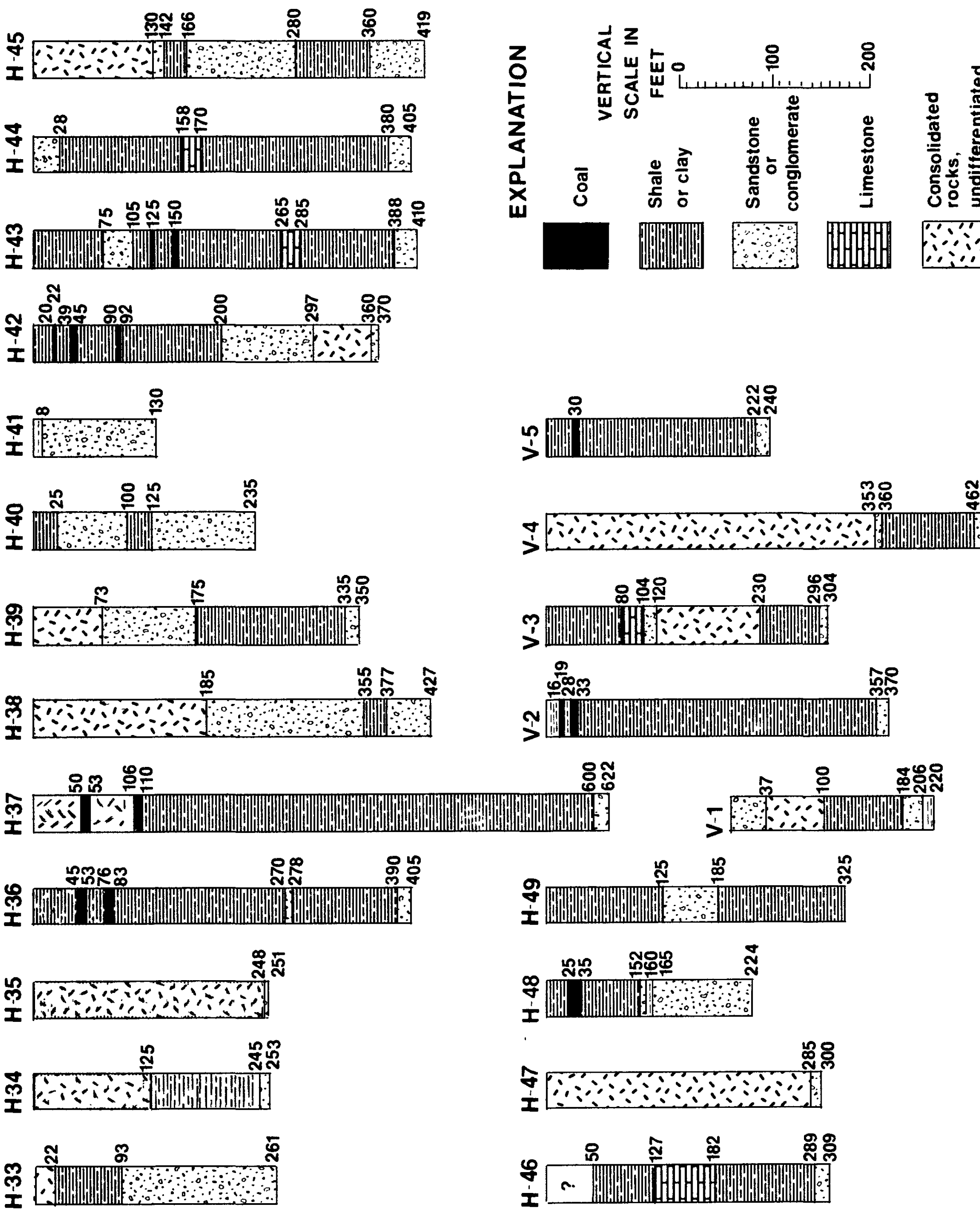


Figure 18. --Logs of wells listed in table 3 (continued).

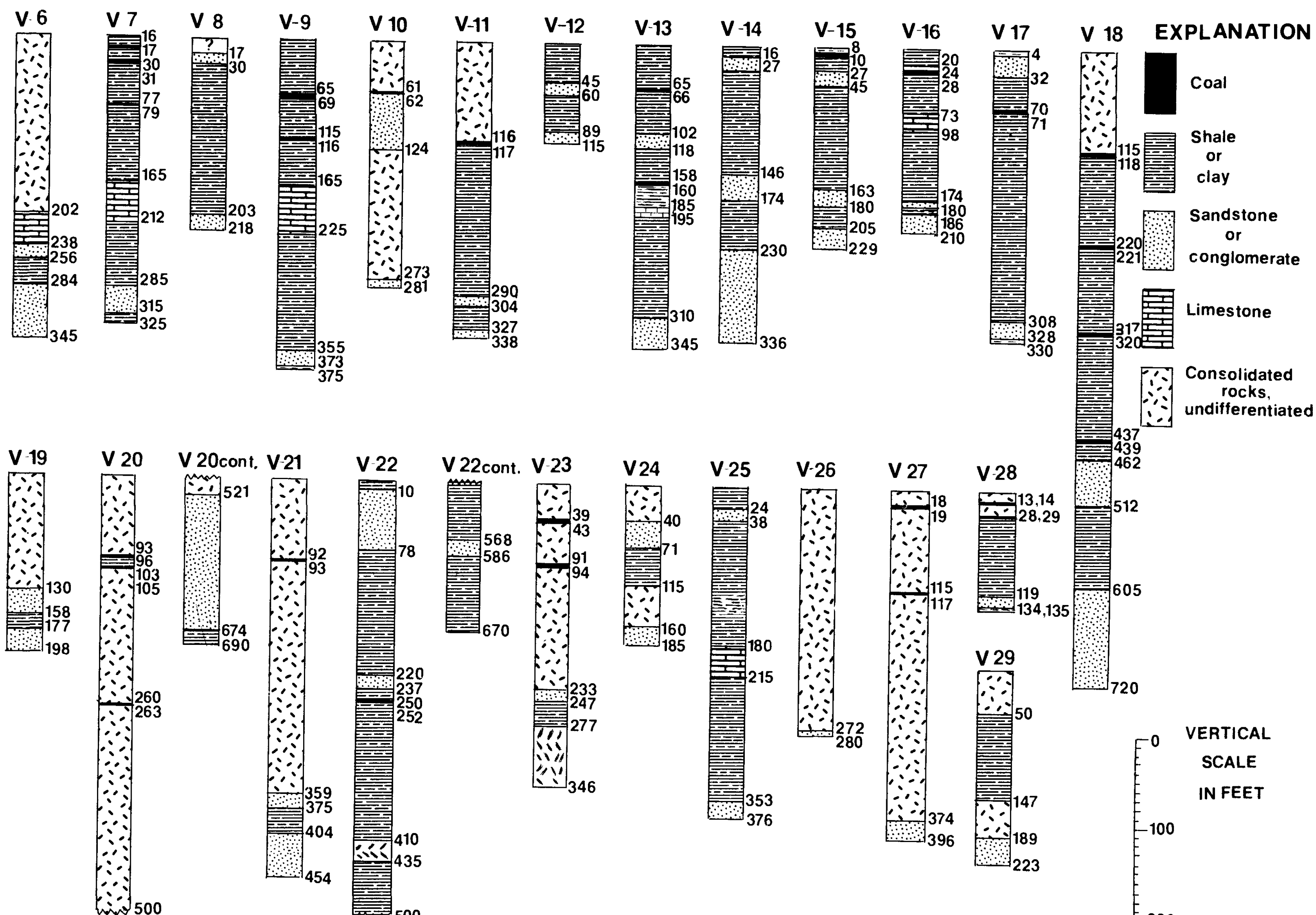


Figure 18. --Logs of wells listed in table 3 (continued).

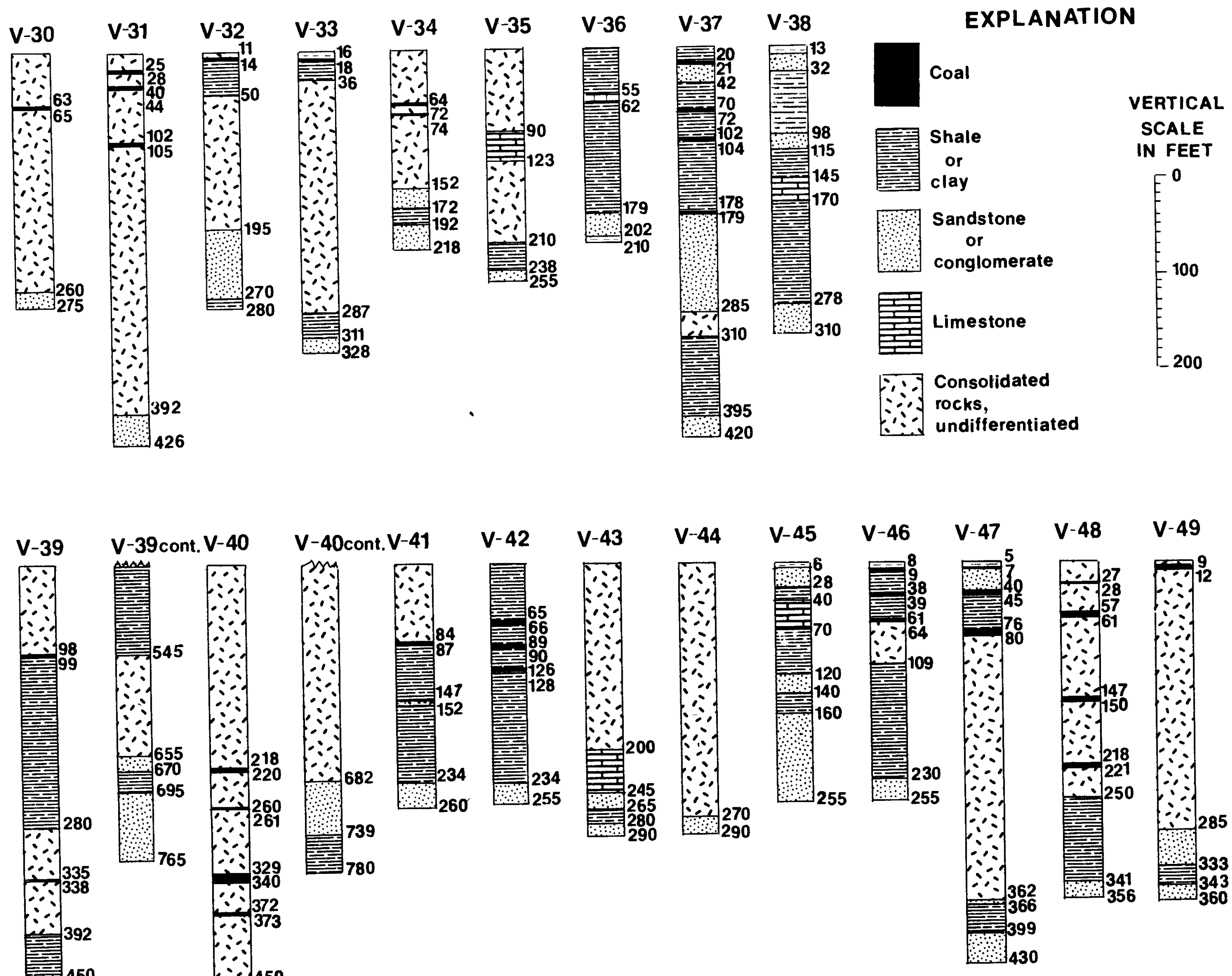


Figure 18. --Logs of wells listed in table 3 (continued).

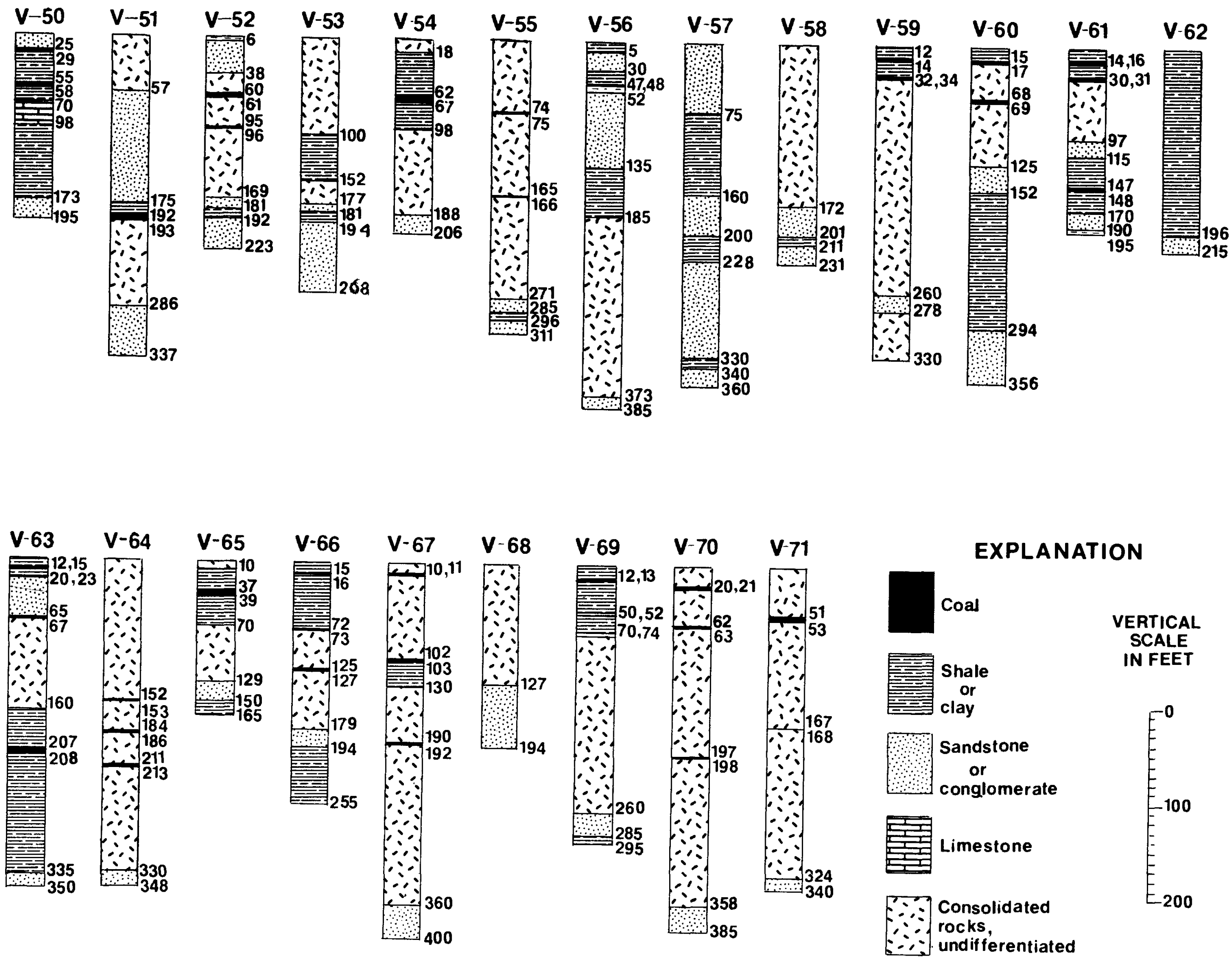


Figure 18. --Logs of wells listed in table 3 (continued).

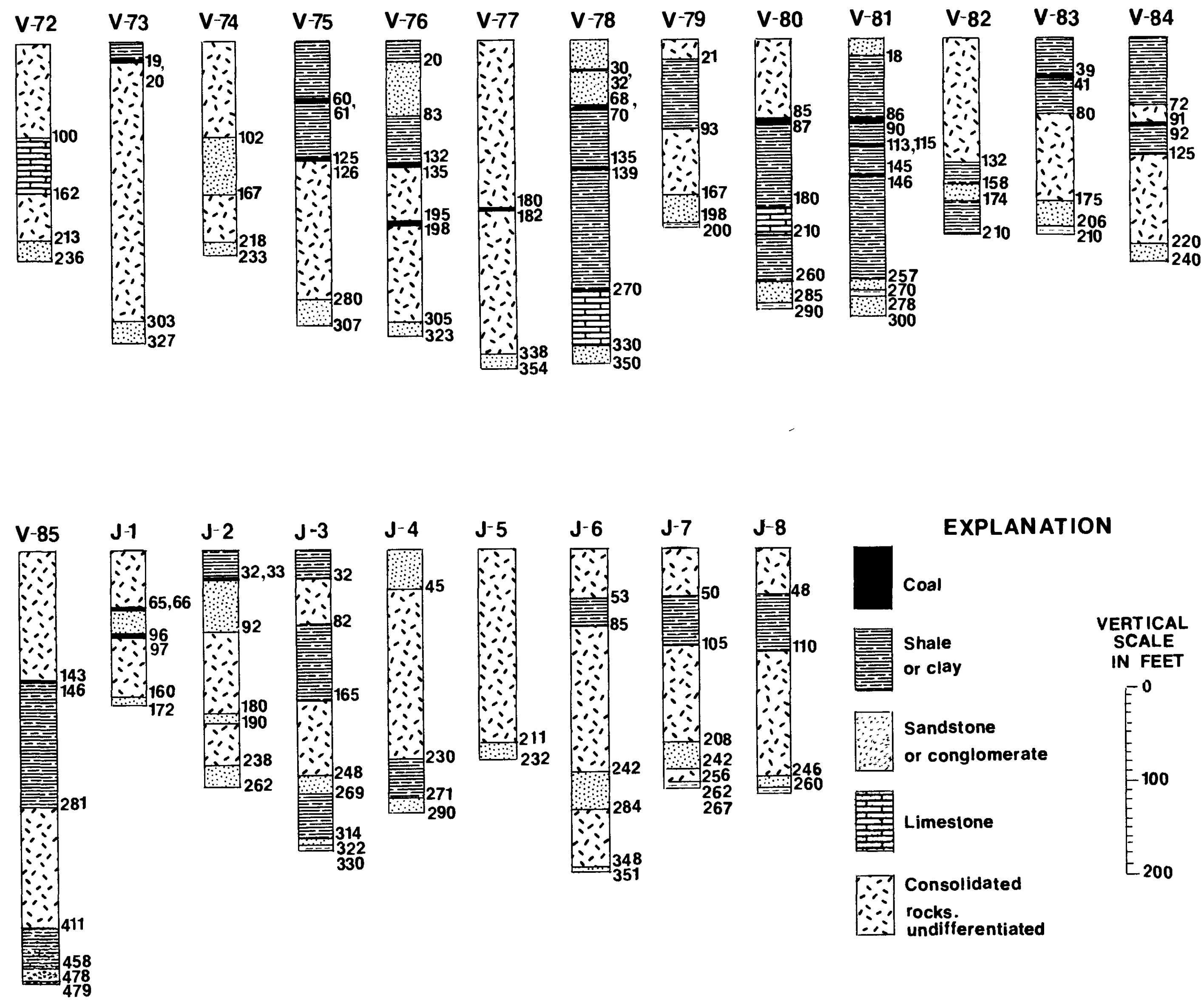


Figure 18.--Logs of wells listed in table 3 (continued).

SUMMARY AND CONCLUSIONS

The Black Hand Sandstone Member of the Cuyahoga Formation and Allensville Conglomerate Member of the Logan Formation, of Mississippian age singly and in combination, are major sources of water in much of Hocking, Vinton, and parts of adjacent counties in southeast Ohio. Dependable water supplies can readily be obtained from these aquifers in most places, except where the Black Hand contains brine. Individual wells commonly yield sufficient water for typical farm and home requirements.

Large water supplies have been developed at McArthur, where estimated municipal and industrial pumpage totals about 300,000 gallons per day (200 gal/min), but withdrawal has been accompanied by declining ground-water levels in the past 10 years in about 10 square miles. Future increases in pumpage are likely to result in an accelerated rate of decline, which ultimately may require drilling additional wells and spreading pumping over a larger area.

Water-yielding properties of the aquifers are not high. The specific capacity of wells is generally less than 0.5 (gal/min)/ft of drawdown, exceeding this value only in two township-sized areas, one in Vinton County and the other in Hocking County.

Aquifer transmissivity, a measure of the property of an aquifer to transmit water under a hydraulic gradient, determined at McArthur from a well open to both the Black Hand and Allensville, is 135 ft^2/d, a low value compared to that of a typical sand and gravel aquifer. For example, the transmissivity of a sand and gravel aquifer 60 feet thick in the Scioto River valley at Piketon, Ohio, at a fairly typical site,is 27,000 ft^2/d (Norris and Fidler, 1969). The relatively low transmissivity of the sandstone aquifers, combined with low rates of infiltration through many feet of overlying shale, rules out these aquifers as sources of very large ground-water supplies. Ultimately, if the demand for industrial or municipal water supplies increases, development of surface-water sources will have to be considered.

The chemical quality of the ground water is such that it is generally suitable for most purposes. Of 30 samples collected from wells, 16 were below 500 mg/L in dissolved solids, EPA's recommended upper limit for drinking water. Iron was below U.S. EPA's recommended limit of 0.3 mg/L in all but three samples.

The ground water in the western part of the area is predominately a sodium bicarbonate type, typical of sandstone aquifers, and it changes, as it moves downdip and downgradient, to a sodium chloride type in the eastern part of the area. Ultimately, as the water moves farther beneath sediments of increasing thickness, it becomes too salty for ordinary use. It is unlikely that water from the Black Hand and Allensville is potable as far east as Athens County.

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