LINEAMENTS AND FRACTURE TRACES, DECATUR COUNTY, INDIANA

By Theodore K. Greeman

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ILLUSTRATIONS

FACTORS FOR CONVERTING INCH-POUND UNITS TO THE INTERNATIONAL SYSTEM OF UNITS (SI)

Multiply inch-pound unit	By	To obtain SI (metric) unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
gallon per minute (gal/min)	3.785	liter per minute (L/min)
million gallons per day (Mgal/d)	3,785	cubic meter per day (m^3/d)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
square mile (mi^2)	259.0	hectare (ha)

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By Theodore K. Greeman

ABSTRACT

Lineaments and fracture traces have been mapped throughout Decatur County, Indiana. These lineaments and fracture traces may indicate that solution-enlarged vertical fractures in the limestone and dolomite aquifers underlie most of the county. The use of lineament and fracture-trace maps in selecting bedrock-drilling sites results in a significant increase in the number of usable sites. Bedrock wells drilled on or near mapped lineaments and fracture traces have a higher average yield than wells drilled into interfracture areas.

Parts of Decatur County and several adjacent counties are economically restricted by inadequate water supplies. The Greensburg Municipal Water Works, supplying 35 percent of the county's population, obtains 25 percent of its water from six wells in Greensburg. The remaining 75 percent is pumped from the Flat Rock River. This water is piped 8.25 miles and lifted 183 feet to the treatment station. Although the Flatrock River has adeduate flow to supply Greensburg's water needs, a ground-water supply can probably be developed nearer the treatment plant.

Pleistocene till covers most of the nearly horizontal bedrock. Although averaging about 50 feet thick, this unconsolidated unit does not seem to inhibit the mapping of lineaments and fracture traces. Bedrock is middle Paleozoic limestone, dolomite, and shale. Two sequences of limestone and dolomite, separated by a thin shale unit, constitute the principal aquifer. The extremely variable well yields from this aquifer indicate that the bedrock permeability is also variable.

Well placement is important in a fractured bedrock terrane, as fractures are a principal source of water to the well. Here, the most productive bedrock wells are at the mapped intersection of two or more fracture traces or lineaments and at the lowest local altitude. Use of a fracture-trace map will not guarantee a sufficient supply of ground water but will reduce the chance of drilling an inadequate well.

INTRODUCTION

This report is the result of a 1-yr (year) study by the U.S. Geological Survey in cooperation with the Indiana Department of Natural Resources and Decatur County. The purpose of the study was to map the locations of lineaments and fracture traces observed in Decatur County (pl. 1). The report describes water-supply problems, geology, and use of lineaments and fracture traces for locating ground water in Decatur County. This report is similar to another report (Greeman, 1981) on Jennings County and Jefferson Proving Ground, immediately south of Decatur County.

Decatur County is underlain by a nearly horizontal limestone-dolomite aquifer. Water moves through the aquifer along interconnecting bedrock joints, fractures, and solution channels. Locations of some bedrock fractures are indicated by lineaments or fracture traces at the land surface. These features are helpful in prospecting for ground water.

In the terminology suggested by Lattman (1958), lineaments and fracture traces are natural linear and curvilinear features consisting of topographic, vegetative, soil-tone, and drainage alinements visible on aerial photographs and mosaics. In bare-rock areas, bedrock joints mapped on aerial photographs are included in this terminology. The difference between lineaments and fracture traces is based on length. Lineaments are discernible in lengths of 1 mi (mile) or more and may be discernible as several segments totaling many miles, whereas fracture traces are less than a mile in length. Moore (1976, p. 48) stated that all lineaments are composed of short, discontinuous segments. The ability of the interpreter to fuse these segments into a lineament depends mostly on the resolution, scale, and contrast of the aerial photographs.

Although the preceding definitions impart no information on the origin of lineaments and fracture traces, Hine (1970) and Moore (1976, p. 30), working in areas underlain by nearly horizontal bedrock similar to the bedrock in Decatur County, determined that fracture traces and lineaments are the mapped expressions of vertical bedrock fractures. All vertical fractures in Decatur County are assumed to be bedrock joints that formed as local adjustments to regional tectonic movement. Connection between mapped lineaments and fracture traces and underlying vertical bedrock fractures was verified at several locations. Although vertical bedrock fractures may also form by faulting, displacement is not apparent along any of these observed bedrock fractures.

Most sedimentary rocks contain water within voids. For example, limestone, dolomite, and shale contain from 4 to 30 percent water-filled pore spaces by volume (Davis and DeWiest, 1966, p. 348-349). However, this water is trapped and unable to move unless the pore spaces are interconnected. Vertical fracturing of the bedrock produces the conduits necessary for movement of the trapped water.

After vertical fracturing occurs, surface water can move downward into the rock. Weak acids form when carbon dioxide and soluble organic compounds dissolve in water moving through an organic soil. Limestone and dolomite are slightly soluble in these acids. Continuous chemical dissolution of the bedrock by the acids enlarges the water-filled voids and the circulation paths. Mapped lineaments and fracture traces are presumed to indicate the most prominent vertical bedrock fractures in Decatur County, and water wells drilled on these mapped lineaments and fracture traces should offer the greatest likelihood of intersecting water-filled solution cavities.

BACKGROUND

Decatur County, 370 mi^2 (square miles) of southeastern Indiana (fig. 1), had a population of 23,841 (U.S. Department of Commerce, 1980) in 1980. Greensburg, the centrally located county seat and largest city in the county, had a population of 9,254 in 1980 (U.S. Department of Commerce, 1980). The 1970 census (U.S. Department of Commerce, 1970) placed more than 60 percent of the county population in a rural category.

Although ground water is difficult to develop in Decatur and other neighboring counties, it is the only source of water available to more than 70 percent of Decatur County's population. Limestone and dolomite bedrock are the principal source of water. Well yields from this aquifer are extremely variable. Bedrock wells in southeastern Indiana are generally 6 in. in diameter. Many wells drilled at randomly selected sites do not yield enough water for domestic needs. Drift covers the bedrock in most of the county; however, the drift is composed of clay and fine sand, which transmit little water to a well.

Decatur County has three water utilities. Greensburg's municipal water works, the largest, can treat 4.0 Mgal/d. About 75 percent of this supply is pumped from the Flatrock River, and the remainder is pumped from bedrock wells in town (Bob Shafer, superintendent of Greensburg Water Works, oral commun., October 30, 1979). The Westport Water Company obtains most of its 0.15 Mgal/d from Sand Creek (Lee Day of the Westport Water Co., oral commun., January 9, 1980). Flow-duration records (for 1949-67) indicate Westport's use exceeds flow in Sand Creek more than 10 percent of the time from August through October and that 60 consecutive days of no flow can be expected with a recurrence interval of 10 yr. Therefore, Westport recently increased the capacity of its holding ponds to 35 Mgal (Lee Day, oral commun., January 9, 1980). Streamflow can be pumped into the holding ponds for use during low flow. The privately owned third utility supplies water to Lake Santee, a private lakeside recreational development whose water use is seasonal. Lake Santee's normal water supply comes from three wells in the bedrock aquifer. During the summer of 1979, this utility supplied an average of 0.06 Mgal/d (Frank Smith of Lake Santee Inc., oral commun., January 10, 1980). Lake Santee's utility can supplement ground water with lake water if demand exceeds the 0.09 Mgal/d well supply, or if the well field must be repaired.

Although more than 60 percent of the county population is rural, none of these utilities has a rural distribution. Less than 100 rural customers are able to hook up to water lines. Thus, adequate private-well supplies are essential.

Greensburg's experience in developing and expanding a water supply from a thin limestone-dolomite aquifer is not uncommon. Established as a private utility in 1921, the Greensburg Municipal Water Works began distributing water from a shallow well in the drift. Since becoming a public utility in 1937, the water works has drilled about 50 bedrock wells. Only 17 were ever used by the utility, and of those, only 6 are still producing adequate yields.

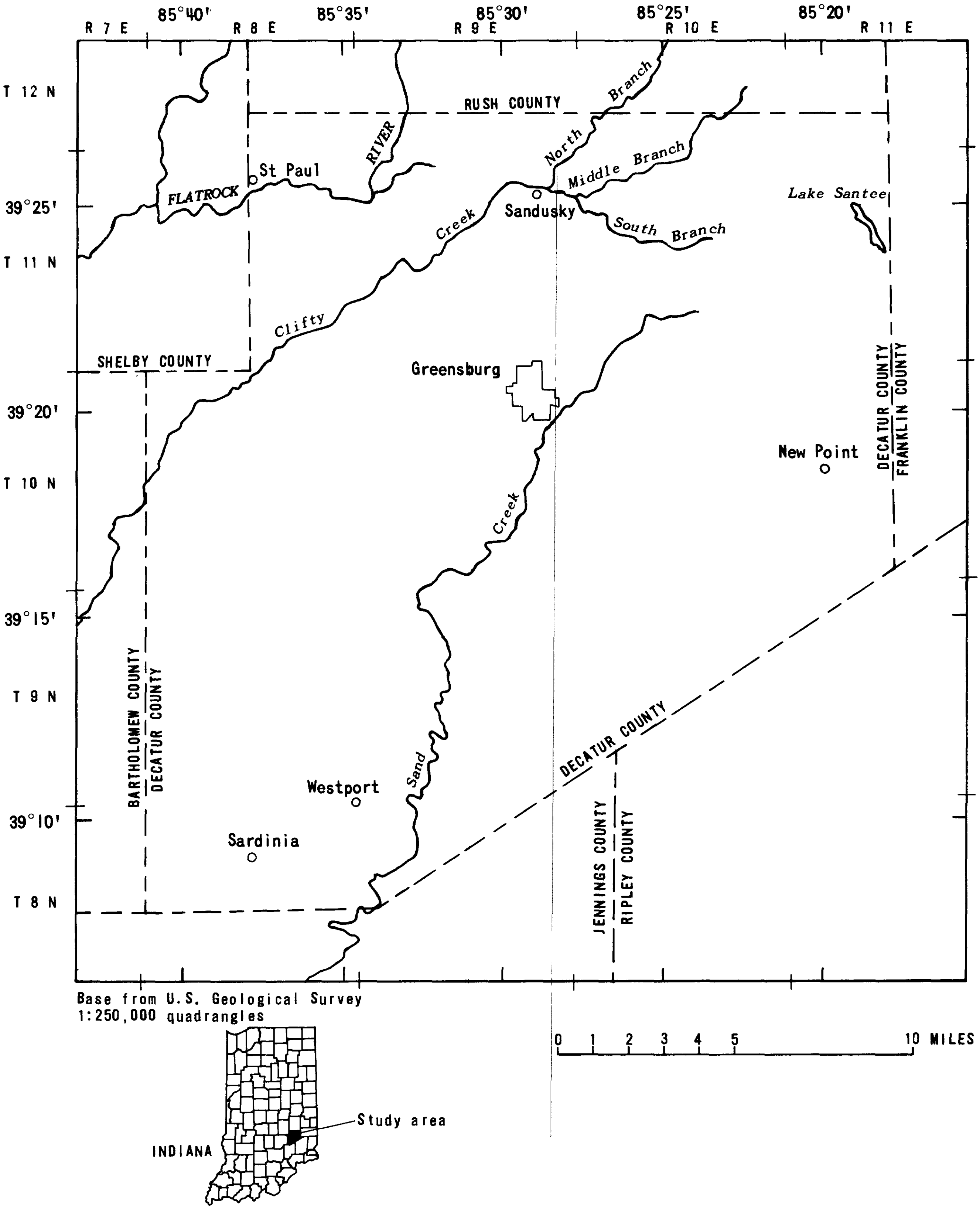

Figure 1.-- Study area, Decatur County.

To supplement the ground-water supply, the Greensburg Municipal Water Works began pumping water from the Flatrock River in 1956. This water is piped 8.25 mi and is lifted 183 ft to the treatment plant. Although the six remaining wells could supply more than 90 percent of the 1.5 Mgal/d supplied by the utility in 1978, only 25 percent of the utility's production came from the bedrock wells; the remainder was pumped from the Flatrock River impoundment (Bob Shafer, oral commun., October 30, 1979).

In Decatur County, reliance on surface water as a supply for Greensburg and Westport is the result of problems experienced in random exploration for ground water. Although many rural landowners believe that Decatur County needs a rural water-distribution system, adequate supplies of ground water are probably available to meet Decatur County's needs.

GEOLOGIC SETTING

The bedrock has been covered by unconsolidated Pleistocene drift composed largely of sedimentary rock debris. The drift is a fine-grained mixture of clay, silt, and sand containing some gravel and boulders. Erosion has exposed the bedrock in many places, especially along streams. Illinoian and Wisconsinan glaciations are indicated by surficial till units. Buried till units, exposed only in stream cuts, may indicate as many as six periods of pre-Illinoian glaciation (Teller, 1972).

Illinoian and pre-Illinoian glaciation covered the county with drift averaging less than 25 ft in thickness (Baldwin and others, 1922, p. 8). The more recent Wisconsinan glaciation advanced over all but the southeastern quarter of the county and covered the older tills. The southern limit of Wisconsinan glaciation is indicated in most places by a distinct change in topography. The altitude of the gently rolling surface of the Wisconsinan till abruptly decreases 20 to 30 ft at the terminus to the nearly level surface of the Illinoian till. The well-defined Wisconsinan terminus extends northeast-southwest across the county from 2 mi south of Sardinia to the northeast corner of the county (fig. 2). Northwest of this boundary, the thickness of Wisconsinan and older drift averages about 50 ft, although 141 ft of unconsolidated drift is reported (drillers' log) where a preglacial stream channel is buried.

Although most of the Wisconsinan drift in Decatur County is well drained, the older Illinoian drift surface is poorly drained because of its low relief and the buildup of impervious soil zones. The surface of the Wisconsinan drift sheet dips southwest 14 ft/mi.

Paleozoic bedrock units, horizontal when deposited, dip southwest 14 ft/mi, whereas the bedrock erosion surface slopes in the same direction 12 ft/mi (Schneider, 1966, p. 44). This similarity in slope between the bedrock dip and bedrock surface indicates structural control.

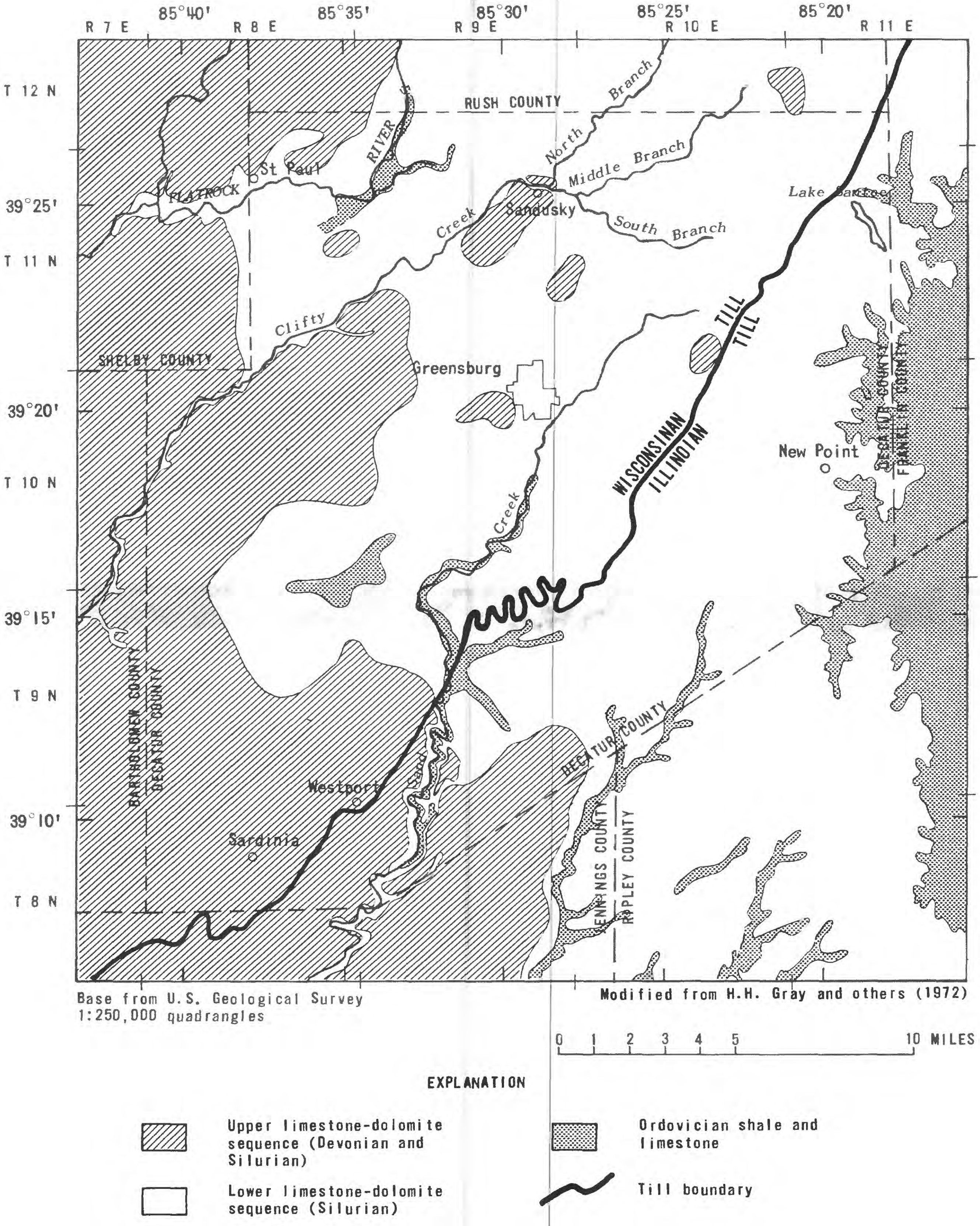

Figure 2.-- Bedrock and surficial geology of Decatur County, Ind.

A structural high (Cincinnati arch) began developing during Ordovician time in the tristate area of Indiana, Ohio, and Kentucky. Upper Ordovician and younger formations thin as they approach this uplifted area. During the Silurian and continuing for the remainder of the Paleozoic Era, deep structural depressions developed in southern Illinois (Illinois Basin), eastern Ohio (Appalachian Basin), and the Lower Peninsula of Michigan (Michigan Basin). Owing to the development of basins to the east and west, the shape of the arch became elongated north-south. The curved axis of the arch lies approximately 50 mi east of Decatur County and trends north to north-northwest in Indiana and Ohio. The bedrock dip decreases near the crest of the arch. This change in dip is indicated by Ordovician bedrock inliers west of the Ordovician outcrop area (fig. 2).

The Paleozoic bedrock ranges in age from Late Ordovician through Middle Devonian. Bedrock is exposed by stream erosion at numerous locations in the county. Ordovician rocks, which underlie the entire study area, are exposed in the steep ravines along the east edge of the county. These same rocks are more than 160 ft below land surface near the southwest corner of the county. The Late Ordovician rocks are composed of thin alternating layers of shale and shaly limestone. Their shale content increases with depth. High shale content makes the Ordovician rocks a poor source of water.

Silurian limestone and dolomite, overlying the Ordovician rocks, indicate the end of silt deposition. Limestone was deposited almost continously in southeast Indiana, from Early Silurian, until the end of the Middle Devonian. Some of this limestone has been chemically altered to dolomite, increasing the porosity. The combined thickness of the Silurian and Devonian limestone and dolomite is as much as 125 ft. The limestone and dolomite can be subdivided into the upper and the lower hydrologic sequences (fig. 2). A discontinuous Silurian shale, as thick as 6 ft, separates the upper and the lower sequences in some areas.

The lower limestone-dolomite sequence (Silurian age) attains a maximum thickness of 100 ft in Decatur County. The Laurel Member of the Salamonie Dolomite forms a resistant cap rock that protects the lower sequence. This resistant unit is a fine-grained, thick-bedded dolomite containing numerous chert nodules. In outcrop, the protective cap rock allows the lower sequence to form a low relief plain extending southward into Kentucky from the terminus of the Wisconsinan glaciation. North of the Wisconsinan terminus, the thickness of the overlying drift obscures this stratigraphic plain. Underlying the Laurel Member is the Osgood Member of the Salamonie Dolomite. The member consists of thin upper and lower limy shales and a thick interbedded clayey dolomite. The widely variable shale content of the member is greatest in the eastern part of the county. The lowest formation included in the lower limestone-dolomite sequence is the Brassfield Limestone of Silurian age.

The Waldron Shale of Middle Silurian age discontinuously seperates the upper and the lower sequences in southwest Indiana. Several periods of erosion have affected the distribution of this shale and the overlying lowest formation in the upper limestone-dolomite sequence. After deposition of the Middle Silurian Louisville Limestone, one or more periods of erosion during Late Silurian-Early Devonian time removed the Waldron and Louisville Formations from all but 50 mi^2 of Decatur County. The Waldron Shale underlies the west side of

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the county, near Sandusky, and north of Westport. This shale has no distinctive outcrop area. Where unaffected by previous erosion, the shale's distribution is the same as that of the upper sequence, which acts as a protective cover and prevents erosion. Where uneroded, the shale retards the circulation of water between the upper and lower limestone and dolomite sequences.

Formations that compose the upper limestone-dolomite sequence are Middle Silurian through Middle Devonian in age. Although most of the Silurian age rock of the upper sequence was removed by Late Silurian-Early Devonian erosion, Devonian age formations of the upper sequence underlie almost one-third of the county (fig. 2). The upper sequence is as thick as 75 ft in the southwest corner of the county, even though no complete section is known within the county. Formations that compose the upper limestone-dolomite sequence are thinner bedded and less resistant than those in the lower sequence. The upper sequence is more porous than the lower and, therefore, a better source of water.

The oldest formation in the upper limestone-dolomite sequence is the Middle Silurian Louisville Limestone. Other formations in the sequence were deposited during Devonian time. They are, from oldest to youngest, the Geneva Dolomite, Jeffersonville Limestone, and the North Vernon Limestone. The combined thick ness of the North Vernon and Jeffersonville Limestones ranges from 0 to 50 ft. Color ranges from dark gray to brown. The Geneva Dolomite is a fine-grained, buff to chocolate brown dolostone that has a texture similar to that of loaf sugar. Its thickness ranges from 0 to 30 ft. The upper limestone-dolomite sequence crops out in the west half of the county, where stream erosion has removed the overlying till.

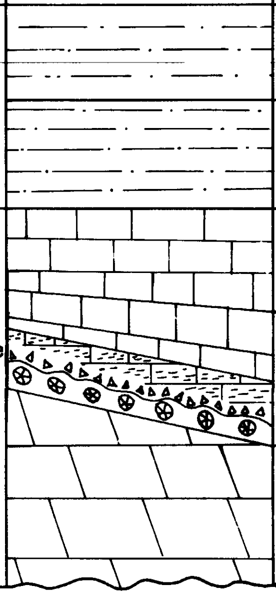
Although bedrock jointing is prominent in both the upper and the lower limestone-dolomite sequences, dissolution along joints is more pronounced in the upper sequence. Lithology and aquifer characteristics of each geologic formation are given in the generalized stratigraphic column (fig. 3), which is based on data in Shaver and others (1970) and on well records filed with the Indiana Department of Natural Resources, Indianapolis.

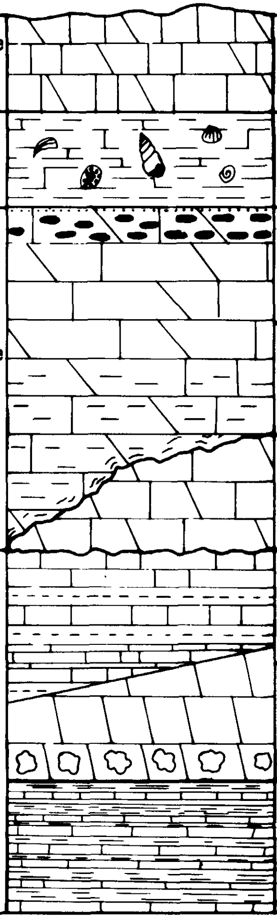
INTERPRETATION OF LINEAMENTS AND FRACTURE TRACES

The probable locations of vertical bedrock fractures delineated on the lineament and fracture-trace map (pl. 1) were interpreted on 1:24,000-scale, black and white aerial photographs obtained on March 15, 1977, by the State of Indiana. Original photographic interpretations were transferred to 1:24,000 scale topographic maps. Original maps and aerial photographs are available for inspection at the Geological Survey office in Indianapolis.

Many factors affect the mapping of lineaments and fracture traces on aerial photographs. Lattman (1958), Moore (1976, p. 16-28), and Trainer (1967) discussed the effects of film type, photographic scale, time of year, method of

ERATHEM	SYSTEM	SERIES OR STAGE	STRATIGRAPHIC UNIT	THICKNESS (FEET)	HYDRO-GEOLOGIC UNIT	REPRESENTATIVE STRATIGRAPHIC SECTION WITH LITHOLOGIC DESCRIPTIONS AND WATER-YIELDING CHARACTERISTICS OF UNITS: UNIT CHARACTERISTICS	WATER-YIELDING CHARACTERISTICS
Cenozoic	Quaternary	Pleistocene	Wisconsinan deposits	0-100	Till	Unconsolidated till and minor segregation of coarse material; soils brownish-gray to reddish-brown; undulating surface, low relief.	Poor source of water because of lack of sand and gravel aquifers and possibility of contamination.
				0-141			
			Illinoian deposits and older	0-67		Unconsolidated till, mostly clay; soils light-gray on flats to reddish-gray on slopes; flat uplands, deeply dissected by streams.	
Paleozoic	Devonian	Erian	North Vernon Limestone[1]	0-20	Upper limestone and dolomite sequence	Limestone, dark-gray to blue-gray, fine to coarse-grained, hard and fossiliferous. Upper half, thick bedded; lower half, thin to medium bedded.	Good source of water for domestic and possibly larger uses; springs common at base of Jeffersonville Limestone.
			Jeffersonville Limestone[1]	0-30		Limestone, gray to brown; greatly varying lithology from top to bottom with laminated breccia zone and coral zone; abundant calcite and pyrite recrystallization.	
		Ulsterian	Geneva Dolomite[1]	0-30		Dolomite, buff to chocolate-brown; fine-grained, soft, sugary texture; thin bedded at top and thick bedded at base; large recrystallized calcite common.	





Era	System	Series	Formation	Thickness (ft)		Description	Water-bearing characteristics
Paleozoic	Silurian	Niagaran	Louisville Limestone	0-30	Upper limestone and dolomite sequence	Dolomitic limestone, tan to brown, very fine grained, argillaceous; thick-bedded; fossils distorted, commonly mottled and with chert zones.	Good source of water for domestic and possibly larger uses.
			Waldron Shale	0-6	Shale	Shale, blue-gray and clayey; thin bedded; very fossiliferous and easily eroded.	Only confining unit in the 150 feet of carbonate strata.
			Salamonie Dolomite[1]: Laurel[1] Member	0-90	Lower limestone and dolomite sequence	Dolomitic limestone, light-gray to tan, fine-grained and argillaceous; thick bedded with abundant chert.	Poor source of water; limited domestic and stock use.
			Salamonie Dolomite[1]: Osgood[1] Member			Dolomite or limestone, tan to tan-gray, highly argillaceous; shale content increases southward.	
		Alexandrian	Brassfield Limestone	0-10		Limestone, variable white, yellow-brown to salmon-pink, medium- to coarse-texture, and fossiliferous; some dolomite and irregular shale lenses.	Minor yields to water wells.
	Ordovician	Cincinnatian	Whitewater Formation	0-60	Increasing shale	Interbedded calcareous shale and limestone, light- to dark-gray, thin bedded; thins southward from Decatur County.	Chiefly a confining unit; high shale content.
			Saluda Formation	20-50		Dolomitic limestone, gray, silty, basal coral zone; unit thins northward.	Good domestic use; industrial and farm supplies possible.
			Dillsboro Formation	~ 300		Argillaceous limestones and calcareous shales; thin, interbedded, highly fossiliferous, containing about 70 percent shale.	Poor water production; chiefly a confining formation.

[1]Usage of the Indiana Geological Survey.

Figure 3.-- Generalized geologic column for Decatur County, Ind.

examination, and length of viewing time per photograph on interpretations of lineaments and fracture traces. Maintaining a uniform length of interpretation time per photograph is essential to the areal continuity of the result in density of lineaments and fracture traces mapped.

Another factor affecting the density of mapped lineaments and fracture traces is lithology. Different bedrock lithologies develop different fracture spacings. Thick-bedded nonporous limestone and dolomite develop a low density of long, continuous lineaments, whereas thick-bedded shale develops a high density of short, discontinuous fracture traces. Examination of plate 1 indicates that a high density of lineaments and fracture traces has been mapped in most of Decatur County. This mapped density resembles that of a shale overlying a thin-bedded limestone.

Pleistocene drift ranging from 0 to 141 ft thick overlies the limestone and dolomite bedrock. The areas displaying the highest density of mapped lineaments and fracture traces correspond to the areas having the thickest accumulations of drift, whereas areas having only a thin drift cover have the lowest density. Working with similar drift-covered Paleozoic bedrock, Mollard (1957) reported that patterns formed by lineaments are "to a large extent...quite independent of topography as well as the age, composition and depth of surface materials in which they are expressed." Mollard (1957) also interpreted lineaments in areas where the bedrock is overlain by more than 350 ft of unconsolidated materials of Pleistocene and Holocene age.

Although the drift may not inhibit the mapping of lineaments, the effect of the drift on the mapped density of lineaments and fracture traces is not understood. Therefore, the numerous, closely spaced fracture traces mapped in Decatur County may represent the jointing pattern of the drift, superimposed onto the characteristic jointing pattern of the limestone and dolomite bedrock.

Although each lithologic unit expresses a characteristic fracture density, relief can cause major variations in the mapped density of fracture traces and lineaments. Relief accentuates the effects of erosion on bedrock fractures and thus enables the interpreter to observe and map a greater density of fracture traces and lineaments than would be possible without it.

Differences in land use also cause variations in the mapped density of line aments and fracture traces. Many of man's activities tend to obscure subtle natural features. In urban areas, man changes the landscape by rechanneling drainage, building roads and structures, and leveling undulating land so that only lineaments can be recognized. A good example of this effect can be seen in the city of Greensburg (pl. 1). Extensive earth-moving and drainage rechannelling has obscured all fracture traces within the urban area; only lineaments are visible for mapping.

Agricultural activity also tends to obscure some fracture traces but seldom changes natural drainage patterns. Therefore, although the mapped density of fracture traces may be changed, the effect of agriculture on the mapped density of lineaments is minor. Native vegetation, where allowed to establish natural growth, yields the most complete lineament and fracture-trace interpretation. This vegetation is not very noticeable in an agricultural area like Decatur County, as only 10 percent of the county has forest cover.

Fracture traces and lineaments are generally associated with surface-drainage paths. Major streams and main tributaries, equally spaced and parallel, drain the study area and flow southwest down the regional bedrock slope. Short minor tributaries drain generally northwest or southeast. The most prominent fracture-trace and lineament orientations mapped (pl. 1) are conjugate and are oriented northeast-southwest and northwest-southeast, parallel with the principal drainage orientations. Less prominent fracture-trace and lineament orientations are mapped north-south and east-west.

The orientation of streams draining Decatur County is not random. Rather, surface-drainage paths are controlled by fractures in the bedrock. Further indication of fracture-controlled drainage is the nearly right-angle meanders of these streams, whereas segments in between are straight.

SOURCES OF WATER TO BEDROCK WELLS

Limestone and dolomite of Silurian and Devonian age compose the principal bedrock aquifer in Decatur County. This aquifer includes both the upper and the lower limestone and dolomite sequences. Well records indicate that the yield from the limestone-dolomite aquifer ranges from 0 to 250 gal/min. Water enters wells through openings in the limestone and dolomite. The greater the number and the size of interconnecting water-filled openings intersected by the well bore, the greater the yield.

Work in other areas (LaRiccia and Rauch, 1976; Siddiqui, 1969) indicates that wells on or very near vertical bedrock fractures mapped as lineaments and fracture traces have significantly higher yields than wells in interfracture areas. The work of these investigators also indicates that a significantly higher percentage of wells having adequate yields have been drilled on lineament or fracture-trace sites than on randomly chosen sites. Working with thick dolomite and limestone formations, Lattman and Parizek (1964) reported that wells on a fracture trace (or lineament) intersect a greater number of cavernous openings than wells drilled in interfracture trace areas. All these studies indicate that fracture traces and lineaments overlie vertical zones of advanced solvent activity and, therefore, are useful prospecting guides for locating the high permeability zones within a limestone or dolomite aquifer.

Locations of numerous mapped lineaments and fracture traces were verified by field checking. In addition, examination of bedrock exposures along Clifty Creek, Sand Creek, and Flatrock River, and in rock quarries at St. Paul and near Newpoint verified that vertical bedrock fractures underlie these mapped features. Water draining from a vertical fracture mapped as a fracture trace was observed at the quarry near Newpoint.

Zones of high permeability within the limestone and dolomite aquifer have developed since deposition, owing to vertical fracturing and solvent action. Stresses within the bedrock have been released by numerous vertical fractures (joints). Chemical and mechanical erosion are accelerated by the water that infiltrates the fractures and penetrates the aquifer. The resulting differential erosion rates induce preferential development of surface drainage routes along fractures. Vertical bedrock fractures underlying lineaments and fracture traces are widest near the land surface, where ground-water velocities and solvent action are greatest.

Most reports of inadequate bedrock wells are from areas where only the dense, thick-bedded lower sequence remains after erosion has removed the upper limestone and dolomite sequence. Permeability in the lower sequence is low because the siliceous dolomite capping the lower sequence is extremely resistant to dissolution along vertical fractures and horizontal bedding planes. Wells on lineaments and fracture traces associated with surface-drainage routes have the best possibility for producing domestic or larger water supplies from the lower sequence. Yields of as much as 20 gal/min may be obtained from the lower sequence along lineaments and fracture traces in the zone of high permeability associated with most perennial streams.

Well records for the upper-sequence outcrop area indicate that drillers commonly obtain adequate domestic supplies of water above the lower sequence, even in areas where erosion reduces the upper-sequence thickness to 10 ft. Perennial streams draining the upper-sequence outcrop area flow in narrow, fracture-controlled channels in the high permeability zones adjacent to these streams.

DRILLING OF WELLS ON LINEAMENTS AND FRACTURE TRACES

Placement of the well is the most important step involved in developing a usable water supply in a fractured limestone or dolomite terrane. Wells in an unfractured limestone or dolomite produce from water-filled horizontal openings along bedding planes and interconnected water-filled voids penetrated by the well bore. Exemplifying this situation are wells drilled in interfracture areas, where yields are generally small. Interfracture wells in the thin-bedded upper limestone-dolomite sequence penetrate numerous bedding planes and generally have small-to-moderate yields. Similar wells in the dense, thick-bedded lower sequence are commonly abandoned because of low yields.

Wells drilled into a vertical bedrock fracture, or into the intersection of two or more fractures, produce from vertical, water-filled openings, as well as from horizontal bedding planes and interconnected water-filled voids penetrated by the well bore. Vertical bedrock fractures transmit a large part of the water that moves through the limestone-dolomite aquifer, and wells in the fractures generally yield sufficient supplies for domestic needs. Lineaments and fracture traces overlie the vertical bedrock fractures carrying much of the flow through the limestone-dolomite aquifer toward the lowest surface drainages. Therefore, the most productive well sites are at the intersection of two or more lineaments or fracture traces and at the lowest local altitude.

Well-site selection based on lineament and fracture-trace mapping enables the planner to determine the probable locations of prominent bedrock fractures. The use of lineament and fracture-trace mapping does not guarantee an adequate ground-water supply because this depends on the needs of the invididual user. However, the use of lineament and fracture-trace mapping should allow the planner to determine where the best possible well yield in the immediate vicinity can be obtained.

Locating suitable well sites from lineament and fracture-trace maps may create several problems and expenses not ordinarily experienced in developing a ground-water system. Because the most desirable lineament and fracture-trace sites are generally located in surface drainages, access for drilling equipment is frequently difficult without road construction. Another problem is that many lineaments and fracture-trace sites are several hundred feet from the well drained soils on which houses and other buildings are constructed. However, cost increases due to site preparation and piping distance should be balanced by the savings obtained from drilling fewer inadequate wells, especially in the east half of the county, where the incidence of inadequate wells is highest.

Drilling into vertical bedrock fractures and their intersections may also impose some difficulties on the driller. Deflection of the drill bit by angular surfaces and loose rocks in vertical fractures may result in crooked well bores that are unusable. Greater lengths of casing than normal are needed to seal out mud that has slumped into solution openings in many holes drilled on lineaments. These difficulties may be avoided by drilling immediately adjacent to the bed rock fractures, instead of directly into them. Local well records indicate that highest well yields are obtained within about 100 ft of a lineament. Bedrock fractures underlying fracture traces have less influence on surrounding bedrock permeability than lineaments. Therefore, drilling on fracture-trace locations should not be avoided.

Although the main benefit from drilling on lineaments and fracture traces is the potential for higher yields than are generally obtainable, another possible benefit is shallower drilling depths. Drillers generally stop drilling after suitable quantities of water have been obtained. In areas of low yield, drillers deepen wells to create added borehole storage for meeting peak demands. Data from Decatur County indicate that drilling deeper than 125-150 ft has increased well yield at only a few sites.

SUMMARY AND CONCLUSIONS

This report is intended to aid utility planners, industrial and domestic users, and drillers in locating water supplies. The scale of the lineament and fracture-trace map of Decatur County is 1:48,000 or 1 inch = 0.76 mi. This scale may make on-site determinations difficult. However, a county-wide perspective is needed to locate the best lineament and fracture-trace well site in an area. Maps and the original aerial photographs, both at a scale of 1:24,000, are available for inspection at the Geological Survey office in Indianapolis.

Decatur County and adjacent counties south and east are economically restricted by inadequate water supplies. Examination of drillers' well records and field inspection of 141 well sites indicate that much of the water shortage in Decatur County may be due to drilling of wells in unfavorable locations. Data from Decatur County and other areas that are hydrogeologically similar to southeast Indiana suggest that the probability of locating domestic and larger supplies of water is greatest at well sites on or near bedrock fractures. These fractures are presumed to correspond with the lineaments and fracture traces that can be interpreted from aerial photographs. The most suitable well sites are at the lowest local altitude where lineaments and fracture traces intersect.

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