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LINEAMENTS AND FRACTURE TRACES, JENNINGS COUNTY AND JEFFERSON PROVING GROUND, INDIANA

By Theodore K. Greeman

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CONTENTS

ILLUSTRATIONS

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

Multiply inch-pound unit	By	To obtain SI (metric) unit
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow	
gallon per minute (gal/min)	3.785	liter per minute (L/min)
million gallons per day (Mgal/day)	3,785	cubic meter per day (m^3/day)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
	Area	
square mile (mi^2)	259.0	hectare (ha)

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ABSTRACT

Jennings and several adjacent counties are economically restricted by inadequate water supplies. The North Vernon Water Utility, supplying more than 25 percent of Jennings County's population, obtains its water from the Vernon Fork Muscatatuck River, although streamflow is less than the average daily withdrawal 69 days of the year. The U.S. Army, Jefferson Proving Ground, pipes water more than 5 miles and lifts it 375 feet for fire protection. Another Jennings County utility pipes water more than 15 miles to rural domestic consumers unable to locate sufficient ground-water supplies.

Two nearly horizontal sequences of Paleozoic limestone and dolomite, intermittently separated by a thin, discontinuous shale unit, constitute the principal aquifer. Many wells tapping this aquifer are unable to supply single-dwelling needs, whereas others supply several dwellings with ease. All the wells tapping the aquifer have been located for the owners' convenience and are randomly located in relation to lineaments and fracture traces.

Lineaments and fracture traces were observed throughout the study area, and those most easily interpreted are shown on a map at a scale of 1:48,000. Pleistocene drift, averaging 25-30 feet thick, covers most of the bedrock, but did not restrict the mapping of lineaments and fracture traces from aerial photographs.

The lineament and fracture-trace map indicates probable locations of vertical or near vertical fractures in the bedrock. Wells drilled on these mapped features may yield adequate supplies for domestic use. Larger yields may be available in several areas of southwest Jennings County where lineaments parallel major stream channels.

Well placement is important in this area, as fractures are a principal source of water to wells. In areas of fractured bedrock, the most productive well locations are at the intersections of two or more mapped lineaments or fracture traces and at the lowest local altitude. Use of the lineament and fracture-trace map will not guarantee a sufficent supply of ground water but will minimize the chance of drilling an inadequate well.

INTRODUCTION

This report is the result of a 2-yr (year) study by the U.S. Geological Survey in cooperation with the Indiana Department of Natural Resources and a 0.5-yr study in cooperation with the U.S. Army Jefferson Proving Ground (hereafter referred to as the proving ground). The purpose of these studies was to map the locations of lineaments and fracture traces observed in Jennings County and parts of Jefferson and Ripley Counties within the proving ground (pl. 1).

The study area is underlain by a nearly horizontal limestone-dolomite aquifer. Water moves through the aquifer along interconnecting bedrock joints, fractures, and solution channels. Locations of many bedrock fractures are indicated by lineaments or fracture traces at the land surface. These features are helpful in prospecting for ground water. The report also describes water-supply problems, geology, and interpretation and utilization of lineaments and fracture traces.

Lineaments and fracture traces are linear to slightly curvilinear natural features consisting of topographic, vegetation, soil tone, and drainage alinements visible on aerial photographs and mosaics, according to Lattman (1958). In bedrock areas, joints visible on aerial photographs are included in this terminology. The difference between lineaments and fracture traces is based on length. Lineaments are discernible for 1 mi (mile) or more and may be discerned 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 and that the ability of the interpreter to fuse these segments into a lineament depends on the resolution, scale, and contrast of the photographs.

The preceding definitions impart no information on the origin of lineaments and fracture traces. However, Moore (1976, p. 30) and Hine (1970, p. 21), working in areas underlain by nearly horizontal bedrock, determined that lineaments and fracture traces are the mappable expressions of vertical bedrock fractures. All vertical fractures in the study area are assumed to be bedrock joints that formed as local adjustments to regional tectonic movements. Although vertical bedrock fractures may also form by faulting, displacement is not apparent along any of these mapped fractures.

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

After the trapped water begins to move, vertical fractures can carry surface water down 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 circulation paths. Therefore, mapped lineaments and fracture traces are presumed to indicate the most prominent vertical bedrock fractures in Jennings County and the proving ground, and water wells drilled on these mapped lineaments and fracture traces should offer the greatest likelihood of intersecting water-filled solution cavities.

BACKGROUND

Jennings County, with a population of 21,012, is in southeastern Indiana (fig. 1). North Vernon, with a population of 4,601, is centrally located and the largest town in the county. The town of Vernon, which adjoins North Vernon, is geographically isolated by deeply entrenched meanders of the Vernon Fork Muscatatuck River. Vernon, the county seat, has a population of 472. The populations are estimates for July 1, 1977 (U.S. Department of Commerce, 1979).

The principal source of water for the rural population of Jennings County is the limestone-dolomite bedrock. Yields from this aquifer, which underlies most of the county at shallow depth, are extremely variable. Bedrock wells are generally 6 in. (inch) in diameter and are equipped with submersible electric pumps. Many wells drilled at randomly selected sites have yields that are inadequate for domestic needs. To relieve this problem, 5 of the 7 water companies operating in Jennings County supply only rural areas and small towns. Of the companies, three pipe water into the county to supply customers, some more than 15 mi from the source. The other companies obtain their water from the North Vernon Water Utility's intake on the Vernon Fork Muscatatuck River.

During 1978, the North Vernon Water Utility withdrew an average of 1.773 Mgal/d (million gallons per day) from the Vernon Fork Muscatatuck River (Joe Siener, Utility Superintendent, oral commun., 1979). Flow-duration data collected from October 1956 through September 1977 at the stream-gaging station on the Vernon Fork Muscatatuck River, 5 mi upstream from the utility intake, indicate that for 69 days of the year streamflow is less than the utility's average daily withdrawal. The North Vernon Water Utility supplies water to more than 2,000 customers, including 3 other utilities that supply about 800 additional customers (Joe Siener, Utility Superintendent, oral commun., 1979).

Surface-water deficiencies were accentuated by below-normal precipitation during 1940, 1944, and 1949. As a result, Brush Creek Reservoir, a controlled surface-water impoundment, was constructed in 1954. This reservoir sustains flow in the Vernon Fork Muscatatuck River during normal low-flow periods. During extreme low flow, Brush Creek Reservoir may be drained at a rate of 2.6 Mgal/d for 210 days into the Vernon Fork Muscatatuck River, approximately 6 mi upstream from the North Vernon Water Utility intake.

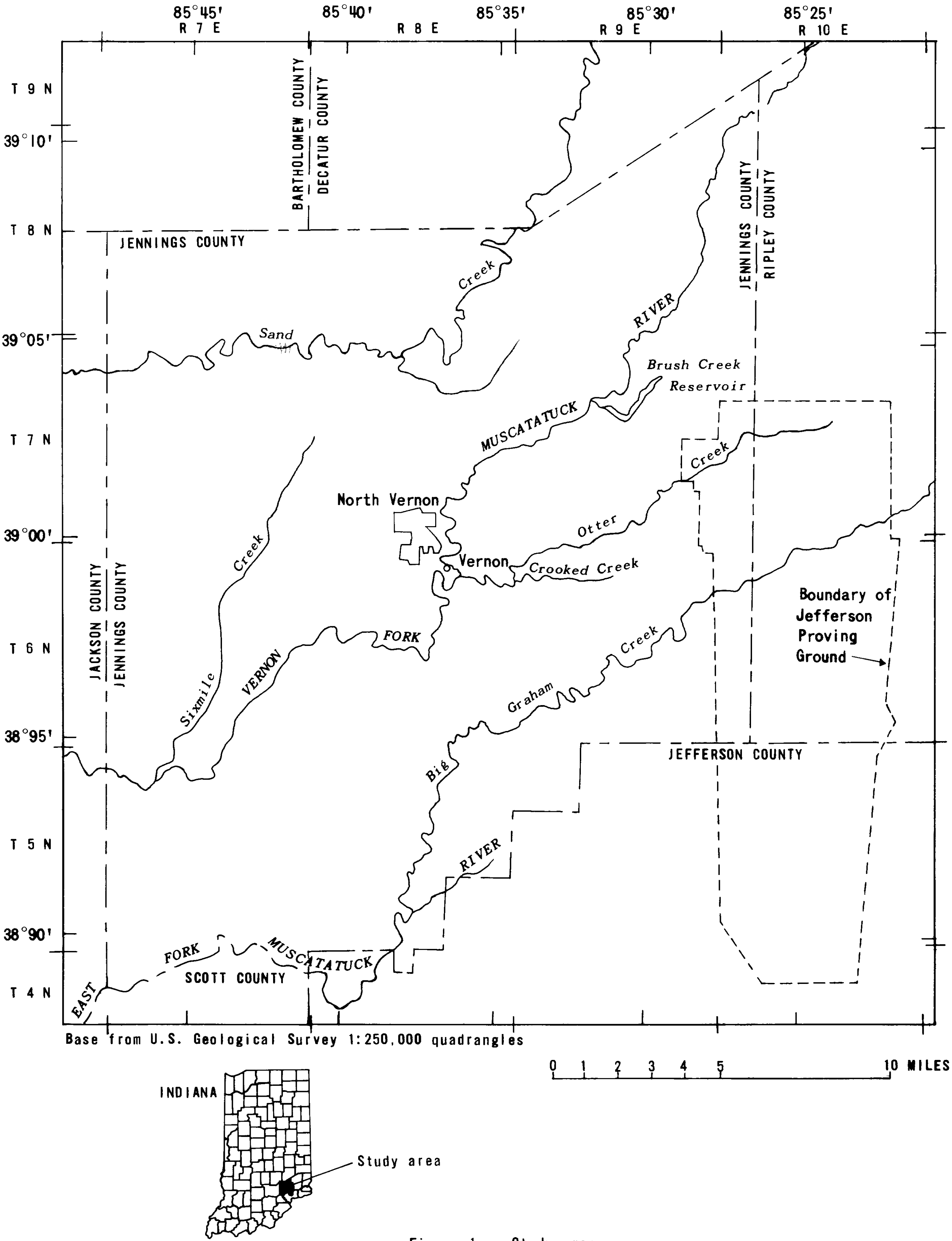


Figure 1.-- Study area.

At Vernon, Indiana, in 1940, there were 31 consecutive days of zero flow in the Vernon Fork Muscatatuck River, followed by 6 days of flow that averaged 0.086 Mgal/d and another 17 consecutive days of zero flow. During similar zero-flow periods, much of the water discharged from Brush Creek Reservoir is likely to enter the ground-water system through bedrock fractures in the streambed before it can reach the North Vernon Water Utility intake.

The U.S. Army, Jefferson Proving Ground is an 86.35-mi^2 (square mile) area (fig. 1) used for munitions testing. The proving ground, which is in adjoining parts of Jennings, Jefferson, and Ripley Counties, became operational in the early 1940's. Most of its area, once cleared for farming, has now reverted to forest. Water for the proving ground is pumped from wells in a gravel aquifer along the Ohio River. This water supply must be piped more than 5 mi and lifted 375 ft (feet) to reach the south boundary of the proving ground. Water from this supply is available only within the south 3 mi of the 17-mi long proving ground.

In Jennings County, reoccurring surface-water shortages in the Vernon Fork Muscatatuck River and the need for rural water utilities emphasize the need for adequate ground-water supplies. Aerial photographs used in identifying lineaments and fracture traces have been helpful in developing moderately large ground-water supplies in other areas underlain with limestone and dolomite (Lattman and Parizek, 1964). Therefore, these procedures would probably be helpful in locating water supplies within the study area.

GEOLOGIC SETTING

The bedrock in Jennings County and the proving ground is covered by an average of 25 ft and commonly more than 50 ft of Pleistocene drift. Erosion has exposed the bedrock in many places, especially along streams. According to Kunkel (1940, p. 1), the surface of the drift slopes west-southwest at 18 ft/mi (foot per mile). The drift is poorly drained, owing to its low surface relief and the impervious silt and clay that predominate.

Paleozoic bedrock units dip west-southwest at about 20 ft/mi, whereas the bedrock erosion surface slopes in the same direction at 12 ft/mi (Schneider, 1966, p. 44). The similarity in slope between the bedrock dip and bedrock surface indicates structurally controlled erosion of the bedrock surface.

A structural high began developing in the tri-corner area of Indiana, Ohio, and Kentucky during Ordovician time (Cincinnati arch). 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

Cincinnati arch became elongated north-south. The curved axis of the Cincinnati arch lies approximately 60 mi east of the study area and trends north to north-northwest in Indiana and Ohio.

Limestone and dolomite in Jennings County and the proving ground can be grouped into two sequences, the upper and the lower (fig. 2). A discontinuous Silurian shale, as thick as 12 ft, separates the upper and the lower sequences in some areas.

The lower limestone-dolomite sequence is of Silurian age and 50 to 60 ft thick, except where erosion has thinned or removed it. A fine-grained, thick-bedded dolomite unit, containing numerous chert nodules, forms a resistant protective cover for the lower sequence. In outcrop, the lower sequence forms a low relief plain that underlies the proving ground. This plain is traceable northward in Indiana, until obscured by thickening till cover, and southward into Kentucky for more than 50 mi. Beneath the lower limestone-dolomite sequence are thin, interbedded, argillaceous limestone and shale beds of Ordovician age that crop out along several stream channels on the east side of this area.

Several periods of erosion have affected the distribution of the Silurian shale, which separates the upper and lower sequences in some places. Before the deposition of Devonian rocks in the upper sequence, one or more periods of erosion during Late Silurian time removed this shale and an overlying limestone from much of the area east of North Vernon. Where unaffected by pre-Devonian erosion, the distribution of the shale is the same as the distribution of the upper sequence, which acts as a protective cover preventing present-day erosion. Silica, which formed chert nodules in the top horizon of the lower sequence, is of secondary origin. This silica probably originated in the shale and migrated to its present location during compaction. Together, the shale and the chert nodules effectively prevent circulation of water between the two sequences.

The upper limestone-dolomite sequence of Silurian and Devonian age, averages about 75 ft in thickness where uneroded. Formations in the upper sequence are thinner bedded and less resistant to erosion than formations in the lower sequence. Within Jennings County, the major outcrops of the upper sequence are in the north and the east and along the major streams in the southwest part of the county. The upper sequence has been eroded along the extreme east boundary of Jennings County and from all the proving ground. In outcrop, the upper sequence has an undulating surface, and streams are entrenched into steep rock-walled valleys. Near Vernon, the Vernon Fork Muscatatuck River is entrenched about 170 ft below the upland surface.

Overlying the upper limestone-dolomite sequence in the west half of the study area is a thick black shale unit of Devonian and Mississippian age. Nearly 100 ft of this shale is present at some locations along the west boundary of Jennings County. Short straight valleys with steep slopes dominate the outcrop area of this shale.

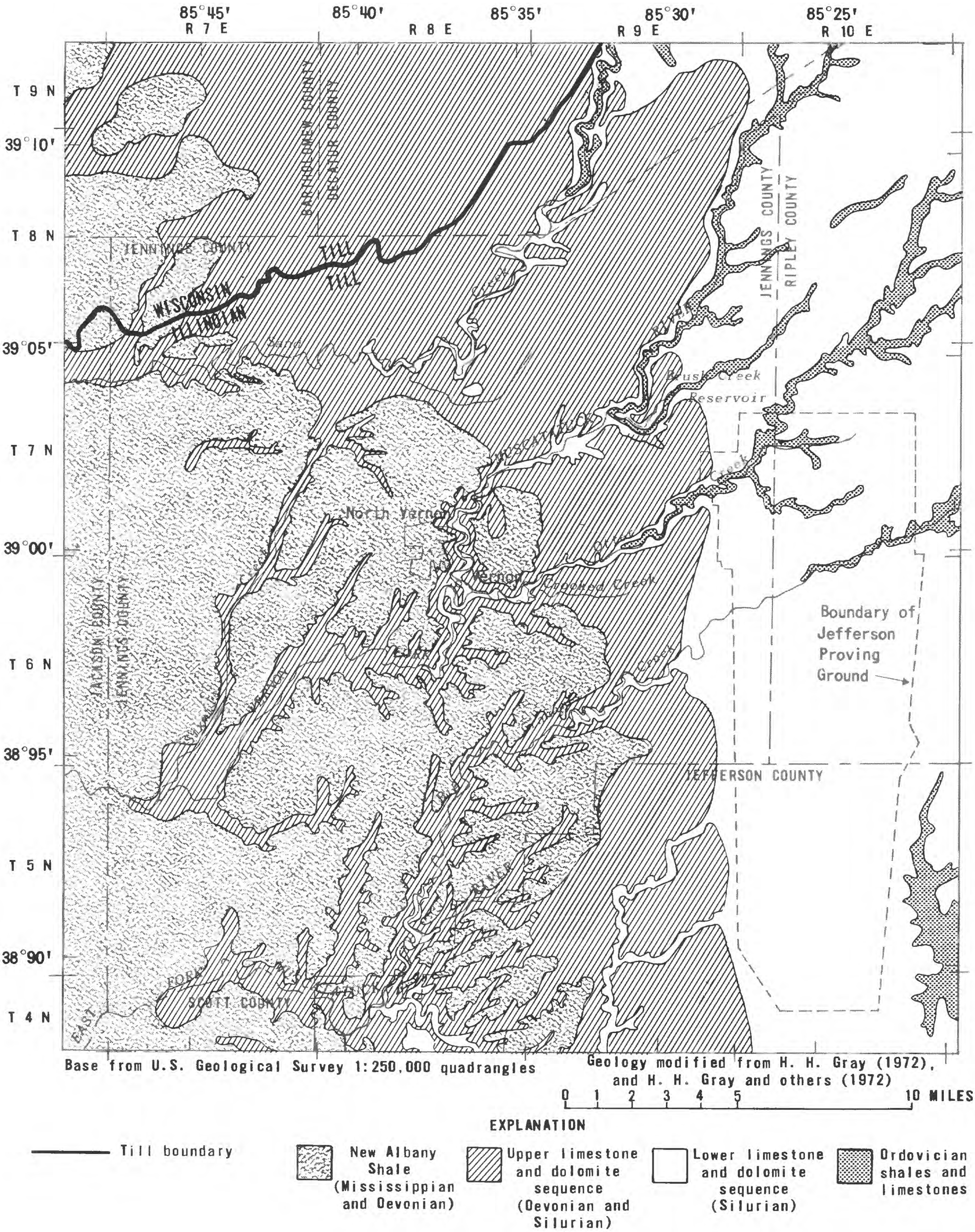


Figure 2.-- Bedrock geology of Jennings County and Jefferson Proving Ground, Ind.

Although jointing is prominent in both the upper and lower limestone-dolomite sequences, dissolution along joints is most pronounced at the top of the upper sequence, as indicated by solution sinkholes and swallow holes near the top of the upper sequence. Symbols indicating sinkholes can be seen on plate 1 along the Vernon Fork Muscatatuck River from secs. 18 and 19, T. 6 N., R. 8 E. eastward for several miles; between Crooked Creek and Otter Creek (formerly South Fork, Vernon Fork) in secs. 5, 6, and 7, T. 6 N., R. 9 E.; and along Big Graham Creek between secs. 14 and 30, T. 6 N., R. 9 E. A large swallow hole is located in NW¼SW¼, sec. 5, T. 6 N., R. 9 E.

Lithology and aquifer characteristics of each geologic formation are given in the generalized geologic column (fig. 3), which is based on data in Shaver and others (1970), Dawson (1941, p. 37-48), and well records on file with Indiana Department of Natural Resources, Indianapolis.

INTERPRETATION OF LINEAMENTS AND FRACTURE TRACES

The probable locations of vertical bedrock fractures indicated on the lineament and fracture-trace map (pl. 1) were interpreted on 1:24,000-scale, black-and-white aerial photographs obtained on March 7, 1976, by Indiana Department of Natural Resources, and on April 18, 1977, by Accu-Air Surveys, Inc., for the Geological Survey. 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, Ind.

Pleistocene drift, which ranges in thickness from 0 to 81 ft, did not inhibit the mapping of underlying bedrock fractures. Although the effect of drift thickness on the mapped density of lineaments and fracture traces is unknown, Mollard (1957, p. 30) reported that the 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, p. 36) also interpreted lineaments where the bedrock is covered by more than 350 ft of unconsolidated materials of Pleistocene and Holocene age. This interpretation suggests that lineaments and fracture traces form by an ongoing process that moves upward from the bedrock into overlying unconsolidated materials.

Many factors affect the mapping of lineaments and fracture traces on aerial photographs. Lattman (1958), Trainer (1967), and Moore (1976, p. 16-28) discussed the effects of film type, photographic scale, time of year, method of 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 resulting map. Variations in the length of time spent interpreting individual photographs from a set of photographs will lead to variations in the density of lineaments and fracture traces mapped. For example, in the south end of the proving ground (pl. 1), where additional lineament and fracture-trace mapping was done, the density of mapped fracture traces is much greater than in adjacent areas.

Another factor affecting the density of mapped lineaments and fracture traces is lithology. Different bedrock lithologies develop different fracture spacings. Shale develops numerous short joints, as shown by the mapped fracture traces in the west half of the study area (pl. 1). Except along main streams, where erosion has removed the thick black shale, a high density of short fracture traces is observed.

Limestone and dolomite develop a low density of long fracture traces and lineaments. Bedding thickness partly controls fracture spacing and length. The Salamonie Dolomite (local usage), which is dense and thick-bedded, underlies the proving ground, an area of widely spaced lineaments and fracture traces (pl. 1).

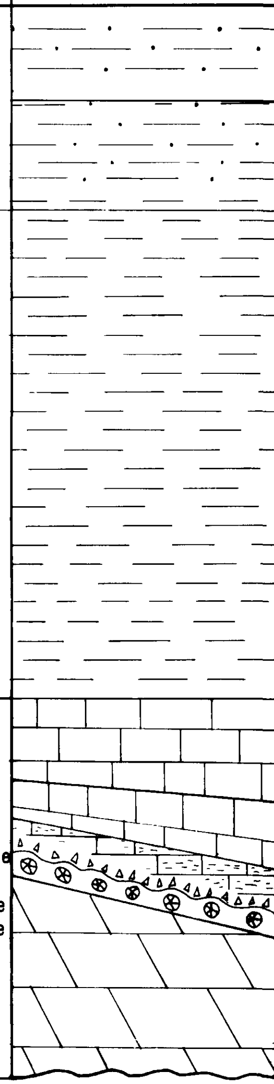
Although each lithologic unit expresses a characteristic fracture density, relief can cause major variations in the mapped density of fracture traces and lineaments. Relief accentuates the effects of erosion on bedrock fractures and thus enables the interpreter to observe and map a greater density of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

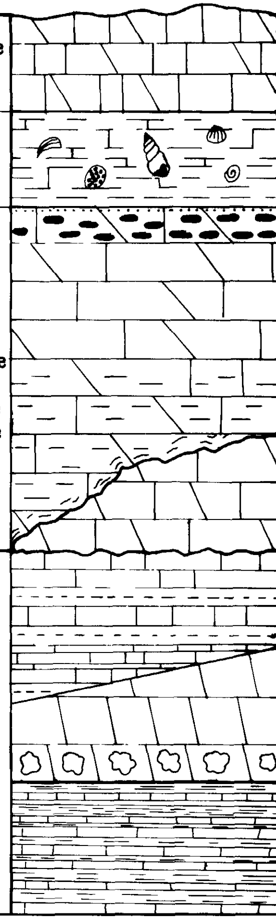
Differences in land use also cause variations in the density of mapped lineaments and fracture traces. Many of man's activities tend to obscure subtle natural features. In urban areas, man changes the landscape by rechanneling drainage, building roads and structures, and leveling undulating land so that only lineaments can be recognized. Two airports within the study area show this effect very well. One airport is 2 mi northeast of North Vernon (pl. 1). The other, now abandoned, is at the south end of the proving ground (pl. 1). Extensive earth moving and drainage rechanneling has obscured nearly all fracture traces and all but one lineament in these areas.

Agricultural activity tends to obscure some fracture traces but seldom changes natural drainage patterns. The influence of agriculture on the mapped density of lineaments is minor. Vegetation, where allowed to establish natural growth, yields the most complete lineament and fracture-trace interpretation. Most of the proving-ground area, which has been unaffected by man since the early 1940's, imparts a slightly higher density of mapped lineaments and fracture traces than adjacent areas of Jennings County (pl. 1).

Fracture traces and lineaments are generally associated with surface drainage paths. Major streams and main tributaries, equally spaced and almost parallel, drain the study area and flow southwest down the regional bedrock slope. Short minor tributaries drain generally northwest or southeast and descend rapidly to the main streams from the level uplands (Kunkel, 1940, p. 2). In the study area (pl. 1), the most prominent fracture-trace and lineament orientations mapped are conjugate and are oriented northeast-southwest and northwest-southeast, parallel to the principal drainage orientations. Less prominent fracture-trace and lineament orientations are mapped north-south and east-west. Most of these less-prominent orientations are in the outcrop area of the New Albany Shale, south and west of North Vernon.

REPRESENTATIVE STRATIGRAPHIC SECTION WITH LITHOLOGIC DESCRIPTION AND WATER-YIELDING CHARACTERISTICS OF UNITS

ERATHEM	SYSTEM	SERIES OR STAGE	STRATGRAPHIC UNIT	THICKNESS (FEET)	HYDRO-GEOLOGIC UNIT	SECTION	UNIT CHARACTERISTICS	WATER-YIELDING CHARACTERISTICS
Cenozoic	Quaternary	Pleistocene	Wisconsinan stage	~ 20 average 0-81	Till		Unconsolidated till with minor segregation of coarse material. Surface color brownish gray to reddish brown. Undulating surface, low relief.	Poor source of ground water because of lack of sand and gravel aquifers and possibility of contamination.
			Illinoian stage and older	~25 average			Unconsolidated till, mostly clay. Surface color light gray on flats to reddish gray on slopes. Flat uplands, deeply dissected by streams.	
Paleozoic	Mississippian	Kinderhookian	New	0-100 in Jennings County	New		Shale, black to brown, green to greenish gray with lenses of dolomite and dolomitic quartz sandstone, Shale is fissile, pyritic, and organically rich.	A very poor source of ground water. Acts as a confining bed although some water is found along cracks at shallow depth.
	Devonian	Senecan and Chautauquan	Albany		Albany			
			Shale		Shale			
		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 ground water for domestic use. Springs common at base of Jeffersonville Formation.
			Jeffersonville Limestone	0-40			Limestone, gray to brown. Greatly varying lithology from top to bottom with laminated breccia zone and coral zone. Abundant calcite and pyrite recrystalization.	
		Ulsterian	Geneva Dolomite	0-30			Dolomite, buff to chocolate brown, fine grained, soft, saccroidal texture. Thin bedded at top and thick bedded at base. Large recrystalized calcite common.	



Paleozoic	Silurian	Niagaran	Louisville Limestone	0-35	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 ground water for domestic use.
			Waldron Shale	0-10	Shale	Shale, blue-gray and clayey. Thin bedded; very fossiliferous and easily eroded.	Only confining unit within 150 feet of carbonate strata.
			Salamonie Dolomite[1]: Laurel Member[1]	0-80	Lower limestone and dolomite sequence	Dolomitic limestone, light gray to tan, fine grained and argillaceous. Thick bedded with abundant chert.	Poor source of ground water; limited domestic and stock use.
			Salamonie Dolomite[1]: Osgood Member[1]			Dolomite or limestone, tan to tan gray, highly argillaceous; shale increasing southward in study area.	
		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 yield to water wells.
	Ordovician	Cincinnatian	Whitewater Formation	0-60	Increasing shale	Interbedded calcareous shales and limestones, light- to dark-gray, thin bedded. Thins southward from Decatur County.	Chiefly a confining unit owing to high shale content.
			Saluda Formation	20-50		Dolomitic limestone, gray, silty, basal coral zone. Unit thins northward.	Good aquifer for domestic use with 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 Jennings and parts of Jefferson and Ripley Counties, Ind.

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

SOURCES OF WATER TO BEDROCK WELLS

The principal bedrock aquifer in Jennings County and the proving ground consists of the upper and lower limestone-dolomite sequences. Well records for Jennings County indicate that the yield from the limestone-dolomite aquifer ranges from 0 to 150 gal/min (gallon per minute). 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 (Siddiqui, 1969; LaRiccia and Rauch, 1976) indicates that wells on or 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 adequate wells 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 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.

Zones of high permeability within the limestone and dolomite aquifer have developed since deposition, owing to vertical fracturing and subsequent solvent action. Stresses within the bedrock have been released by numerous vertical fractures (joints). The processes of chemical and mechanical erosion are accelerated by the water that infiltrates the fractures and penetrates the aquifer surface. 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 ground surface, where ground-water velocities and solvent action are greatest. Solution sinkholes adjacent to several major drainage routes are further evidence of the subsurface drainage near the streams.

Most reports of inadequate bedrock wells are from areas where erosion has removed the upper limestone-dolomite sequence, leaving only the dense, thick-bedded, lower 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 water supplies from the lower sequence.

Yields of as much as 50 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 in the study area.

In the upper-sequence outcrop area, well records 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 that are deeply entrenched in the high-permeability zones adjacent to these streams.

Shale of varying thickness overlies most of the upper limestone-dolomite sequence in the west half of the area. Narrow, entrenched stream channels, common upstream, broaden and become alluvium-filled valleys in this area. These valleys are widest where the top of the upper sequence has dipped to stream level and meanders have cut laterally into the overlying erodible shale. The bedrock permeability in Jennings County is highest in these valleys. Yields of 150 gal/min or more may be possible from bedrock wells drilled on lineaments and fracture traces in the wide valleys. The shale unit that forms the upland surrounding the valleys greatly restricts recharge to the underlying limestone and dolomite aquifer. Some wells drilled through the shale to reach the underlying aquifer are unable to produce more than domestic supplies. Hydrogen sulfide, which indicates a restricted ground-water circulation, is detected in many of the wells penetrating the shale.

DRILLING WELLS ON LINEAMENTS AND FRACTURE TRACES

Placement of the well is the most important step in developing a usable water supply in a fractured limestone or dolomite terrain. 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 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.

However, wells in a vertical bedrock fracture or in 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 is moving through the limestone-dolomite aquifer, and wells in the fractures generally yield sufficient supplies for domestic needs. Because lineaments and fracture traces indicate underlying vertical bedrock fractures and flow through the limestone-dolomite aquifer is generally toward the lowest surface drainage routes, the most productive well sites will be at the intersection of two or more lineaments or fracture traces, 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 individual well user. However, the use of lineament and fracture-trace mapping should allow the planner to determine where the best 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 lineament and fracture-trace sites are several hundred feet from the well-drained soils used for house and building construction. However, costs due to site preparation and piping distance should be balanced by the savings obtained from drilling fewer inadequate wells, especially in the east third of the study area, 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 a drill bit by angular surfaces and loose rocks in vertical fractures may result in crooked well bores that are unusable. In many holes, greater lengths of casing than normal are needed to seal out mud that has slumped into solution openings. When drilling on lineaments, these difficulties may be avoided by drilling immediately adjacent to the bedrock openings, and not directly into them. Local well records indicate that highest well yields may be obtained within 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 storage capacity for meeting peak demands. Data from the Jennings County area indicate that drilling below 125-150 ft has increased well yields 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 Jennings County and the Jefferson Proving Ground is 1:48,000 or 1 inch = 0.76 mi. This scale may make onsite determinations difficult. However, it allows the 467-mi^2 area to be viewed on one sheet, a perspective that is needed when searching for the largest lineament and fracture-trace well yields 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.

Jennings County and adjacent counties to the north 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 Jennings County may be due to drilling wells in hydrogeologically unfavorable locations. Data from 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 seen on aerial photographs.

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