ENVIRONMENTAL GEOLOGY OF ALLEN COUNTY, INDIANA

Special Report 13

State of Indiana
Department of Natural Resources

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Environmental Geology of Allen County Indiana

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Environmental Geology of Allen County, Indiana

By N.K. BLEUER *and* MICHAEL C. MOORE

Abstract

This report is designed to provide geologic data for planning the use of mineral resources (including ground water), the disposal of domestic and industrial wastes, and foundation engineering for structures in Allen County.

The surficial morphology of the county, its linear moraine ridges, glacial and postglacial drainage routes, and lake plain, reflects various modes of glacial and glacial lake or stream deposition. The near-surface unconsolidated materials, clayey glacial till, stream-deposited sands and gravels, and lake clay, reflect these origins as well. But beneath these surface materials lies buried a stack of similar deposits, including hard loamy tills, of earlier glacial episodes.

The surface of the buried hard till mirrors the present surface topography, much of which may be inherited from that earlier glaciation. Drift ranges from less than 40 feet to more than 300 feet in thickness, and it covers an erosional surface developed on Devonian and Silurian limestone and dolomite and on Mississippian black shale.

The predominantly limestone and dolomite bedrock in Allen County was deposited in an ancient sea basin centered in Michigan. The rock is tilted slightly northward. The basin margin environment proved conducive to reef growth at times, especially during the Silurian Period.

Developed mineral resources in Allen County include crushed stone, sand and gravel, peat, petroleum, and water. Crushed stone produced within the county comes from carbonate rocks of Silurian and Devonian age, strip-mined in the south half of the county where glacial drift is thinnest. The drift is thinner than 40 feet only near present valleys, but changing economic conditions may permit stripping of thicker overburden and development of underground mining.

Sand and gravel will remain an important source of aggregate materials, and future pits will be developed along major drainageways and along a few of the minor streams. Major reserves will be found in the glacial drainageways, the Wabash-Erie Channel, and particularly in the Eel River sluiceway.

Mining costs, availability of land, quality of material, nearness to markets, and restrictions based on environmental quality and reclamation proposals will control the rate at which the various prospective areas are developed. All other things being equal, transportation costs, including both handling and haulage distance, are the most important factor. Thus knowledge of the best sites may promote the most efficient resource use.

Production of peat, clay, and other industrial minerals will play a minor role in the future of Allen County. Petroleum resources are not abundant in Allen County, and more activity is likely to be expended in developing pipelines and gas storage reservoirs.

Except for municipal supplies from impoundment of the St. Joseph River, public, private, and industrial water supplies in Allen County are derived from ground water. Aquifers in unconsolidated sediments, mostly in the northwestern part of the county, are buried outwash channels and outwash plains which are not uniformly distributed. In the southern and southeastern parts of the county, glacial aquifers are few and bedrock supplies must be used. Water derived from bedrock and drift aquifers differs significantly; concentrations of iron, zinc, and bicarbonate are highest in drift aquifers, and strontium and sodium are highest in bedrock aquifers. Ion concentrations in the bedrock aquifer (except for bicarbonate) are consistently highest in the south and southeast. Potential exists for considerable suburban and rural development of ground-water supplies in the immediate future.

Solid wastes must, by law, be disposed of in sanitary landfills. Such sites require proper drainage conditions and overall environment. Abundant suitable sites are available in Allen County, but geologic factors control their distribution.

Domestic septic systems are also practical only where drainage and water table conditions permit adequate percolation. Many tight till and lake clay areas are unsuitable, while use of areas of outwash may lead to contamination of nearby water wells. Disposal of liquid waste in a well at great depth is

probably feasible, but such proposals should be scrutinized carefully.

Most near-surface materials in Allen County have sufficient bearing capacity for large buildings. Some soft clays and loose wet sands occur in lakebed and sluiceway areas, but their volume is minor. Of greater importance are muck and peat in the Eel River and Little River drainages, but even these materials seldom exceed a few feet in thickness. Poor drainage is likely to be the most prevalent construction problem. The lower hard till can be extremely difficult and expensive to excavate.

Several scenic and historic geologic sites may be suitable for inclusion in parks or for designation by educational markers or displays.

Introduction

Allen County and greater Fort Wayne (fig. 1) are growing in population, and concurrently the problems stemming from man's need to live on and in harmony with the land have shown a steady increase. Each person added to the population places additional demands on the environment, so that wise planning is a necessity. The compilation of facts about the physical environment, including its geology, has become an increasingly important aspect of planning.

Vital to the future of Allen County are reserves of land for agricultural use, extraction of mineral commodities, and urban development. Some directions taken by inevitable expansion could prove to be extremely detrimental to future living conditions. Intelligent use of resources requires careful planning and setting of priorities. Goals cannot be set wisely until all relevant conditions and limits are fairly well known. It is the function of advisory bodies, such as the Indiana Geological Survey, the Soil Conservation Service, public health boards, planning consultants, and public interest groups, to provide this information to planning bodies and government officials.

Previous studies of the geology of Allen County date from 1862 when Richard Owen described landforms and drainage. In 1889 Charles R. Dryer published his report on the geology of Allen County, and in 1906 J. A. Price described and mapped road materials in

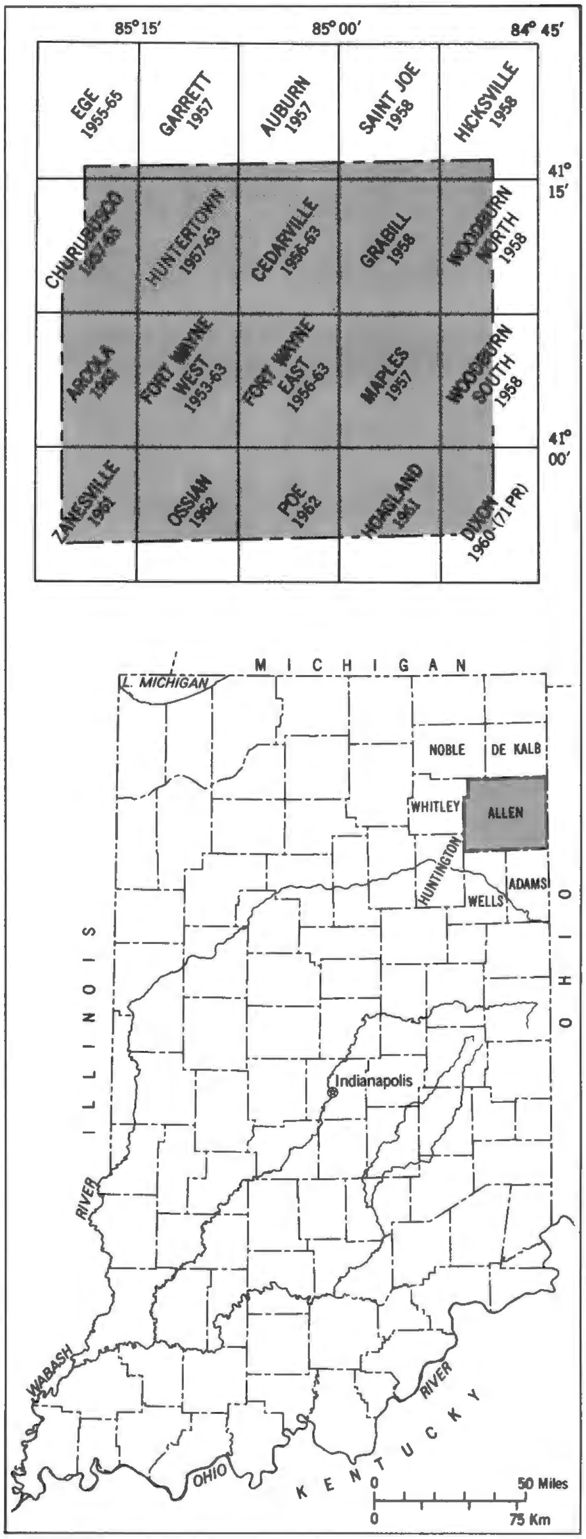


Figure 1. Map of Indiana showing location of Allen County and index to U.S. Geological Survey topographic map coverage.

the county. Many of Dryer's ideas pertaining to glacial geology were incorporated in the much better known monographs by Leverett (1902) and Leverett and Taylor (1915). Little work specifically on Allen County was published subsequent to Leverett and Taylor until the completion of the Fort Wayne and Muncie Regional Geologic Maps by the Indiana Geological Survey (Johnson and Keller, 1972, and Burger and others, 1971). More recent work by Bleuer and Moore (1972, 1975), Moore and Bleuer (1973), Bleuer (1974), and Foley and others (1973) has added to our knowledge of the glacial materials and ground-water quality. Ground-water availability is presently being studied in detail by the United States Geological Survey.

This report treats the geology of Allen County both in a general manner and by a detailed examination of specific geologic topics. These topics include mineral production, water supply, liquid and solid waste disposal, and foundation engineering, but all can be better understood when placed in a unifying framework of geologic history for the Allen County area. Thus a historical synopsis is presented first and is followed by discussions of the environmental topics and an appendix. The material in this report is current through 1974.

Acknowledgments

We are particularly indebted to Soil Testing & Engineering, Inc., Fort Wayne, and to the Indiana State Highway Department, the City of Fort Wayne Pollution Control Department, and the office of the Allen County Surveyor for making engineering boring records and samples available for our study.

Some sections of this report were authored separately from the contributions by the principal authors. These titled sections and their authors are: "Mineral Aggregates," Curtis H. Ault and Michael C. Moore; "Water Quality and Ground-Water Development," William C. Herring and N. K. Bleuer; and "Petroleum Resources," Leroy E. Becker. Correct bibliographic citations of these sections is, for example: Ault, C. H., and Moore, M. C., 1978, Mineral aggregates, *in* Bleuer, N. K., and Moore, M. C., Environmental geology of Allen County, Indiana: Indiana Geol. Survey Spec. Rept. 13 . . . .

General Geology

LANDFORMS

The most readily appreciated aspect of the geology of Allen County is the land surface itself, its ridges, valleys, and plains, each of which owes its form to the action of past glaciers, to meltwater issuing from glacial ice, or to waves and currents in a glacially impounded lake. The topography (fig. 2) and major landform features of the area, the lake plain, the end moraines, the intermorainal till plains, the glacial sluiceways, and the present stream valleys, can be grouped according to overall form (fig. 3; table 1) as well as according to geologic materials. (See the following section on unconsolidated materials.) These features are illustrated well by the U.S. Geological Survey's suite of topographic quadrangle maps (fig. 1) (scale, 1:24,000; contour intervals, 5 and 10 feet throughout and in part 1 or 2 feet).

UNCONSOLIDATED DEPOSITS

SURFICIAL GEOLOGY

The distribution of surficial materials of glacial and postglacial age in Allen County (fig. 4) generally parallels the distribution of landform types. Through an understanding of the geologic history of the formation of landforms, the deposition of glacial and nonglacial sediments, and the subsurface stratigraphy, one can interpolate geologic data between scattered data sources.

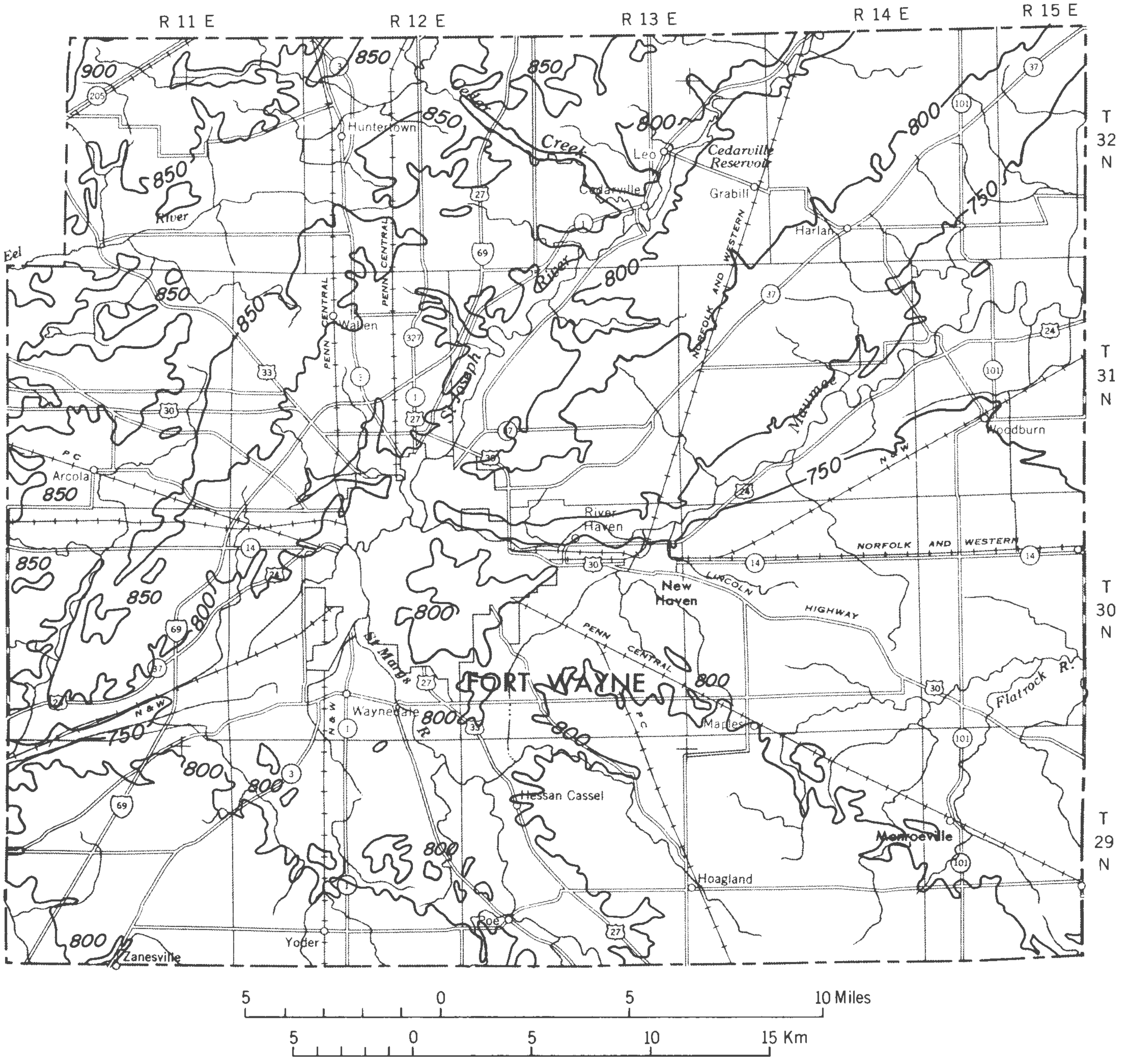


Figure 2. Map of Allen County showing generalized surface topography. Modified from U.S. Geological Survey topographic quadrangle maps. Contour interval is 50 feet. Datum is mean sea level.

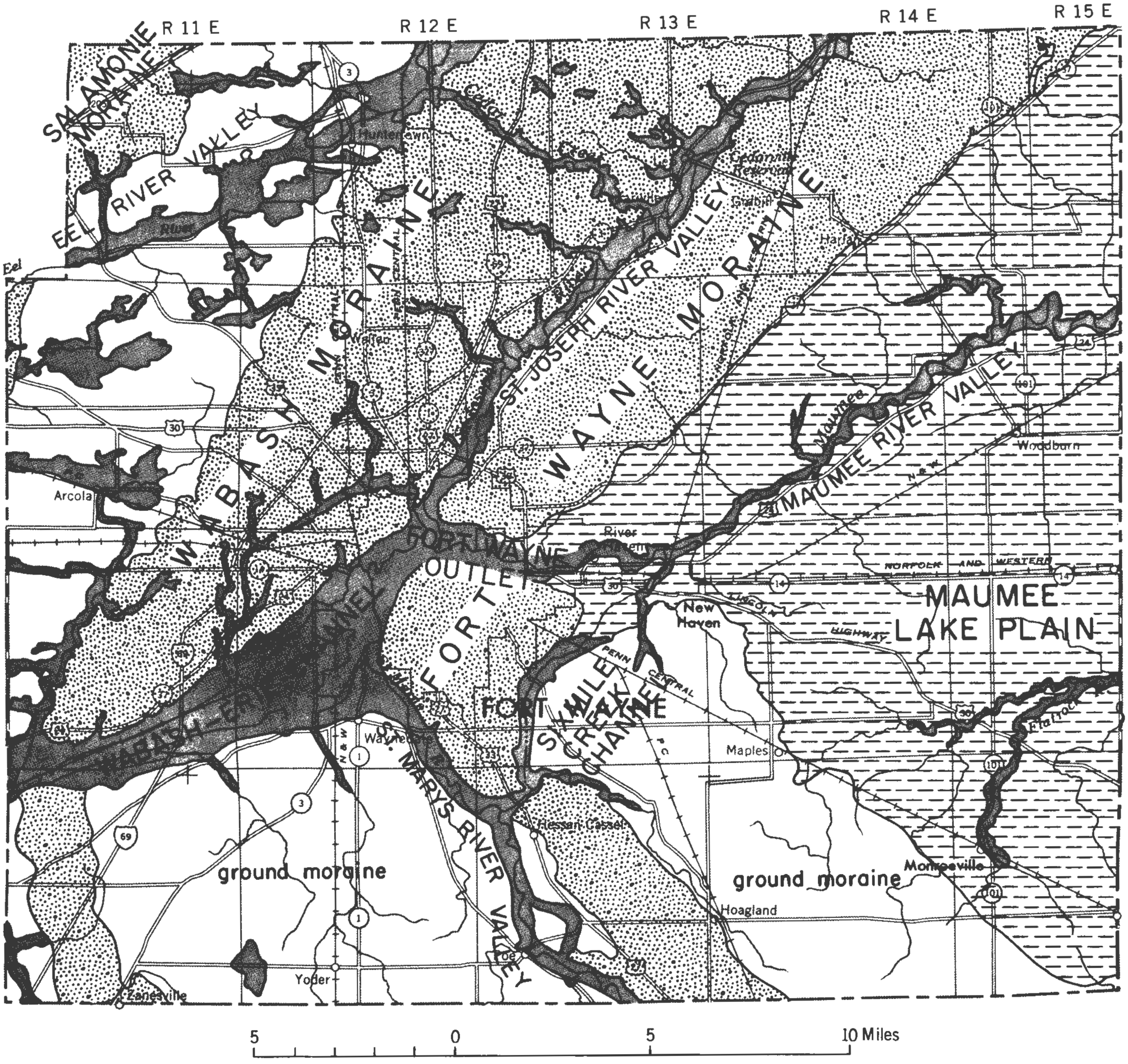


Figure 3. Map of Allen County showing principal landforms.

Table 1. Characteristics of major landform (physiographic) units in Allen County

Physiographic unit	Elevation (ft)	Relief (ft)	Character	Comments
Salamonie Moraine	850-900	10-15	Gently rolling upland; numerous closed depressions.	Ridge of till (Lagro Formation Qt, Qte, fig. 4) formed at or near the edge of the retreating Erie Lobe. Distinguished by ridged form and irregular hummocky topography, resulting from irregular melting of buried ice blocks. Northern moraine limbs are more irregular and more compressed, owing to last ice (Erie Lobe) overriding older till ridge, and perhaps ice (Saginaw Lobe).
Wabash Moraine (north limb)	830-890 (west crest)	5-20	Flat to very gently rolling ridge crest about half a mile wide at western moraine margin; general slope of upland is to east, falling 30-50 ft. In north half moraine grades to particularly irregular hummocky surface; numerous closed depressions.	
Wabash Moraine (south limb)	850-865	5 (crest) 25+ (marginal slopes)	Narrow rolling crest, a quarter of a mile to half a mile wide, with sharply dissected erosional slopes on east and west margins.	
Fort Wayne Moraine (north limb)	810-850	10-25	Gently undulating in south; very irregular hummocky topography to the north.	
Fort Wayne Moraine (south limb)	825-840	5	Wide rolling crest, half a mile wide, with relatively steep erosional slope on west; grades as continuous slope to till plain on east (in southern part).	
Wabash (till plain) (south limb)	795-830	10+	Rolling to flat upland; few closed depressions.	Generally flatter and of less diverse topographic character than moraines. Materials (Lagro Formation Qt, fig. 4) differ little from those of moraine areas.
Fort Wayne (till plain) (south limb)	800-825	5	Very gently undulating upland; scattered shallow closed depressions.	

Table 1. Characteristics of major landform (physiographic) units in Allen County—Continued

Physiographic unit	Elevation (ft)	Relief (ft)	Character	Comments
Maumee lake plain	745-800	5-10 (beach ridges) 15-20 (stream margins)	Flat; poorly drained.	Floor of former lake blocked between retreating ice to east and moraine to west. Beaches range from wave-cut scarps in till to multiple low sandy beach ridges and bars (Qsb, fig. 4). North shore deposits generally sandier than those thinner deposits along more gently sloping south shore. Plain slopes almost imperceptibly toward axial Maumee River. Thin silts or clay cap till (Lagro Formation) in places.
Fort Wayne Outlet	740-750	5	Maumee River floodplain with marginal terraces of scoured lake bottom.	The scoured discharge route of Lake Maumee: cut surface on lower till (Trafalgar Formation) and associated silts; sands and gravel; and some thin surface sand or gravel relates to flow of lake water.
Wabash-Erie Channel	750-760	nil	Dune ridges up to 20 ft in height; outwash terrace remnants in places rise above flat and (originally) marshy Little River prairie.	Broad channel cut by stages of Lake Maumee discharge—mostly stripped surface; cut into lower till (Trafalgar Formation) and associated gravel. Northern part of channel is scored deeper by later lake discharge and filled back to level of main channel by stream silts.
St. Marys River valley	750-780	5-10 (up to 15 ft at channel edge)	Terraces (few and small) rise above flat floodplain.	Valleys floored in part by gravel and sand outwash deposits laid down in beds of meltwater streams; some thin pond and lake deposits (Qgv, Qgm, fig. 4). Modern stream channel sands and overbank silts, swamp peat and muck, and thin lake clay fill parts of valleys. Commonly valleys are floored with lower tills and sands and gravels into which more recent valleys cut (as Wabash-Erie Channel and Fort Wayne Outlet).
St. Joseph River valley	770-790 (terrace surfaces) 760-780 (floodplain)	5	Low relatively flat but well-drained terraces or second bottom occasionally flooded; narrow flat first bottom.	
Eel River valley	830-840	5	Valley of low marsh, half a mile wide; well-drained high gravel terraces and till islands.	
Maumee River valley	725-750	5-10	Gently rolling linear terrace and floodplain, about 15 ft below level of surrounding lake plain; Maumee River incised 10-20 ft below terrace level.	Entrenched valley following the axis of lake plain and earlier the axis of ice flow of the Erie Lobe. Evolved through postglacial capture of the St. Joseph and St. Marys Rivers. Channel now cuts into Trafalgar Formation or an associated gravel in several areas.

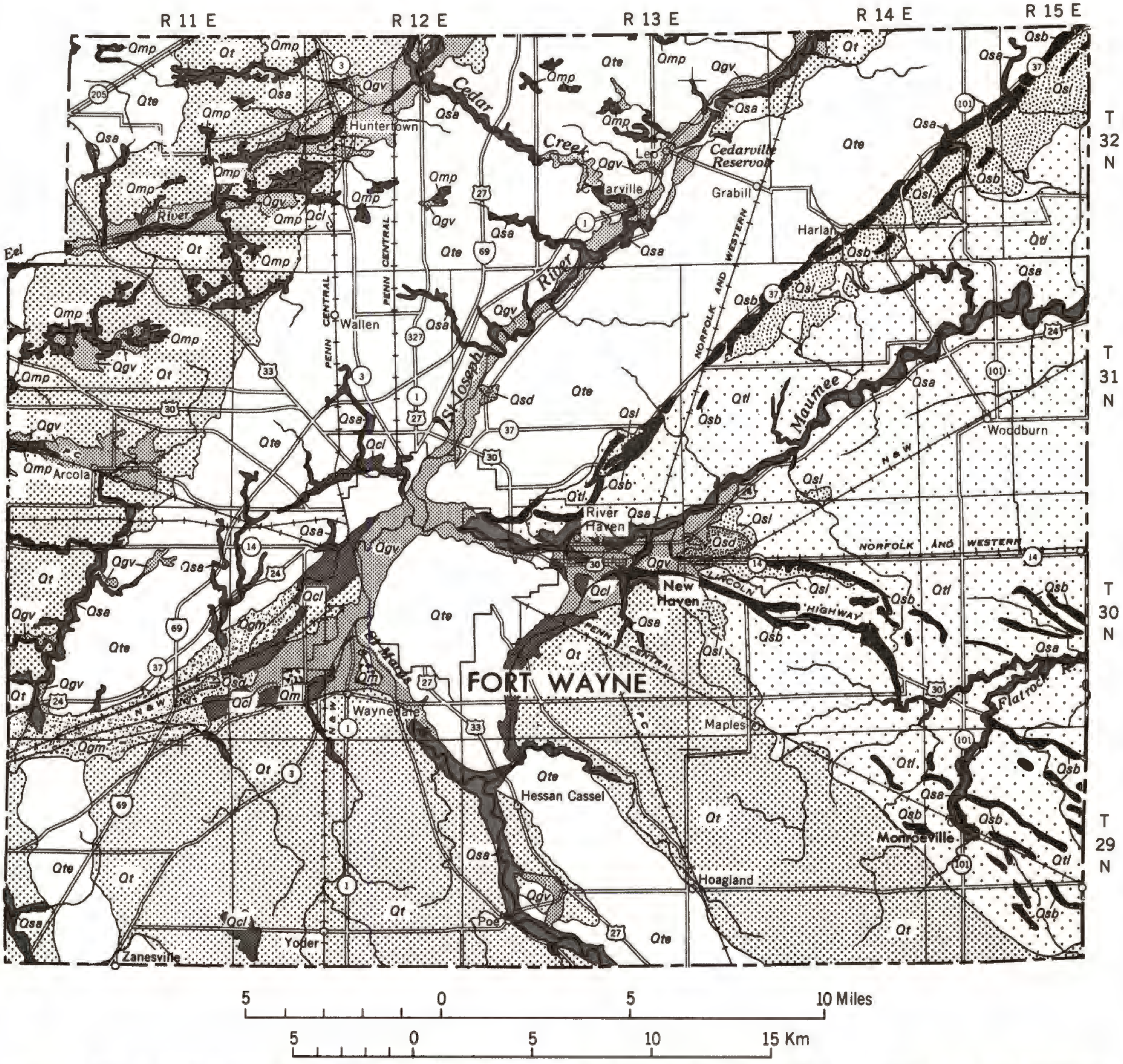


Figure 4. Map of Allen County showing surface distribution of glacial materials (from Johnson and Keller, 1972, and Burger and others, 1971) (explanation on the following page) and generalized cross section across the northern third of the county showing the relationship between surface and subsurface materials.

EXPLANATION

UNCONSOLIDATED DEPOSITS

Qm

Made and modified land

Artificial fill and land substantially modified by the removal of unconsolidated deposits. Many small areas not mapped

Qsa

Silt, sand, and gravel

Mostly stream deposits, but includes some slump and swamp deposits. Martinsville Formation

Qmp

Muck, peat, and marl

Swamp and lake deposits. Martinsville Formation

Qgm

Muck or silt over sand and gravel

Outwash deposits of sand and gravel overlain in places by thin deposits of muck, peat, clay, silt, or fine sand. Martinsville Formation over Atherton Formation

Qsd

Sand and some silt

Dune deposits. Atherton Formation

Qsb

Sand and gravel

Beach and shoreline deposits in bars, spits, deltas, and beaches. Includes some dune sand and till. Atherton Formation

Qcl Qsl

Clay, silt, and sand

Lake deposits. Qcl, mostly clay and silt; Qsl, mostly sand. Atherton Formation

Qgv

Gravel, sand, and silt

Outwash deposits. Atherton Formation

Qtu

Till

Subsurface only (see cross section)
Unnamed member, Lagro Formation

Qt Qte Qtl

Till

Includes some ice-contact stratified drift.
Qt, ground-moraine deposits; Qte, end-moraine deposits; Qtl, wave-scoured lake-bottom till.
New Holland Till Member, Lagro Formation

Qtt

Till

Subsurface only (see cross section)
Trafalgar Formation and lower tills

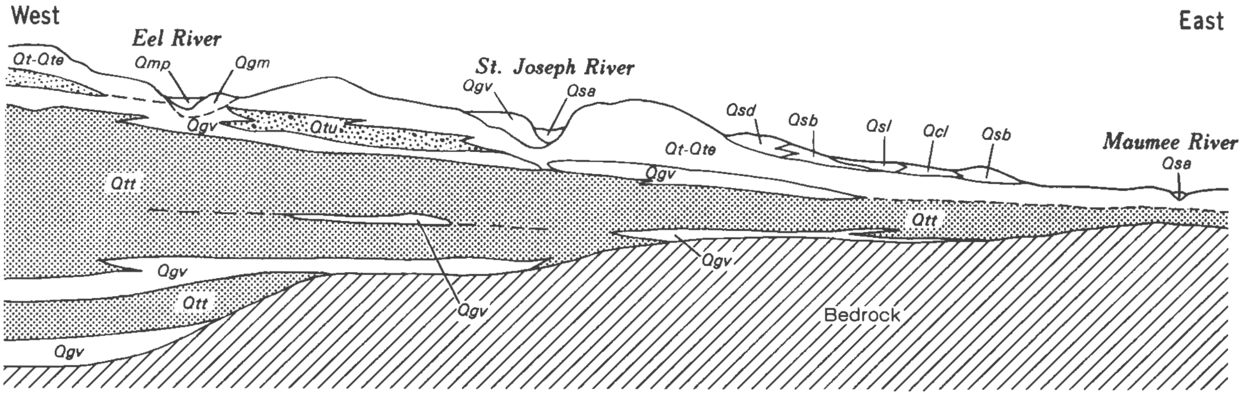
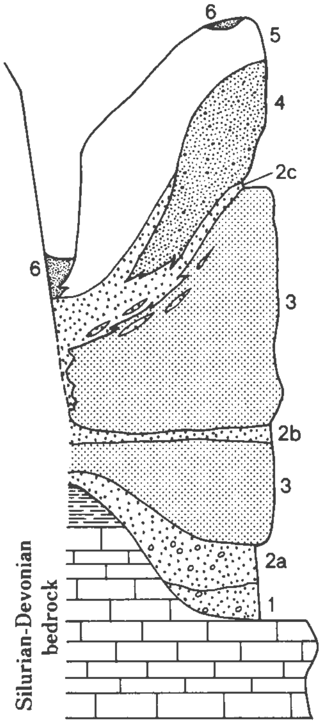


Figure 4—Continued



Formation	Member	Thickness	Map unit
(6) Martinsville		0 - 100 ft	Qsa Qgp, Qgm, Qmp, Qsl
(5) Lagro	New Holland Till (Erie Lobe deposit, eastern source)	0 - 100 ft	Qte, Qt, Qtl
(4) Lagro	Unnamed (Saginaw Lobe deposit, northeastern source)	0 - 50 ft	Qte
(2b-c) Atherton		0 - 100 ft	Qgv, Qgm (mostly subsurface)
(3) Trafalgar		0 - 150 ft	Subsurface only
(2a, 1) Atherton		0 - 60 ft	Subsurface only

Figure 5. Stratigraphy and characteristics of unconsolidated materials in Allen County.

GLACIAL STRATIGRAPHY

The stratigraphy, or layering of glacial sediments, is more complex than that seen only near the surface (fig. 5). Beneath the most recent materials, which are those most often associated with the landforms we see today, are the deposits of earlier glacial advances. Although unraveling this succession of strata from records of widely scattered borings and fortuitous natural and artificial exposures is sometimes uncertain, the record of numerous glacial advances of probable late Wisconsinan age ($<$ 22,000 years old) represented by till units and many nonglacial periods of sand and gravel outwash deposition is clear (appendix).

SURFACE OF THE TRAFALGAR FORMATION

The present land surface in Allen County overlies several former land surfaces. The two most readily defined are the surface of the Trafalgar Formation and the bedrock surface. Both are significant in ground-water and engineering considerations. The surface of the Trafalgar Formation (fig. 6), the lower hard till, is ridged in form and presents a somewhat subdued image of the present surface topography. (See also fig. 2; fig. 8; appendix, sections PP′ and RR′.)

Material type	Relationships
Overbank silt and clay grading downward to channel sand or shelly fine gravel of modern stream-deposited Martinsville Fm., and sand, gravel, and clay of glacial stream-deposited, wind-deposited, or lake-deposited Atherton Fm.	Floodplains of major streams commonly stripped surfaces, underlain by relatively shallow glacial tills, outwash sand, or gravel. Atherton materials interlayer with Martinsville materials, generally atop till of Lagro Fm., although many surface sand and gravel deposits are units that continue laterally beneath Lagro Fm. in valley walls and are actual outcrop of stratigraphically low Atherton units; commercial gravel source in places, particularly in Eel River valley.
Till that is silty clay loam to clay loam and that is massive, firm, and pale brown to light gray; local lenses of sand or plastic clay and massive layers are more common near base; clay loam to clay variant occurs in places at surface in northwestern Allen County; commonly grades downward to more clayey till. ANALYSIS: 10%-20% sand; 40%-50% clay. (See Bleuer and Moore, 1972.)	Thickness greatest in moraine areas, although base of Lagro rises in elevation as does its surface. Unit is the same as comprises the series of concentric moraines looping across northeastern Indiana and northwestern Ohio. Basal clayey zones are probably incorporated preglacial lake clays.
Till that is firm light yellowish-brown to light-gray loam. (See Bleuer and Moore, 1975.)	The surface till of north-central Indiana whose southern edge pinches out between New Holland and Trafalgar tills in northwesternmost townships; it thickens toward northwest and occurs in outcrop in or near Eel River valley in areas of Miami soil type.
Fine dense sand to pea gravel; commonly gradational to, and interlayered with, "flow till" below, or separates massive sheared till lenses.	Thickens into channel phases, or merges with thick sand in major valleys; commercial gravel source in some places, particularly where outcrops in Wabash-Erie Channel.
Till that is massive hard loam containing scattered thin beds of sand, silt, and pea gravel or flow-till mixtures of these, particularly at top; massive repetitive sheared till lenses in places. Consistent sand unit at about mid-depth. ANALYSIS: 35%-45% sand; 15%-20% clay. (See Bleuer and Moore, 1972.)	Equivalent to surface till of central Indiana (deposit of East White Sublobe), highly overconsolidated by ice load; buried surface is a subdued replica of present topography; significant ridges already present before latest ice advances (Saginaw and Erie Lobes).
Sand, gravel, and weathered sand.	In places merges with stratigraphically higher sand units; only encountered in deepest wells or quarries in bedrock, where it is a commercial sand or gravel source. Includes highly weathered pre-Wisconsinan sand unit at base.

Figure 5—Continued

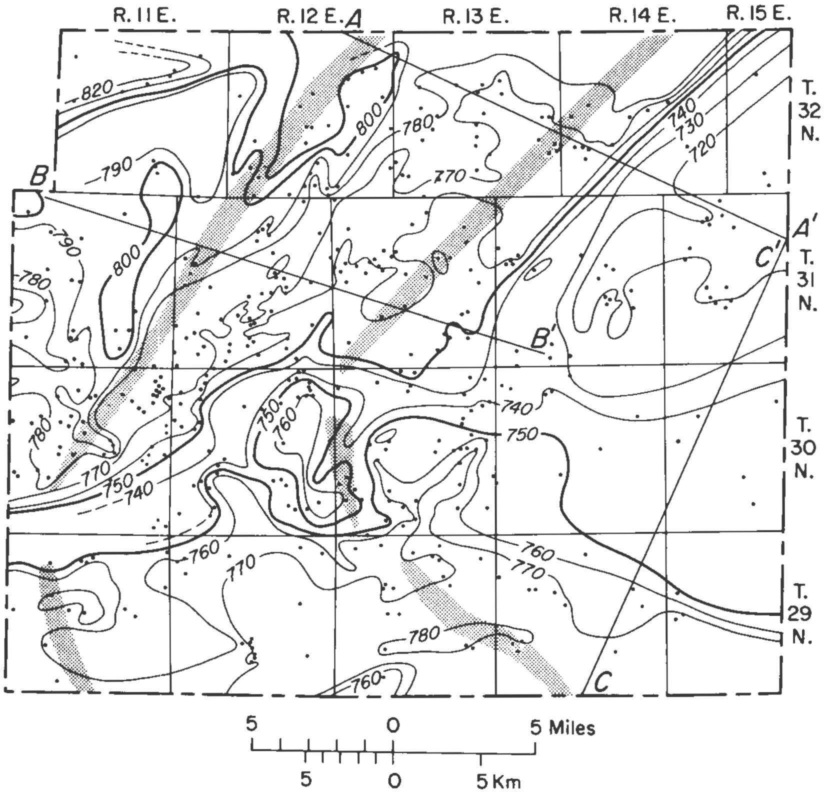


Figure 6. Map of Allen County showing topography of the buried surface of the Trafalgar Formation. Stippled bands mark crests of moraine ridges at the present land surface. Contour interval is 10 feet. From Bleuer, 1974.

BEDROCK SURFACE

The buried surface of the bedrock (fig. 7), the land surface that existed prior to deposition of the materials of the Ice Age, is greatly different from the constructional topography of the present surface and from the buried surface of the Trafalgar Formation (figs. 6 and 8).

Although the total relief in the northeastern and northwestern parts of the county in preglacial time was about 210 feet, similar to that for the glacial topography, the preglacial landscape in Allen County was much like that now found in parts of southeastern Indiana. Drainage from Allen County flowed northward and westward to a southwestward-flowing channel, then merged to the south into the buried Teays Valley, which accommodated a major stream (about the size of the present Ohio River) flowing westward across central Indiana. Thus Allen County was not crossed by a continental divide, as it is today.

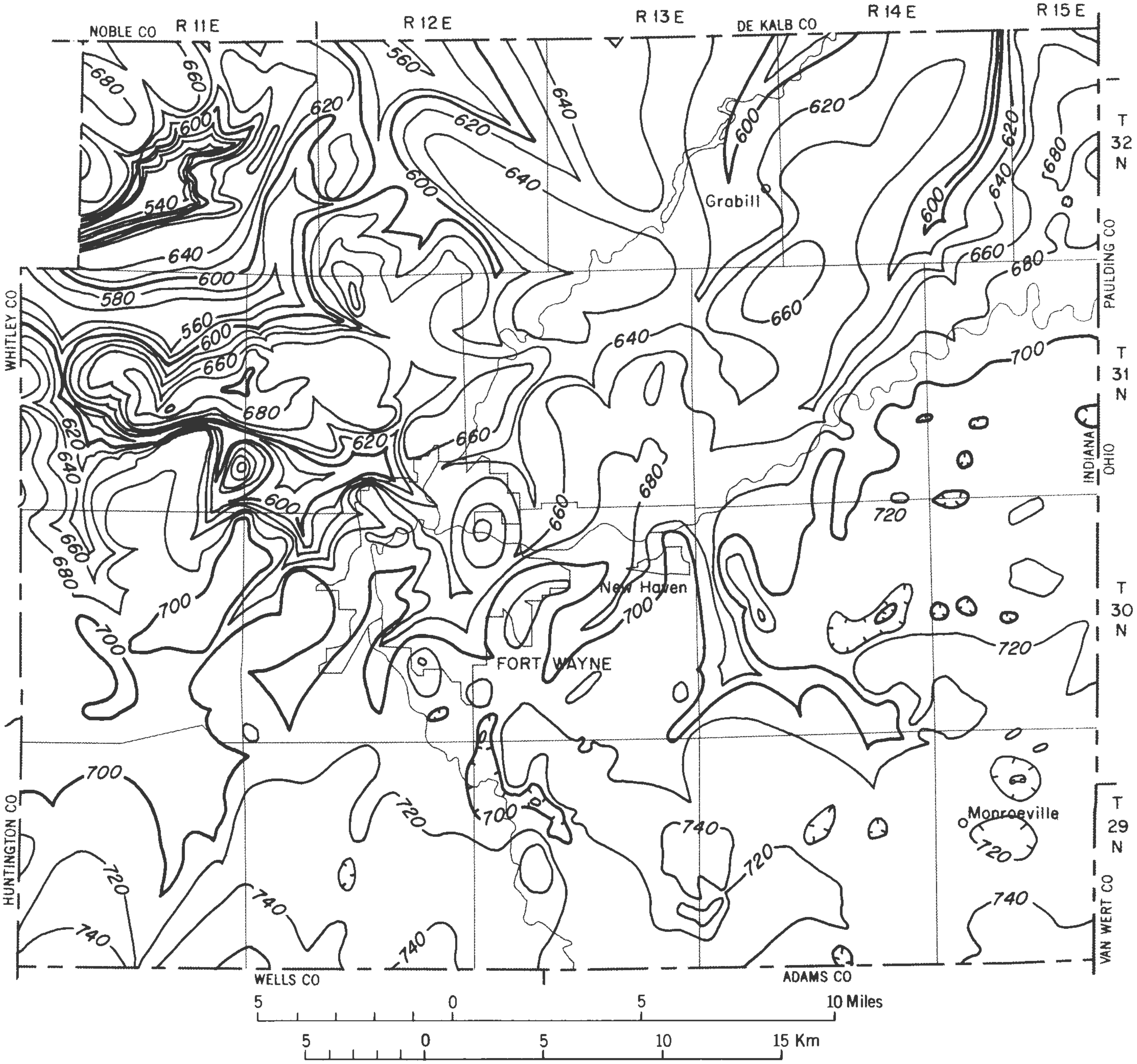


Figure 7. Map of Allen County showing topography of the bedrock surface—the preglacial landscape. Contour interval is 20 feet.

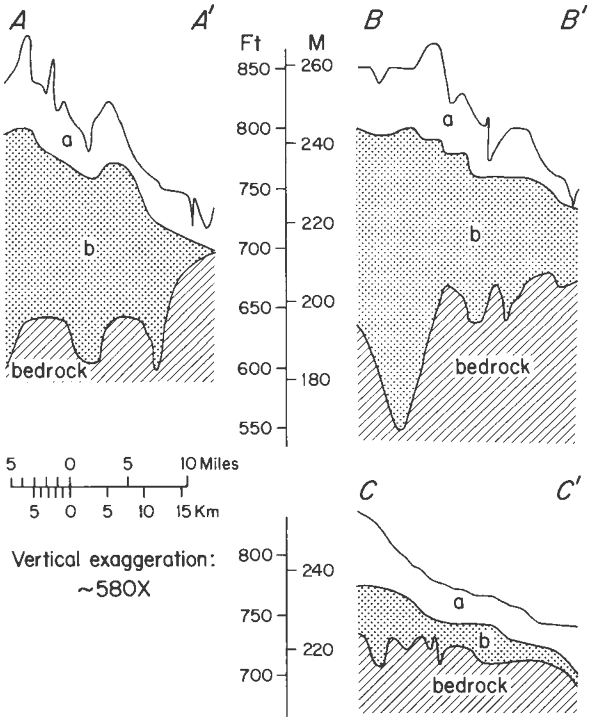


Figure 8. Cross sections showing thicknesses of the Lagro Formation (a), the Trafalgar Formation, and lower glacial units (b) above bedrock. Lines of the sections are shown in figure 6. From Bleuer, 1974. Datum is mean sea level.

THICKNESS OF GLACIAL DRIFT

The thickness of the drift (fig. 9) reflects both the nature of the old land surface on the bedrock and the present land surface. Where ancient buried valleys are present on the bedrock surface, or where there are hills on the present surface, the drift is thicker. Where bedrock ridges or present valleys are found, the drift is correspondingly thin.

Generally, the unconsolidated material becomes thicker to the northwest as the bedrock elevation becomes lower. And drift thickness tends to vary directly with the overlying glacial topography. The thickest drift is probably in a valley system in the northwest corner of the county where water wells and seismic determinations indicate 320 feet of fill. A few areas on the till plains in the southeast may have 40 feet of till and outwash overlying the carbonate rock plateau beneath. In the Maumee valley near the Ohio line, less than 20 feet of fill materials may cover bedrock.

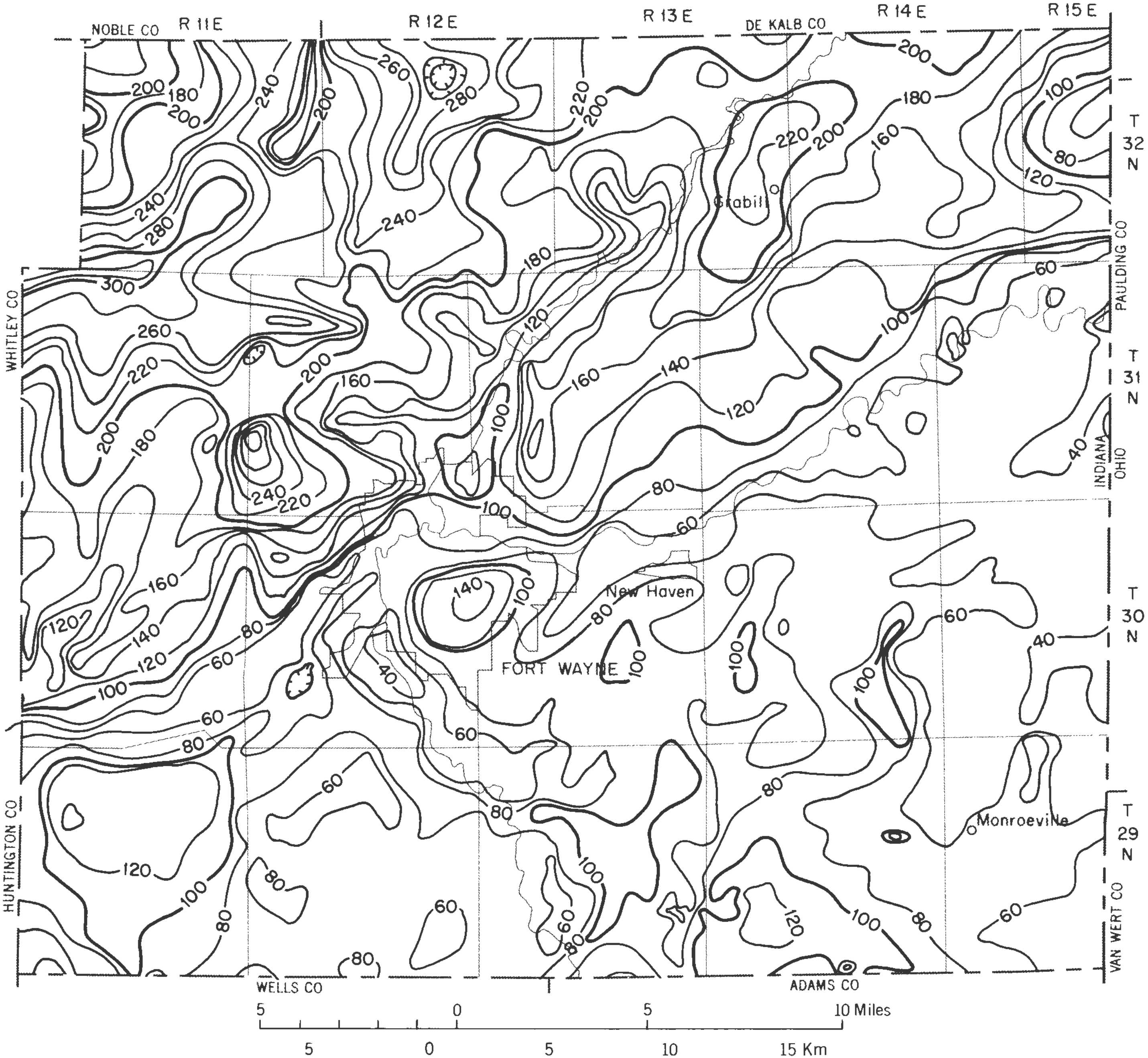


Figure 9. Map of Allen County showing thickness of unconsolidated deposits (drift over bedrock). Contour interval is 20 feet.

BEDROCK GEOLOGY

The bedrock surface in Allen County is composed primarily of limestone, dolomite, or shale and, as previously noted, dips toward the center of the Michigan Basin. The rocks are distributed in east-westward-trending outcrop bands representing the intersection of the bedrock surface with the beveled edges of the slightly northeastward-dipping rock strata (fig. 10). In their vertical sequence, the rock strata (fig. 11) record successive alternations of marine environments and represent a period of time of millions of years.

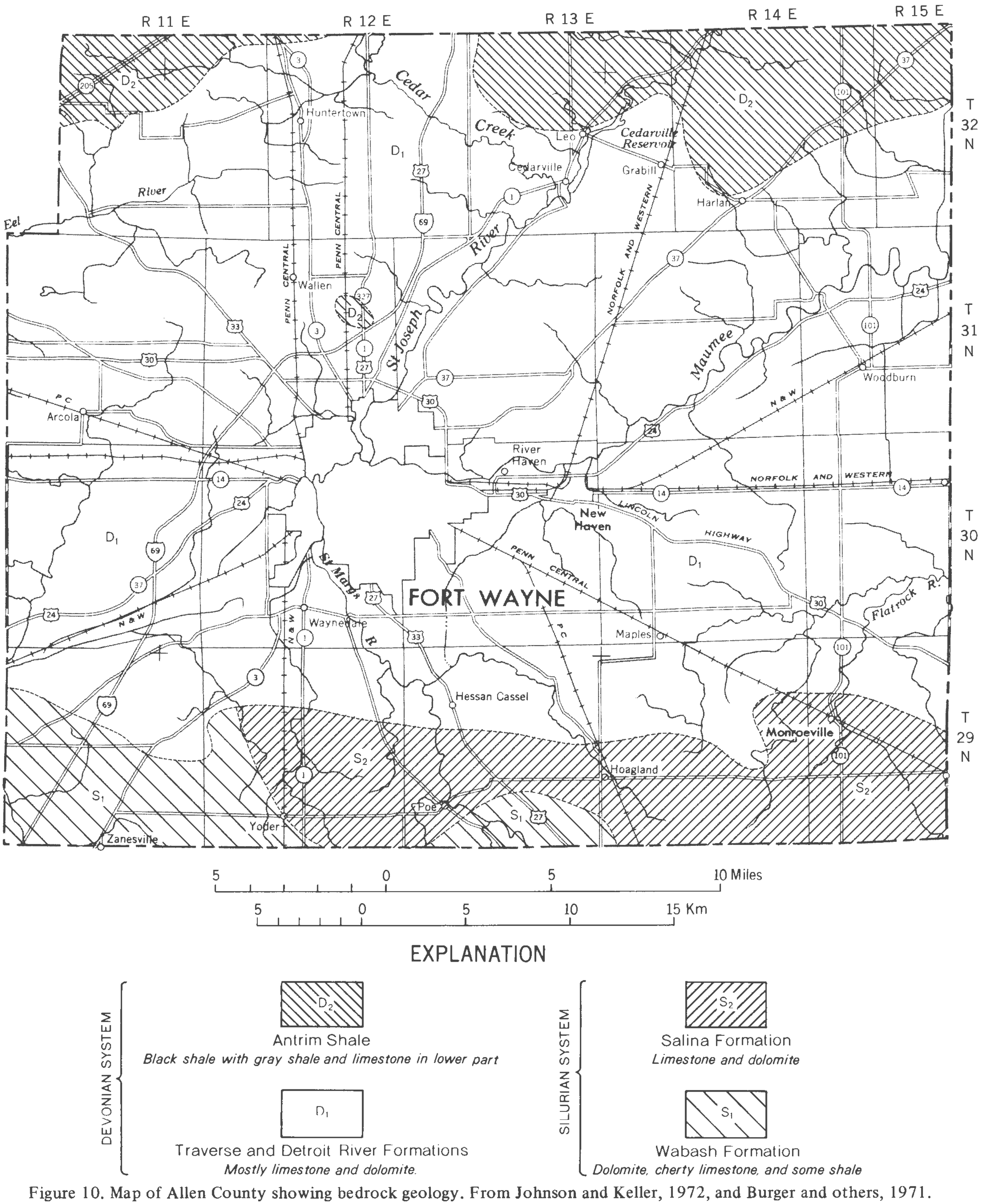
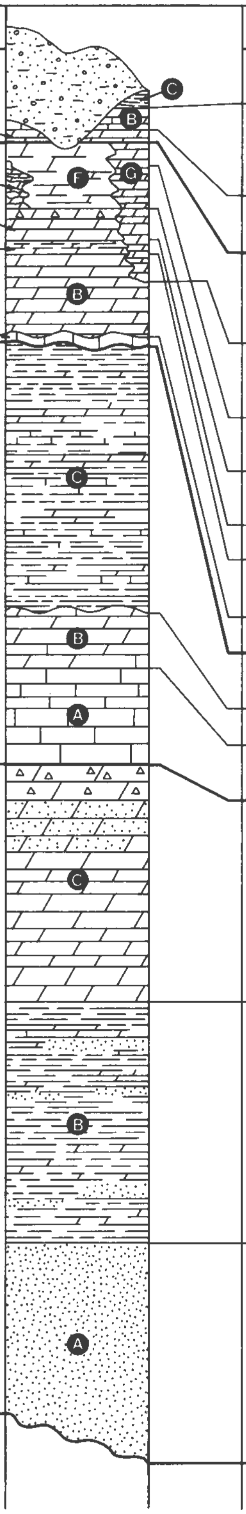


Figure 10. Map of Allen County showing bedrock geology. From Johnson and Keller, 1972, and Burger and others, 1971.



System	Unit	Thickness	Distribution
DEVONIAN	Ⓒ Antrim Sh.	0 - 90 ft	Bedrock surface in northern townships. (See fig. 10.)
	Ⓑ Traverse Fm.	0 - 75 ft	Bedrock surface of much of central Allen County (see fig. 10) except in northernmost townships where the units lie beneath Antrim Shale and in the southernmost townships where they are absent.
	Ⓐ Detroit River Fm.	0 - 70 ft	
SILURIAN	Ⓖ Salina Fm.	0 - 350 ft	Bedrock surface in southern Allen County (see fig. 10) and subsurface in central part of county.
	Ⓕ Wabash Fm. (includes Fort Wayne Bank as Huntington Lithofacies)	0 - 250 ft	Bedrock surface in southwestern Allen County (see fig. 10) and subsurface to the northwest.
	Ⓔ Mississinewa Sh. Mbr.	0 - 23 ft	Exposed in Stone Street Gravel, Inc., Fort Wayne quarry.
	Ⓓ Louisville Ls.	70 - 125 ft	Exposed in May Stone & Sand Co., Inc., Ardmore Ave. quarry.
	Ⓒ Waldron Fm.	16 - 35 ft	Subsurface only.
	Ⓑ Salamonie Dol.	180 - 300 ft	Subsurface only.
	Ⓐ Brassfield Ls.	20 - 36 ft	Subsurface only.
ORDOVICIAN	Ⓒ Maquoketa Gr.	685 - 755 ft	Subsurface only.
	Ⓑ Trenton Ls.	115 - 200 ft	Subsurface only.
	Ⓐ Black River Ls.	235 - 285 ft	Subsurface only.
CAMBRIAN	Ⓒ Knox Dol.	575 - 750 ft	Subsurface only.
	Ⓑ Eau Claire Fm.	600 - 675 ft	Subsurface only.
	Ⓐ Mount Simon Ss.	350 - 600 ft	Subsurface only.
P€			Subsurface only.

Figure 11. Schematic geologic column showing bedrock units. Thicknesses of the individual units are variable. Total thicknesses of the sedimentary rock column above the Precambrian basement is about 3,000 feet.

Rock type	Comments
Shale, brownish-black; grenish gray in lower part.	
Dolomite and limestone, tan to gray-brown; petroliferous staining at some localities. Contains shaly partings and may contain quartz sand near base. Contains chert in two local quarries. Fossiliferous in bands, commonly containing large colonial corals.	
Dolomite, dense, fine-grained; characterized by thin color laminations in part; brecciated in part; sparse relict fossils; mostly recrystallized.	Contains evaporites in Michigan Basin; breccias in Allen County are probably due to solution of once-present evaporites.
Dolomite, fine-grained, light-gray to brown, slightly calcareous. Characteristically vuggy in Allen County, with recrystallized poorly defined fossil molds and casts. Partly laminated in Edgerton quarry core and less so at Woodburn quarry.	The basinward finer grained sediment deposited at time of Fort Wayne Bank or Huntington Lithofacies deposition. Missing owing to erosion and nondeposition in much of southern Allen County; thickens abruptly to northeast.
Dolomite, gray to blue, vuggy, biohermal, biostromal; reef core rock lacking in sedimentary structure, with steeply dipping flank beds.	Fort Wayne Bank is a reef deposit fringed by Michigan Basin and marking the edge of the more structurally stable Cincinnati Arch. Basinward (north and east) from the reef core and flank beds are finer grained nonreef deposits, the Salina. Similarly behind the reef fringe are Mississinewa and Liston Creek sediments. Such reefs, or bioherms and biostromes, are accumulations of coarse fossil-fragmental limestone which built up above the sea floor and characterized midwestern Silurian sedimentation.
Dolomite, clayey and silty, gray, dense, massive; dominated by cherty fossiliferous dolomite approaching lithology of Fort Wayne Bank.	
Dolomite, brown mottled blue-gray; common thin clayey laminae.	
Dolomite, fine-grained, silty, dark; thin shale laminations.	
Dolomite, fine-grained to vuggy to granular, white to tan to brown; beds range from pure dolomite to very cherty dolomite.	
Similar to Salamonie; somewhat coarser grained.	
Shale and limestone, interbedded; predominantly shale near base and more common limestone near top. (See Gray, 1972.)	
Limestone, dolomitic, tan, fossiliferous.	
Limestone, dolomitic, very finely crystalline, clayey, darker and more clayey near base.	
Dolomite, finely saccaroidal; some chert; coarser and more cherty and oolitic in upper part.	
Interbedded: sandstone or siltstone, dolomitic, pink, glauconitic; shale, green, maroon, or black, glauconitic, and micaceous; dolomite, silty or sandy with some glauconite.	
Sandstone, fine- to coarse-grained, gray to pink, friable to slightly silica-cemented.	
Volcanic flows and andesitic basalt.	Large-scale geophysical anomalies in Allen County indicate probable volcanic flows.

Figure 11—Continued

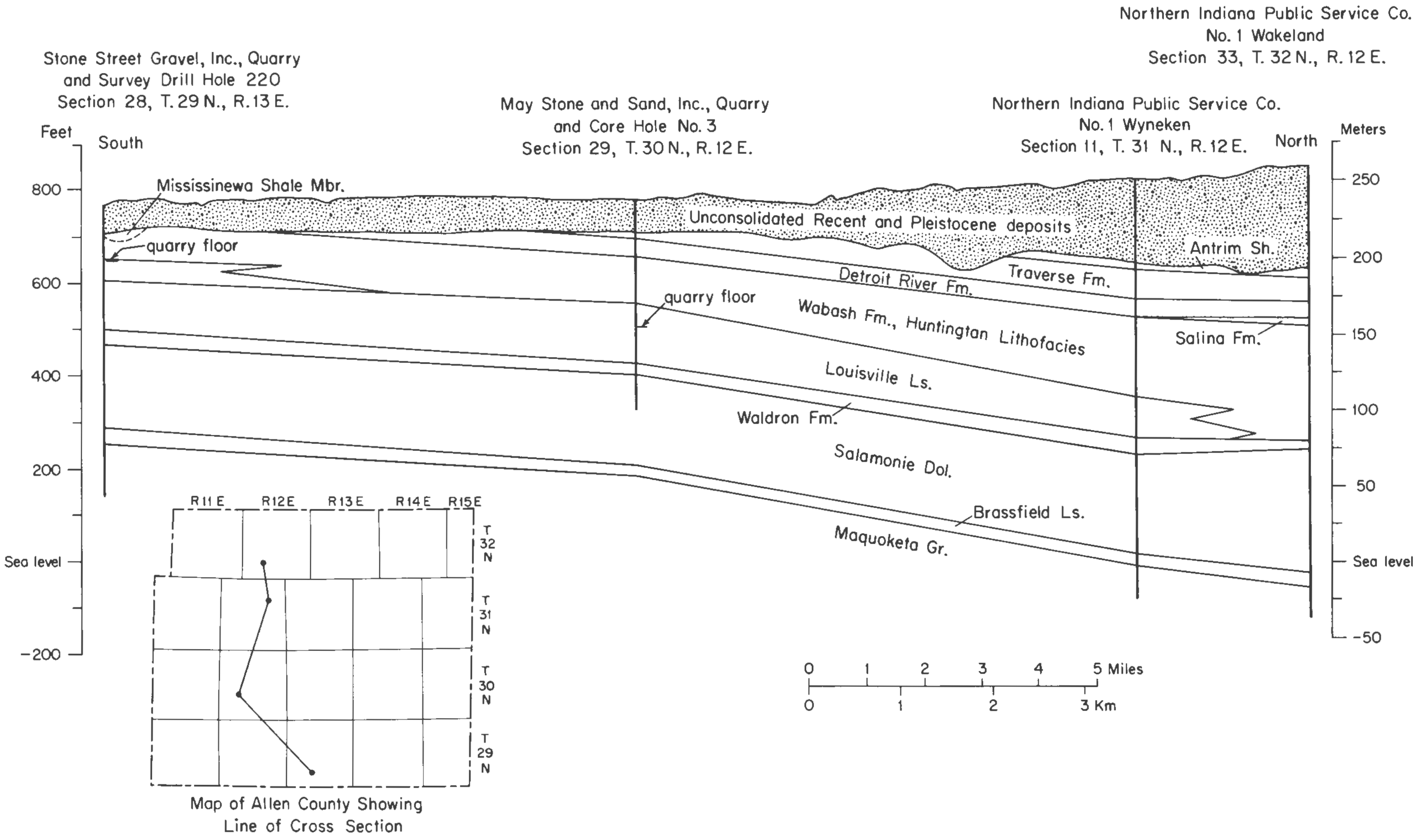


Figure 12. Cross section showing correlation and structure of quarryable Silurian and Devonian carbonate rocks in Allen County.

Mineral Resources

Only some of the earth's materials underlying Allen County may be placed in the resource category. These are: petroleum and natural gas, crushed stone, sand and gravel, peat, clay, and water.

MINERAL AGGREGATES

By Michael C. Moore and Curtis H. Ault

Mineral aggregates are the fundamental materials for most structures and roads in Indiana. Allen County is fortunate to be well endowed with two sources of aggregate, each having unique geologic distribution: dolomitic limestone bedrock and sand and gravel in the overlying glacial drift. Sand, gravel, and crushable rock are found in almost limitless supply in Allen County, but sites where these materials may be economically extracted are rare. It is paradoxical that although a growing metropolitan area requires ever-increasing supplies of sand and gravel, its very growth tends to eliminate the most convenient sites of extraction. Supply and demand pressures in the marketplace should encourage initial development of the best sources and ultimate use of lower quality deposits. In practice, however, such orderly progressions of resource use do not occur, because, first, not all locations of the best deposits are known and, second, competing and unrelated uses exist for the land under which mineral deposits are found.

Table 2. Stone quarry operations in Allen County and formations quarried

[Locations of A, B, C, D, and E are shown in fig. 14]

	Company and location	Quarry and year opened	Overburden and exposed formations (ft)		Cored formations (ft)	
A	May Stone & Sand, Inc., NW¼NE¼ sec. 29, T. 30 N., R. 12 E., Ardmore Ave., Fort Wayne	Ardmore 1951	Overburden (sand and gravel, 40 ft) Traverse Detroit River Wabash Louisville	65 11 35 96 48 255	Louisville Waldron Salamonie	80 25 84
B	May Stone & Sand, Inc., NW¼NE¼ sec. 23, T. 31 N., R. 14 E., 6 miles east of New Haven near Woodburn on U.S. Route 21	Woodburn 1967	Overburden (sand and gravel, 30 ft) Traverse Detroit River	50 61 12 123	Detroit River Salina	29 132
C	Midwest Aggregates Corp., center sec. 36, T. 30 N., R. 11 E., Lower Huntington Road, Fort Wayne	Lower Huntington Road 1970	Overburden (sand and gravel, 20 ft) Traverse Detroit River Wabash	60 10 39 11 120		
D	Midwest Aggregates Corp., SW¼NW¼ sec. 8, T. 30 N., R. 15 E., 2 miles west of Edgerton on State Road 14	Edgerton 1963	Overburden Traverse Detroit River	45 36 34 115	Salina Wabash Louisville Salamonie	132 79 71 33
E	Stone Street Gravel, Inc., SE¼SW¼ sec. 28, T. 29 N., R. 13 E., 2 miles south of Hessen Cassel and 1 mile west of U.S. Route 27	Fort Wayne 1967	Overburden (sand and gravel, 30 ft) Wabash	50 55 105	Wabash Louisville Waldron Salamonie Brassfield Cincinnatian	45 114 28 180 36 16

Table 3. Characteristics of quarryable Silurian

Unit	Thickness and distribution	Rock type
Devonian Traverse	60-75 ft; less thick where eroded in central and southern Allen County.	Limy dolomite and limestone; contains shaly partings and chert in places; and may contain thin quartz sand near its base.
Detroit River	20-70 ft in central and northern parts of county; thin or missing in south.	Limy dolomite with thin color laminations and brecciated (fractured and recemented) units.
Silurian Salina	0-350 ft; thickens abruptly in north; missing over much of west and south.	Dolomite, usually with dark bands and laminations; vuggy and fossiliferous near Woodburn quary.
Wabash (Huntington Lithofacies)	75-250 ft; present in central and south-central parts of county.	High-purity dolomite: vuggy and fossiliferous.
Wabash (Mississinewa Shale Member)	0-23 ft; exposed only in Stone Street quarry in Fort Wayne; possible distribution only in southwestern part of county.	Dolomite: clayey and silty; mottled gray to blue gray.
Louisville	70-125 ft in central southern Allen County; missing in north.	Dolomite with thin clayey laminae; may contain abundant chert in part.
Waldron	16-28 ft where measured in cores; not recognized with certainty in eastern Allen County.	Dolomite with thin irregular black shale laminations.
Salamonie	180 to more than 300 ft county wide.	Dolomite: fine-grained, porous, and fossiliferous.
Brassfield	Less than 20 to about 36 ft or more county wide.	Fossiliferous dolomite; may contain shaly laminae.

and Devonian carbonate rocks in Allen County

Aggregate potential	Chemical potential	Comments
Good potential; much of the formation is normally suitable for class A aggregate, but it may contain soft units, and cherty zones may be unsuitable for use in concrete.	18 ft of cherty limestone in Woodburn quarry has 5 percent or less of magnesium carbonate; possible use in cement making; however, high in magnesium carbonate elsewhere and usually contains other impurities.	Extent of low-magnesium limestone unknown.
Fair potential; measurements of soundness and resistance to abrasion may not fall within limits for class A aggregate.	High-purity carbonate where analyzed (more than 95 percent $CaCO_3$ and $MgCO_3$), but contains zones with more than 5 percent quartz.	Should be extensively tested before considering for chemical uses.
Good potential in central Allen County; unused source of high-quality rock, but poorly accessible by open-pit mines.	Extremely pure at Woodburn quarry; suitable for most chemical purposes for dolomite, but iron content may be too high for glass flux.	Composition varies; extent of high-purity dolomite at Woodburn may be limited.
Excellent potential; used extensively in Ardmore and Lower Huntington Road quarries. Meets all state specifications for class A aggregate.	Potentially suitable for all chemical purposes for dolomite.	
Poor potential; poor durability due to clay content.	Unsuitable for chemical purposes.	
Fair potential; usually passes class A specifications, except where chert or other siliceous material prohibits use in concrete and bituminous mixes.	Potential for chemical uses is poor. Clayey laminae and other impurities are widespread.	
Fair potential; it has not been tested for aggregate.	Probably poor potential because of clay impurities.	
Qualified good potential; although it is a source of class A aggregate in other counties, its depth and possible softness limits its use in Allen County.	Almost pure carbonate at May Stone & Sand, Inc., quarry on Ardmore Ave. Suitable for most chemical uses for dolomite.	Widespread and uniform in composition, but information is sparse, particularly chemical analyses.
Probably little forseeable use because of thick overlying dolomite.	Possible shaly impurities limit usefulness; depth beneath overlying suitable rocks may delay its use indefinitely.	

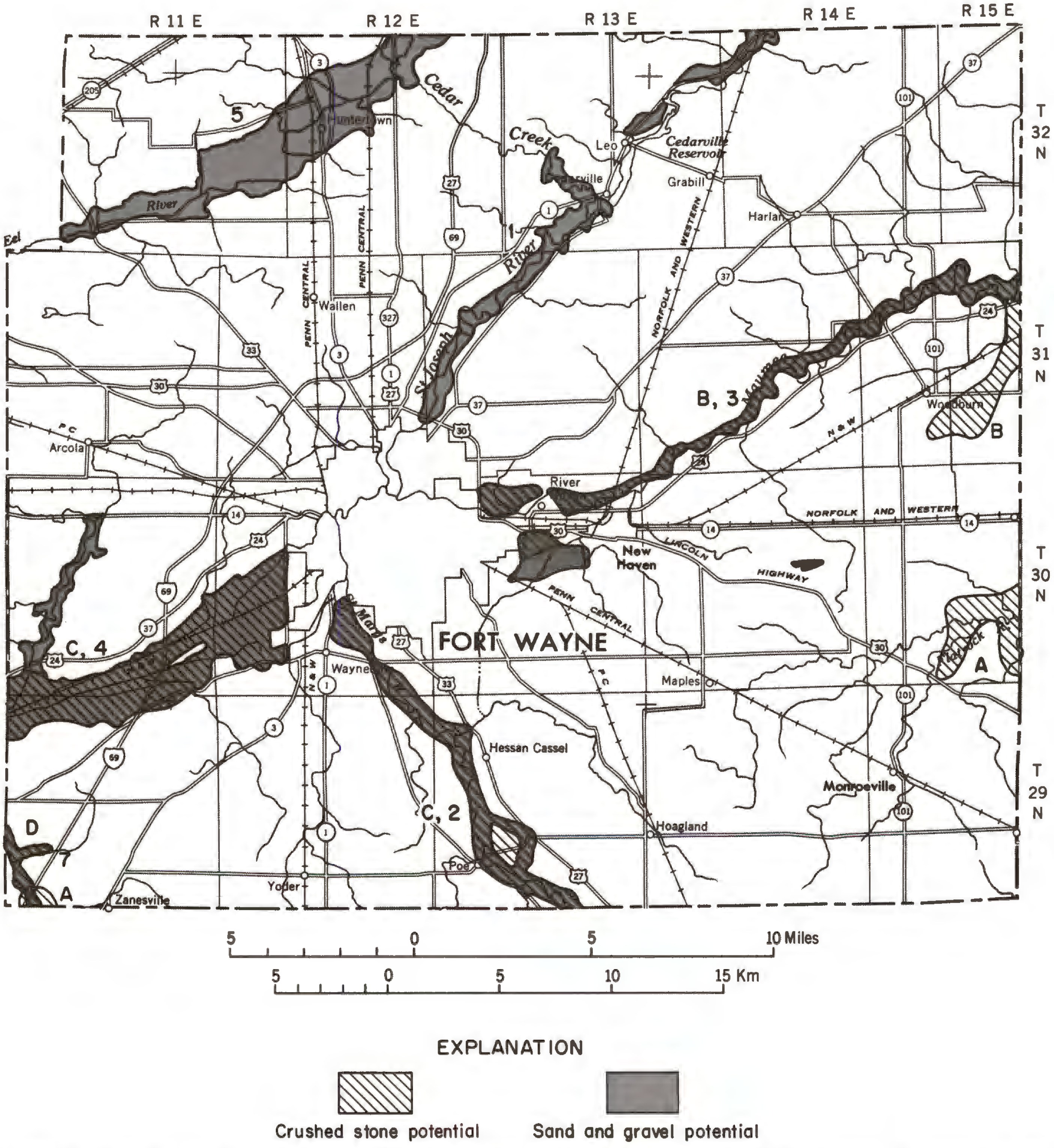


Figure 13. Map of Allen County showing areas of potential quarry and sand and gravel pit development. Explanation is on the following page.

CRUSHED STONE POTENTIAL

Favorable areas for crushed stone quarries

A. 40 feet or less of overburden over Silurian and Devonian carbonate rocks.

B. Silurian and Devonian bedrock overlain by 40 to more than 60 feet of overburden with some potential for sand and gravel along the Maumee River.

C. Silurian and Devonian bedrock overlain by less than 60 to more than 80 feet of overburden with potential sand and gravel along the St. Marys River and the Wabash-Erie Channel.

D. Some potential for quarrying carbonate bedrock depending on presence of commercial sand and gravel deposits in overburden 40 to 80 feet thick.

SAND AND GRAVEL POTENTIAL

1. ST. JOSEPH VALLEY

Urbanization has eliminated the lower reaches from consideration for gravel reserves. A few meanders have been worked, and the best prospects lie between Paper Mill Bridge and the Cedarville Reservoir. Upstream from Leo possible siltation downstream and narrow valley width are drawbacks. The valley widens north of the county line, and some abandoned pits are present in terraces at Spencerville in DeKalb County.

2. ST. MARYS RIVER VALLEY

Extensive terraces that are underlain by potentially commercial gravel deposits lie along this stream course. Active and abandoned pits are present despite the short valley stretch within Allen County. Pits might possibly be developed in association with stone quarries where shallow bedrock is found.

3. MAUMEE RIVER VALLEY

Sand and gravel may be derived from bars inside meanders. The deposits are generally thin, fine grained, and of limited extent. Immediately west of New Haven small pits have been developed and some potential exists here, as well as east of New Haven, but urbanization is approaching. Sand and gravel could be further exploited in the western part of the stream course. The valley was intimately associated with glacial drainage, and there is a great variety of interbedded materials in the trough surrounding the river. Lack of uniformity may assure low quality or difficult working of such deposits.

4. WABASH-ERIE CHANNEL

Several gravel layers are superimposed and add to relatively great thicknesses in places; elsewhere one or all beds are thin or absent. Very hard till (Trafalgar Fm.) may be found in lenses and sheets greater than 10 feet thick at various positions in the drift section and would pose a problem for pit development. Fine-grained alluvial silt, clay, or muck cap the surface in varying thicknesses and must be stripped as well. In many areas the gravel is a continuous sheet extending from the valley floor into the valley wall, beneath the upper till (Lagro Fm.). Where the gravel is thick and the capping till thin, some stripping back into the wall is feasible. The area has long been the site of gravel pits, but urbanization has invaded the east end and the Fox Island County Park, Interstate Highway 69, and three aggregate producers already limit the area available to the west. A region 5 miles by 2 miles remains available, although many parts of it have little or no potential.

5. EEL RIVER VALLEY

With the greatest potential for gravel recovery, this region contains surface or near-surface sand and gravel more than 100 feet thick. Most material may be fine grained, but coarser gravel is present. Ground water may prove a problem because of the high water table and the complications of artificial drainage.

Figure 13—Continued

SOURCES OF CRUSHED STONE

Within Allen County, crushed stone is quarried in open pits from rocks of Silurian and Devonian age (table 2). This stone is found in broad, essentially east-west belts (fig. 10) that thicken and dip gently to the north and northeast (fig. 12). Where rocks are at moderate depths, underground mining may be possible. Several presently used limestone and dolomite strata (table 3) could be mined underground. Other, more deeply buried formations also have potential for such use.

FUTURE SOURCES OF CRUSHED STONE

Because of the large reserves of limestone and dolomite suitable for crushed stone in Allen County, future locations of quarries or underground mines will be determined more by associated geologic and economic considerations than by the geographic distribution of the reserves themselves. There are few areas in Allen County where less than 40 feet of overburden is present over bedrock, although less than 20 feet has been reported in driller's logs in sec. 11, T. 31 N., R. 15 E., near U.S. Highway 24 at the Ohio-Indiana border.

Areas of thin overburden containing commercial deposits of sand and gravel offer the best prospects for new open-pit quarries. Such areas include the valley along the St. Marys River south of Fort Wayne, the Wabash-Erie Channel southwest of Fort Wayne, and along the Maumee River from Fort Wayne to the Indiana-Ohio border (fig. 13). The thick overburden in much the rest of Allen County effectively prohibits commercial open-pit quarrying at present and makes underground mining the only effective way of extracting crushable stone in those areas. It is unlikely that underground mining through a shaft will be considered soon unless exploratory efforts reveal deposits of high chemical purity or unique composition. Underground drift mines are more likely to be introduced in present quarries where surface expansion of the pit is not feasible.

SOURCES OF SAND AND GRAVEL

Similar to more than two-thirds of Indiana's counties, Allen County has large reserves of sand and gravel. Sand and gravel are low-unit-price commodities with high place value. The delivered price depends on the distance and difficulty of transportation to market.

All sand and gravel produced (table 4) or potentially available in Allen County comes from sediments of Pleistocene age, most of which were deposited by rivers carrying glacial meltwaters. The mantle of unconsolidated materials that include sand and gravel ranges from less than 40 feet to more than 300 feet in thickness. Overbank materials left by floodwaters, windblown sand, beach deposits, and slump deposits contribute minor amounts to the sand and gravel supply, but running water was by far the dominant agent of deposition.

FUTURE SOURCES OF SAND AND GRAVEL

There are two major sources of sand and gravel in Allen County: valleys of present rivers and abandoned channels of Pleistocene streams. Terraces in the three major river valleys in Allen County have been worked for gravel (fig. 14). The terrace deposits (St. Joseph, St. Marys, and Maumee Rivers) are not more than 20 feet thick, nor do they extend far from the river. Excellent gravels are found in terrace deposits (Qgv, fig. 4), but layers of till and silty sand are interbedded in places, which makes exploitation difficult. The sluiceway deposits (Eel River valley and Wabash-Erie Channel) contain very thick high-quality gravel deposits in places, although even in these areas interbeds of till are commonly present. Some of these surface gravel deposits are continuous with gravels beneath till in the valley walls.

Table 4. Sand and gravel producers in and near Allen County, locations, and nature of deposits

[Numbered locations are shown in fig. 14]

Company and location	Status	Geology
Allen County		
1 Paul C. Brudi Stone & Gravel Co., Inc., Pit No. 1 SW¼NW¼ sec. 27, T. 30 N., R. 12 E.	Active	Terrace sands and gravels of St. Marys River valley; Atherton Formation.
2 Paul C. Brudi Stone & Gravel Co., Inc., Pit No. 3 NW¼ sec. 9, T. 31 N., R. 13 E.	Active	Outwash and alluvium of St. Joseph River valley; Martinsville and Atherton Formations.
Paul C. Brudi Stone & Gravel Co., Inc., Pit No. 4 SW¼SE¼ sec. 8, T. 32 N., R. 12 E.	Active on demand	Outwash sand and gravel of Eel River sluiceway; Atherton Formation.
3 Canyon Sand & Gravel Corp. NW¼SW¼ sec. 9, T. 32 N., R. 12 E.	Active	Outwash sand and gravel of Eel River sluiceway; Atherton Formation.
4 May Stone & Sand Co., Inc., Ardmore Ave. quarry NE¼ sec. 29, T. 30 N., R. 12 E.	Active	Terrace and valley-train outwash in St. Marys River valley and Wabash-Erie Channel; Martinsville and Atherton Formations.
May Stone & Sand Co., Inc., Woodburn quarry NE¼ sec. 23, T. 31 N., R. 14 E.	Inactive	Outwash in axis of glacial Lake Maumee; Martinsville and Atherton Formations.
5 Midwest Aggregates Corp. Pit No. 4 SE¼NW¼ sec. 36, T. 30 N., R. 11 E.	Active	Terrace and valley-train outwash of Wabash-Erie Channel; Martinsville and Atherton Formations.
Midwest Aggregates Corp. former fill pit No. 2 SW¼NW¼ sec. 8, T. 31 N., R. 12 E.	Inactive	Outwash and alluvium of St. Joseph River valley; Martinsville and Atherton Formations.
6 Perfection Gravel Corp. NE¼SW¼ sec. 2, T. 30 N., R. 13 E.	Active on demand	Outwash in Fort Wayne Outlet of glacial Lake Maumee; Martinsville and Atherton Formations.
7 Stone Street Gravel, Inc., Fort Wayne quarry sec. 28, T. 29 N., R. 12 E.	Active	Valley train and terrace of St. Marys River; intertill outwash; Martinsville and Atherton Formations.
DeKalb County		
Paul C. Brudi Stone & Gravel Co., Inc. SW¼SE¼ sec. 21, T. 33 N., R. 12 E.	Active on demand	Valley-train outwash in Little Cedar Creek in Eel River sluiceway; Atherton Formation.
Irving Gravel Corp. SE¼SW¼ sec. 27, T. 33 N., R. 12 E.	Active	Valley train of Eel River sluiceway; Atherton Formation.
Midwest Aggregates Corp. SW¼SE¼SW¼ sec. 35, T. 33 N., R. 12 E.	Active	Valley train of Eel River sluiceway; Atherton Formation.
Rieth-Riley (also pit across line in Allen County) NW¼NE¼ sec. 3, T. 32 N., R. 12 E. NW¼SW¼ sec. 35, T. 33 N., R. 12 E.	Active	Valley train of Eel River sluiceway; Atherton Formation.
Whitley County		
Midwest Aggregates Corp. NW¼ sec. 11, T. 31 N., R. 12 E.	Active	Valley train of Eel River sluiceway; Atherton Formation.
8 W. W. Gravel Co., Inc. Chopine Reserve, T. 30 N., R. 10 E.	Active	Valley train of Wabash-Erie Channel; Atherton Formation.

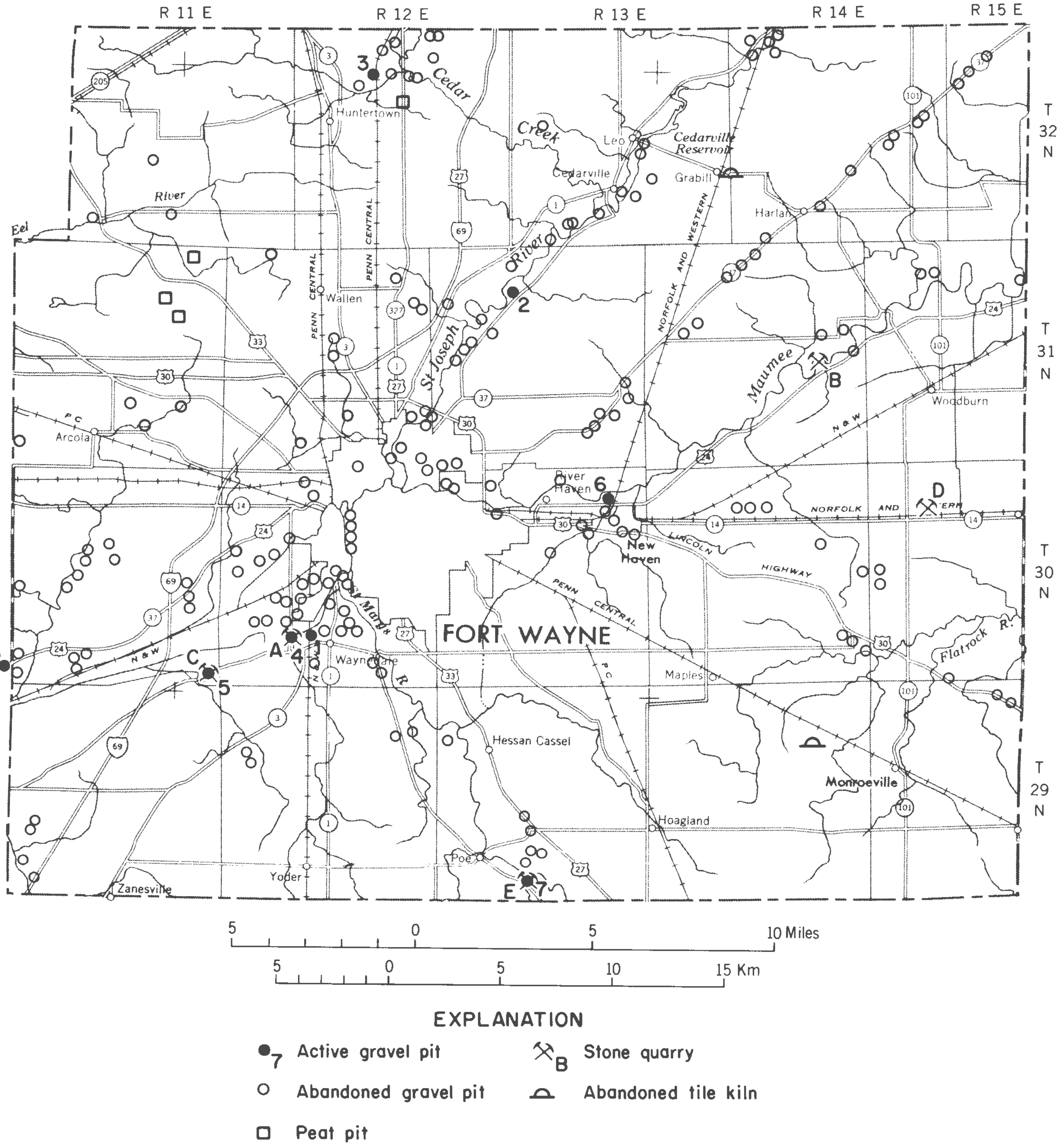


Figure 14. Map of Allen County showing locations of abandoned and active gravel pits, stone quarries, peat pits, and abandoned tile kilns. Letters refer to active quarries (table 2) and numbers refer to active gravel pits (table 4).

MINING METHODS

In Allen County, all stone for crushing is extracted from open-pit quarries. More than 40 feet of overburden must be removed before the stone can be quarried, although the overburden at four of the five quarries in the county contains marketable sand and gravel. Direct cost of quarrying and processing the bedrock does not vary appreciably from quarry to quarry. The consumer usually finds that price differences for crushed stone depend more on distance from the source than on basic prices f.o.b. at the quarry.

Underground mines may be more hazardous than open-pit quarries, and safety and environmental precautions must be taken to prevent roof falls, flooding, surface subsidence, and other conditions not normally associated with open-pit mining.

Offsetting these negative aspects are numerous environmental advantages, including less dust, noise, and blast effects, and an underground mine may have less effect on the movement and levels of ground water than a deep open-pit quarry. Additionally, no large pit requires fencing and surficial reclamation after mining has ended. Although production costs in underground mines are commonly higher than those for open-pit quarries, local economic and geologic conditions may make underground mining attractive. Excessive overburden, restrictive zoning, lack of land for open-pit expansion, frequent surface flooding, high cost of surface rights, and surface pollution problems are among the factors that might influence an operator to consider underground mining.

Limestone and dolomite, unless fractured or uncharacteristically soft, generally provide good mining conditions, permitting large underground rooms, high roofs, and clean working conditions. Most of the Silurian and Devonian rocks discussed previously are found at moderate depths and would probably be suitable for underground mining.

A moderately high face in a dry pit provides the optimum mining condition for sand and gravel, as the material can be loaded directly into trucks or processing equipment. Some cranes and shovels are also used to work dry pits, but they cannot do the additional work of stripping and handling processed materials that can be accomplished by front-end loaders. Unlike the stone industry, in which all rock blasted down must be further crushed and sized before the product can be sold, sand and gravel can be used directly as mined. This gives the producer the option of installing beneficiation and processing equipment to make specification material for a premium price or of simply loading large volumes of fill. As in the quarrying industry, mining activities in dry sand and gravel pits may produce large amounts of dust.

Any sand and gravel pit, dug deep enough, will eventually encounter the water table. Shovels and draglines can be used to stockpile gravel from such pits. Shovels are limited to a shallow water depth which is less than the length of the boom, but draglines can operate to nearly 100 feet below the surface of the water. If the deposit is large enough, a dredge may be installed. A dredge is a floating vacuum cleaner with a cutting apparatus to loosen the gravel. These machines can operate at depths exceeding 50 feet. Dredges have the advantage of preprocessing the material and being able to transport it directly to the processing plant. There are presently no dredges operating in Allen County, but some are working just across the county line to the north and west. Because much of the sand and gravel reserves in the county are in low areas or in the river valleys, it is conceivable that dredging operations will be resumed.

TRANSPORTATION OF MINERAL AGGREGATES

The economics of a sand and gravel or crushed stone operation depends more on such factors as distance to markets, loading and handling requirements, and beneficiation procedures than on the intrinsic value of the material itself. Because of the lower value of sand and gravel compared with that of crushed stone, the transportation costs are proportionately greater for sand and gravel. A commonly quoted truck tariff for Indiana aggregates is 5 to 6 cents per ton-mile.

Production costs (about $1.50 per ton for stone and 90 cents for gravel) may be equaled by the cost of a haul of 30 miles or more, and thus the final cost of the aggregate may be doubled. Transportation by rail is more economical for long distances, but it may be more expensive for short distances. And railroads have not shown a universal willingness to provide required services at acceptable rates to aggregate producers and consumers. Because of the high cost of transportation, it is essential that every effort should be made to allow for mining nearby sources of crushed stone and sand and gravel in rapidly developing urban areas.

ENVIRONMENTAL CONSIDERATIONS IN AGGREGATE PRODUCTION

Location of quarries and gravel pits in industrial areas away from residential neighborhoods is the most desirable solution, but geologic conditions may not permit this. Planners and zoning commissions should be acutely aware of mineral resources in newly developing areas. To permit residential housing or industrial buildings to be placed on vitally needed mineral resources may needlessly multiply future problems of mineral cost and supply.

A very noticeable change in a neighborhood where an aggregate plant has just begun operation is the great increase in truck traffic. Big trucks carrying aggregate are usually noisy, dusty, and a traffic hazard and may soon destroy a light-duty road. Thus it is desirable for the county and the operator that aggregate trucks reach major thoroughfares as rapidly as possible.

Processing equipment, as well as truck traffic, contributes to the dust problem. Most dust produced by an aggregate plant settles quickly, but this provides no solace to the housewife whose freshly hung wash has just been coated with dust, nor to the drivers and workmen who must remain at their machines and face increased chances of respiratory disease. Stockpiles and conveyors can be enclosed to keep dust from blowing. Some operators have paved their haulage roads; others simply wet them down. Many quarry owners have, for reasons of efficiency, installed their crushers in the bottom of the quarry, thereby reducing the amount of dust that can be caught by the wind.

Quarries pose special problems. The stone is first broken by blasting, and noise and bedrock vibration can be a nuisance if the quarry is in a heavily populated neighborhood. Responsible quarriers constantly strive to keep unwanted blasting effects to a minimum. Sequential timing of the shots and the use of numerous small charges instead of a few large ones can virtually eliminate unpleasant or harmful effects of blasting.

In Allen County open-pit quarries deepened below the water table must be drained by pumping before the stone can be extracted (in contrast with sand and gravel pits which could be exploited by underwater dredging). The effect of deep quarries on the water table, bedrock aquifers, and ground-water movement are environmental questions that should be investigated before new quarries are opened. Most aggregate source areas are in natural drainageways within the county. Thus the water table is likely to be high and the quarry or gravel pit will be in a discharge zone.

Because of new federal regulations, disposal of seepage water and of water used in processing operations is a major problem for aggregate producers. An aggregate operation produces effluent that might not be considered a pollutant except for the great amount of suspended matter. Settling ponds are probably the simplest solution to the problem.

All mining operations disrupt the land to some extent. Changes wrought during surface mining are particularly conspicuous. In Allen County as much as 45 feet of unsalable glacial till may have to be scraped from the surface to get at the valuable stone beneath. This material is usually heaped in a large pyramidal pile at the side of the pit or in a ridge around the pit. Not only are such piles unsightly (and in some places potentially dangerous), but also many of these piles cover otherwise usable stone reserves. The operator must sometimes cover future reserves and incur the added expense of handling the overburden when putting it back in the mined-out quarry. The quarry cannot be entirely refilled because most of the material that was in the pit has been marketed.

Abandoned gravel pits and quarries are among the first sites suggested for solid waste disposal. Unfortunately they are not the simple solution for disposal problems that they appear to be. If nearby shallow aquifers are tapped for domestic supplies, the potential of contamination is great. (See the section on surface waste disposal in this report.) Water and leachate could move rapidly through the near-surface layers. But only in the northwest corner of Allen County is a surface aquifer commonly used for water supplies. An additional problem in developing a landfill is the lack of soil-cover material, which is unavailable at many gravel pits.

The usual practice is simply to let the abandoned pit fill with water and use it as a recreational lake or the center for a residential development. Gravel pits are easily adapted to such use, but a stone quarry may be a deep water-filled hole that offers special hazards for recreational use.

PEAT RESOURCES

Extensive peat deposits are present in two belts in Allen County (fig. 4), both associated with glacial sluiceways. These were discussed by Taylor (1907) and by Soper and Osbon (1922). Peat has been produced commercially in both the Wabash-Erie Channel and the Eel River sluiceway in northwestern Allen County. Most of the reserves of peat in Allen County are in the sluiceway, as are the presently active peat operations (fig. 14).

The value of peat, muck, and marl extracted annually in Allen County has never been high. Still, a moderate amount has been removed, and the county contains about 1 percent of Indiana's peat reserves. Soper and Osbon (1922) estimated that 500,000 tons of air-dried peat and muck were available in Allen County.

Peat may form in several distinct environments or in lateral and vertical successions of distinct environments. In Allen County peat is dominantly of the fibrous grass-sedge type (Soper and Osbon, 1922), which accumulated in shallow lakes and bogs associated with Pleistocene drainageways. In many places deposition of marl preceded deposition of peat and muck. The marl is not mined presently and causes problems in the processing of peat.

Three peat operations are now active in the county (fig. 14), two of them hauling peat as far as Henry County, Ohio, a distance of 60 miles. All peat and associated muck or so-called "black dirt" presently mined in Allen County is used as fertilizer and soil conditioner. The largest and most regular customers for peat are commercial nurseries and greenhouses. Although the market has not decreased since World War II, much of it has been taken over by processed and bagged peat from Canada and northern states. The demand for locally derived peat has dwindled and will probably continue to do so unless some producer makes a determined effort at packaging and marketing the product. No sufficiently large single deposit exists in Allen County to warrant such an investment.

CLAY RESOURCES

Allen County lacks the high-quality clays needed for china and high-temperature refractory products. But clay suitable for tile and common brick is readily available in the form of weathered till and glacial lake sediment. Weathered till of the Lagro Formation is available over the whole county, but its leached zone is thin and it contains appreciable silt and sand. An Indiana Geological Survey boring south of Arcola penetrated 70 feet of calcareous clay containing very little silt or sand. Reserves are not great in any one place because most of the drift is calcareous, having been leached in only the upper few feet. An excess of calcium carbonate lowers the fusion point, thereby leading to uneven firing that results in distortion and cracking of the ware.

Local fired-ware industries are historically among the earliest to develop in any given region. By the late 1940's the last brick plant in Fort Wayne had ceased operation. The two remaining tile plants (fig. 14), one at Grabill and one near Monroeville, closed in 1964 and 1959. Competition from larger and more modern plants, advancing age of the owners of family businesses, and competition from plastic, concrete, and metal caused demise of this industry in Allen County.

PETROLEUM RESOURCES

By Leroy E. Becker

OIL AND GAS

Drilling for oil and gas in Allen County began shortly after the discovery of petroleum in the Trenton Limestone of middle Ordovician age near Findlay, Ohio, in 1884. Between 1886 and 1888 eight tests were drilled for natural gas within or near Fort Wayne. All were unsuccessful. The first small oilfield in Allen County was discovered near New Haven about 1899. Between 1899 and 1966 eight additional fields were discovered in the eastern part of the county (fig. 15). All are limited in extent, and although statistics are not available, production from none of them is believed to have been significant (table 5).

Gas was discovered at the Fort Wayne Field (fig. 15) in 1962. Nine gas wells have been completed in this field, and gas is currently being produced from it (table 5).

All oil and gas found to date has come from the upper dolomitized part of the Trenton Limestone. Twelve tests in Allen County have reached the Knox Dolomite or older rocks. Shows of oil or gas have been reported from older rocks in only one of these tests. In other parts of northern Indiana, hydrocarbon reserves have accumulated in the Knox Dolomite beneath relatively impermeable strata of the Black River Limestone.

One of nine petroleum refineries operative in Indiana is in Allen County. This plant, Gladieu Refinery, Inc., had a processing capacity of 3,000 barrels of crude oil per day in 1971.

Table 5. Production statistics of oil and gas fields in Allen County

Field	Year of discovery	Cumulative production Dec. 31, 1971		Average thickness of producing unit (ft)	Proved area (acres)	Number of wells completed to end of 1971		Deepest stratigraphic unit tested to end of 1971	
		Oil (bbl)	Gas (MCF)			Oil	Gas	Name	Depth
Baldwin	1903	(1)	———	25	300	19	0	Trenton	1,450
Edgerton	1905[a]	(1)	———	9	40	2	0	Trenton	1,450
Edgerton North	1925	(1)	(1)	5	20	2	1	Trenton	1,472
Fort Wayne	1962	—	74,473	80	1,440	0	9	Knox	2,065
Huntertown	1964	—	(1)	—	20	0	1	Trenton	1,766
Monroeville	1907[a]	(1)	———	—	20	1	0	Trenton	1,415
Monroeville West (New)	1966[b]	145	———	—	60	3	0	Precambrian	3,672
New Haven	1899[a]	(1)	———	—	60	3	0	Trenton	1,450
Nine Mile	1961	—	(1)	—	20	0	1	Trenton	1,523
Woodburn	1924[a]	(1)	(1)	—	70	5	2	Trenton	1,547
Woodburn North	1927[a]	(1)	———	—	20	1	0	Trenton	1,505

(1)Information not available.

[a] Approximate date.

[b] First year of recorded production, not discovery date.

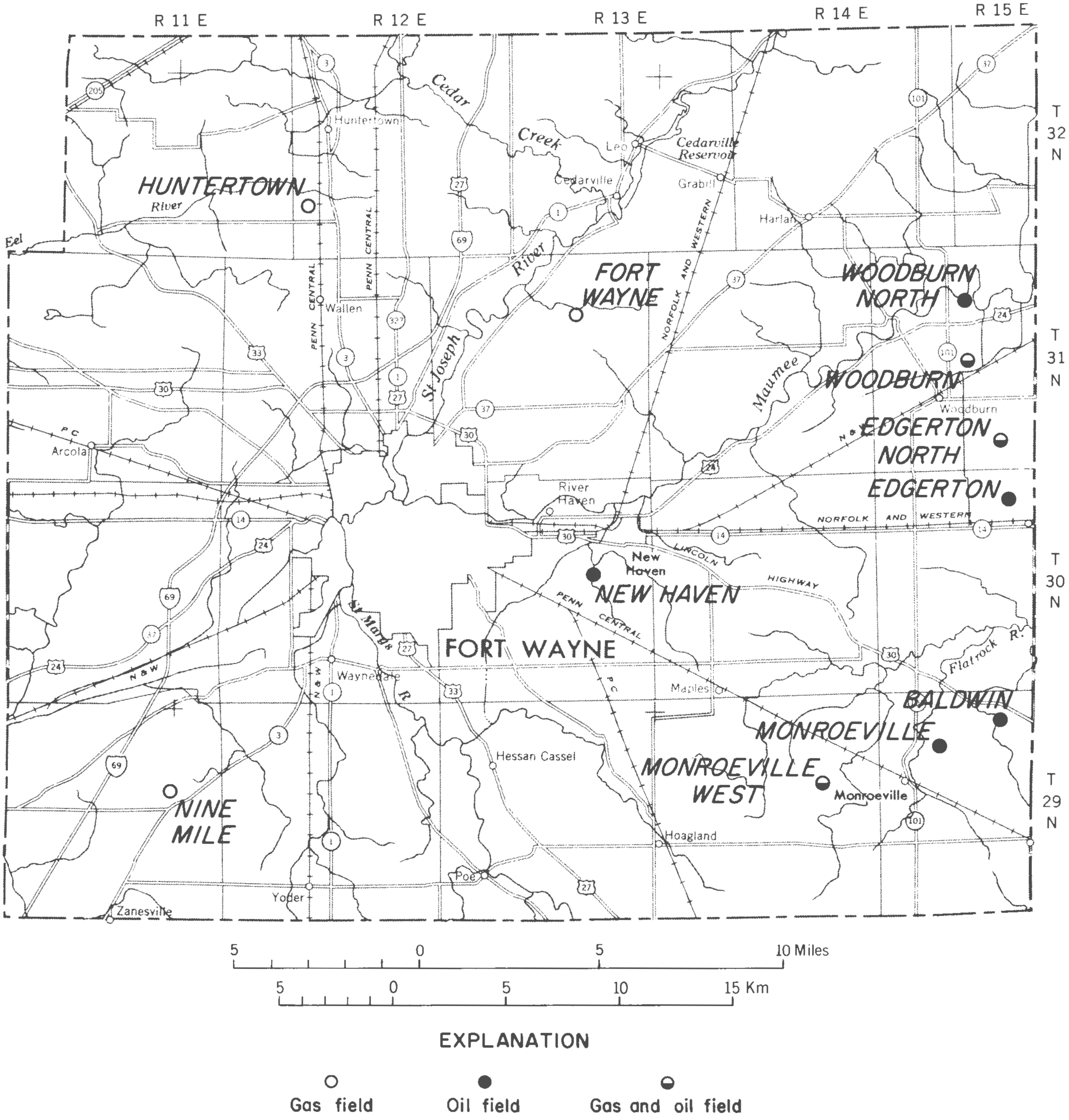


Figure 15. Map of Allen County showing locations of gas and oil fields.

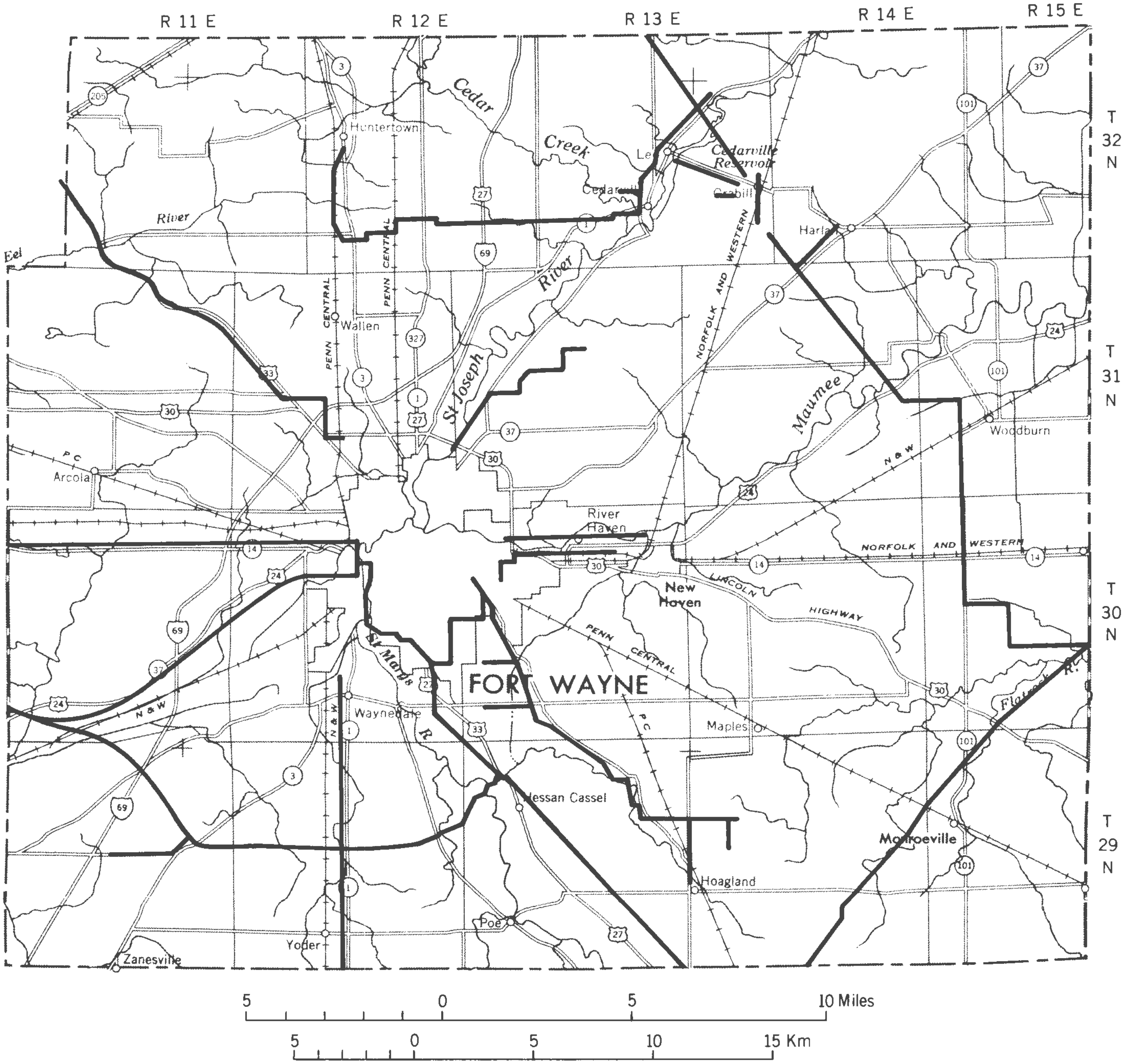


Figure 16. Map of Allen County showing locations of natural gas pipelines. From Keller, 1973.

NATURAL GAS PIPELINES

Major natural gas pipelines crisscross Allen County (fig. 16) and make natural gas available to smaller urban lines in most populated areas. Pipeline companies include Northern Indiana Public Service Co., Northern Indiana Fuel & Light Co., and Panhandle Eastern Pipeline Co.

GAS STORAGE

To equalize rates of transmission throughout the year and to ensure an adequate supply during times of heavy gas usage, utility and pipeline companies seek to store natural gas in underground reservoirs. The gas, which may have been produced as far away as Texas, is pumped back into a bedrock reservoir under pressure and may then be withdrawn at a later time as needed.

Gas can be stored underground only where nature has provided two basic geologic prerequisites: a porous rock stratum to house the gas and an entrapment, structural or stratigraphic, to prevent the gas from migrating (Dawson and Carpenter, 1963). In Allen County the only strata which might have such permeability and porosity characteristics are the Ordovician and the Cambrian rocks. The Trenton and the Knox (fig. 11) may be dolomitized and have developed enough porosity in some places to be good reservoirs. The Mount Simon Sandstone (fig. 11) also has adequate porosity and permeability for gas storage. It is, of course, deeply buried in this area, and the requisite amount of exploratory and developmental drilling would increase costs substantially.

Fault and fold structures are the key to establishing effective gas storage reservoirs in the Ordovician and Cambrian of Indiana (Dawson and Carpenter, 1963, p. 28). No structural features in Allen County which could provide traps in the Mount Simon, Knox, or Trenton rocks are known. But should such a feature be discovered, such as an anticlinal flexure on the upthrown side of a fault, the possibility of developing a gas storage facility in the Fort Wayne area would be inviting. Stratigraphic traps in these formations also would be usable but are more difficult to find.

Ground Water

Public, private, and industrial water supplies in Allen County except those obtained from the St. Joseph River for Fort Wayne and some independent utilities contracting with the city are derived from ground water. Thus the natural availability and quality of ground water and its protection are foremost environmental concerns.

The information contained in this section is derived from our geologic studies in Allen County (completed in 1973), from a survey of the ground-water resources of the Maumee River basin (Herring, 1969), more general water resource studies of the Wabash and Maumee basins (Tate and others, 1973; Pettijohn and Davis, 1973), and a report on the carbonate rock aquifers of northwestern Ohio (Ohio Department of Natural Resources, Division of Water, 1970). Perhaps the most important single source of data is the massive file of water well records at the Indiana Department of Natural Resources, Division of Water. Many of these well records (fig. 17) were used in our general geologic studies. A more detailed study of ground-water supplies being prepared by the U.S. Geological Survey will supersede parts of this section of the report.

MODES OF OCCURRENCE OF GROUND WATER

Subsurface strata that yield useful quantities of water to wells are called aquifers. Aquifers may be composed of permeable sand, gravel, or carbonate rock (limestone and dolomite). The ground water used in Allen County is derived from aquifers of two types: glacial drift aquifers, gravels and sands that most commonly are sandwiched between till (clay or hardpan of well drillers); and carbonate bedrock with sufficient cracks and cavities to hold and conduct water (fig. 18). Some aquifers are continuous to the surface and are under unconfined, or water table, conditions.

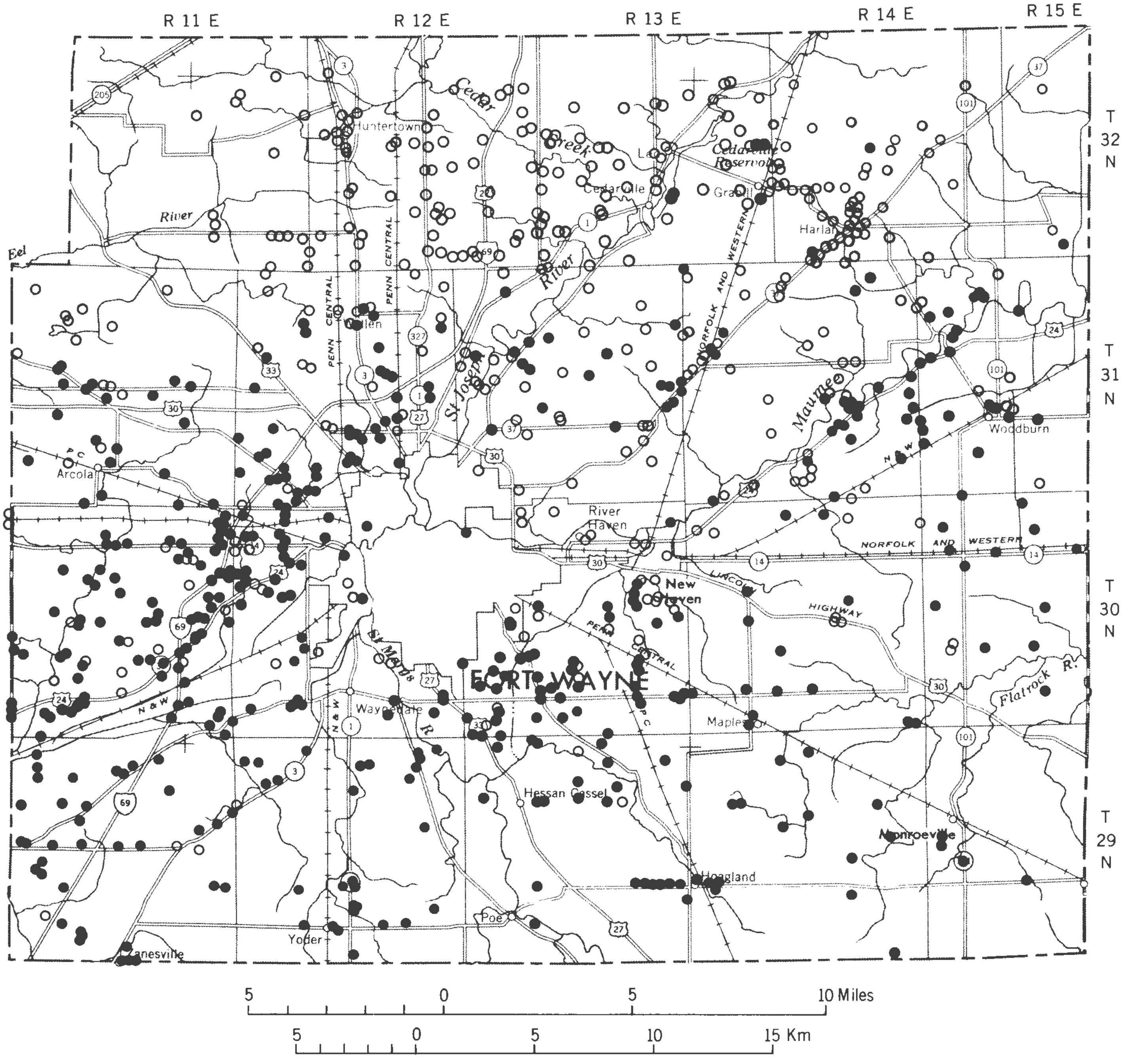


Figure 17. Map of Allen County showing distribution of wells developed in bedrock (dots) and wells developed in sand and gravel (open circles). These wells represent most of the records on open file at the Indiana Department of Natural Resources, Division of Water.

But most individual aquifers in Allen County are confined or are separated from one another or from the surface by relatively impermeable strata, such as glacial till, lake clay, or unfractured and nonporous limestone and dolomite. Some such aquifers in Allen County contain water under artesian head. But most such confined aquifers are leaky or are interconnected to some extent by sand and gravel units that cut through the geologic section.

AQUIFER THICKNESS AND DEPTH

Mapping aquifer depths and thicknesses on a countywide basis is difficult because wells are developed in different aquifers depending on local conditions and are drilled to fulfill differing yield requirements. Thus any such mapping of aquifers must be highly generalized.

The percentage of thickness (fig. 19*A*) of potential water-bearing sand and gravel within the glacial drift illustrates not only the dearth of such aquifers in the Maumee lake plain area in the south-central and southeastern parts of the county but also the higher relative percentages of potential drift aquifers in the northwestern part of the county that lie beneath the Fort Wayne and Wabash Moraines. (This percentage is given as a highly generalized computer average or "trend surface." See cumulative thickness mapping by Tate and others, 1973, and Pettijohn and Davis, 1973. Thickness information is derived from data from wells that commonly do not extend completely through the drift.)

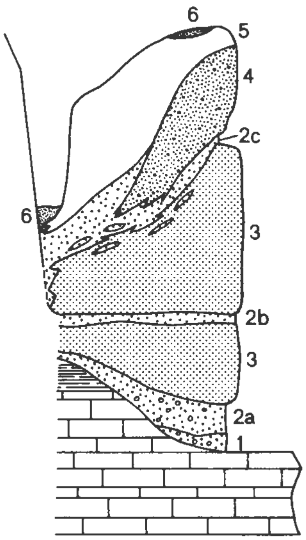
Commonly a potential aquifer is present at a shallower depth than the aquifer that is actually tapped (fig. 19*B*). In the Maumee lake plain the shallowest aquifer, either a sand or gravel bed at the base of the drift or bedrock, is almost everywhere the used aquifer. But elsewhere, particularly beneath the moraine uplands, thin sand or gravel beds, essentially dry in places, are commonly bypassed by well drillers in favor of a better, deeper water source. The depth to this shallowest potential aquifer is discussed later in the section on waste disposal.

The depth of the top of that aquifer tapped as a water source (fig. 19*C*) reflects in large measure the dependence on relatively shallow bedrock wells in the southeastern part of the county and on deeper glacial and bedrock wells in the northwestern part. (See fig. 17.) In summary, wells are completed in the bedrock aquifer in southeastern Allen County not only because that aquifer is shallow but also because the thin cover of glacial drift generally contains a very small percentage of sand and gravel. Similarly, wells are completed most commonly in glacial sand and gravel aquifers in northern and northwestern Allen County not only because bedrock is much deeper there but also because the thicker drift actually contains a greater percentage of potential sand and gravel aquifer within its total thickness.

POTENTIOMETRIC SURFACE

The potentiometric surface of a ground-water reservoir is the level at which water stands in wells drilled into the reservoir. It is the surface below which the ground is permanently saturated, but this surface fluctuates in response to recharge and discharge and in accord with the capacity of the saturated materials to transmit the water laterally. The potentiometric surface has a configuration similar to the topography of the land surface. Ground-water flow is generally in a direction down the slope of the potentiometric surface.

The potentiometric surface defined by water levels in all aquifers (fig. 20; Tate and others, 1973; Pettijohn and Davis, 1973) is essentially the same as the potentiometric surface defined by water levels in the leaky confined bedrock aquifer alone (Foley and others, 1973). The general flow within the aquifers of Allen County converges on the valleys of Little River, St. Marys River, St. Joseph River, and Maumee River.

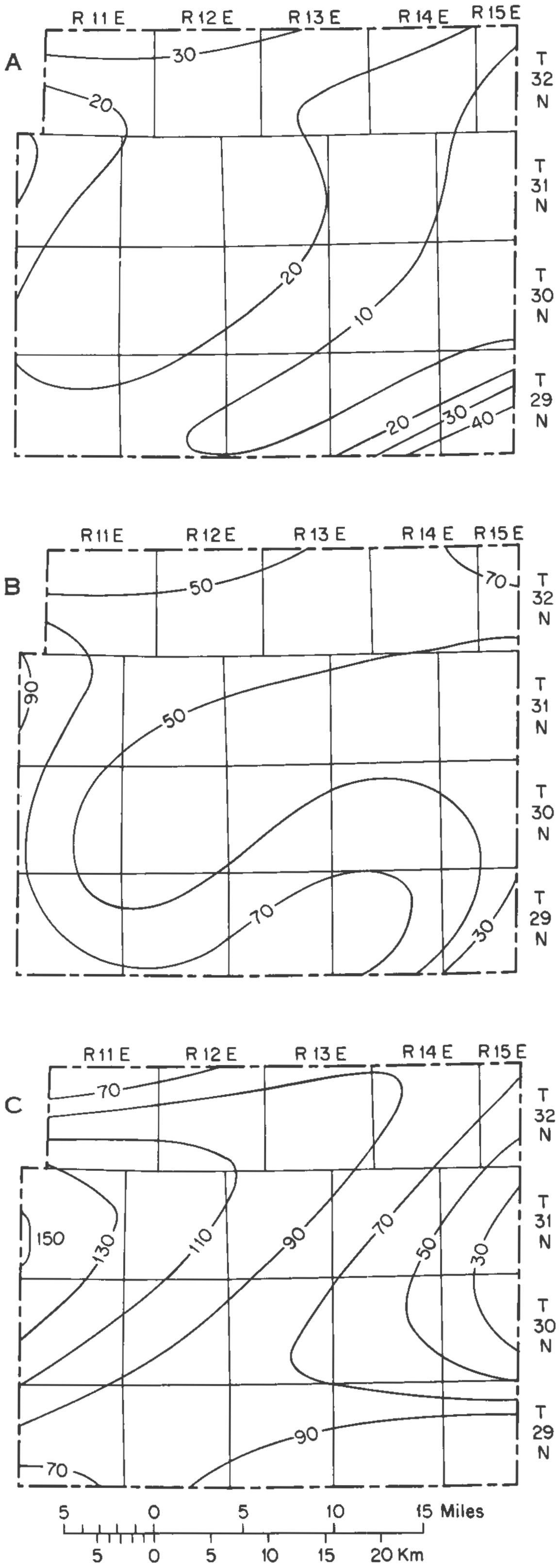


Aquifer	Type	Composition	Thickness
(6) Drift (Martinsville and Atherton Fms.)	Unconfined	Sand and (or) gravel	0 - 100 ft + (See appendix)
(2c, 2b) Drift (Atherton Fm.)	Confined	Medium to fine dense sand, pea gravel, and some coarse gravel; commonly interlayered with "hardpan"	0 - 50 ft +
(2a, 1) Drift (Atherton Fm.)	Confined	Medium to fine sand and (or) gravel	0 - 50 ft +
Bedrock (Silurian-Devonian carbonate rocks)	Confined	Carbonate strata	400 ft +

Figure 18. Characteristics and distribution of primary aquifers.

Distribution and comments
A thick, saturated sand and gravel unconfined aquifer is at the surface only in places in northern Allen County, as at Leo and probably other places in the St. Joseph valley, and in the broad Eel River valley around Huntertown (appendix). The surface gravels in these valleys (fig. 4) are continuous to relatively great depth and are the major aquifers in those areas. In most other parts of the county, however, such surface gravels are relatively thin and are separated from aquifers below by clayey strata of low permeability.
The uppermost confined glacial drift aquifers (units 2a-c and other scattered units not illustrated; appendix) are present and used most commonly in the morainic western and northwestern parts of the county; they are of no significance in the Maumee lake plain in the east-central part of the county. The intersequence unit and the intra-lower sequence unit (and various scattered units) (units 2c and 2b) are probably the most commonly present drift aquifers in northern and northwestern Allen County. Units are of variable thickness and are commonly absent. The position or base of the intersequence unit is marked by material change above and below—Lagro till (clay of drillers) atop Trafalgar till (hardpan of drillers). Position of intersequence aquifer (2c) generally defined by map of Trafalgar Fm. top (fig. 6).
Unit is of variable thickness and is commonly absent. Tapped in central and southeastern Allen County, it is so fine grained and slowly permeable in many places that even where it is relatively thick, drillers choose to extend wells through it and into bedrock. The top of the aquifer, where present, may extend as much as several tens of feet above the bedrock surface (fig. 7).
Water in this aquifer fills vuggy pore spaces and fracture planes. This aquifer is most commonly tapped in southern and southeastern Allen County (fig. 17). This limestone and dolomite aquifer underlies the glacial drift across almost the entire county (fig. 10), but at depths that are highly variable (fig. 9). Detailed descriptions of these carbonate rocks are found in the section on mineral resources. A deep bedrock water supply is available anywhere in the county, but depth and water quality (see below) considerations dictate its use.

Figure 18—Continued



A, Percentage of thickness of sand and gravel in the total section penetrated by wells drilled in glacial materials (expressed as a fourth order trend surface).

B, Depth to shallowest sand or gravel unit having potential as an aquifer in some places (expressed as a fourth order trend surface).

C, Depth to used aquifer (expressed as a third order trend surface; no stratigraphic position or yield inferred).

Figure 19. Maps of Allen County showing characteristics of aquifers.

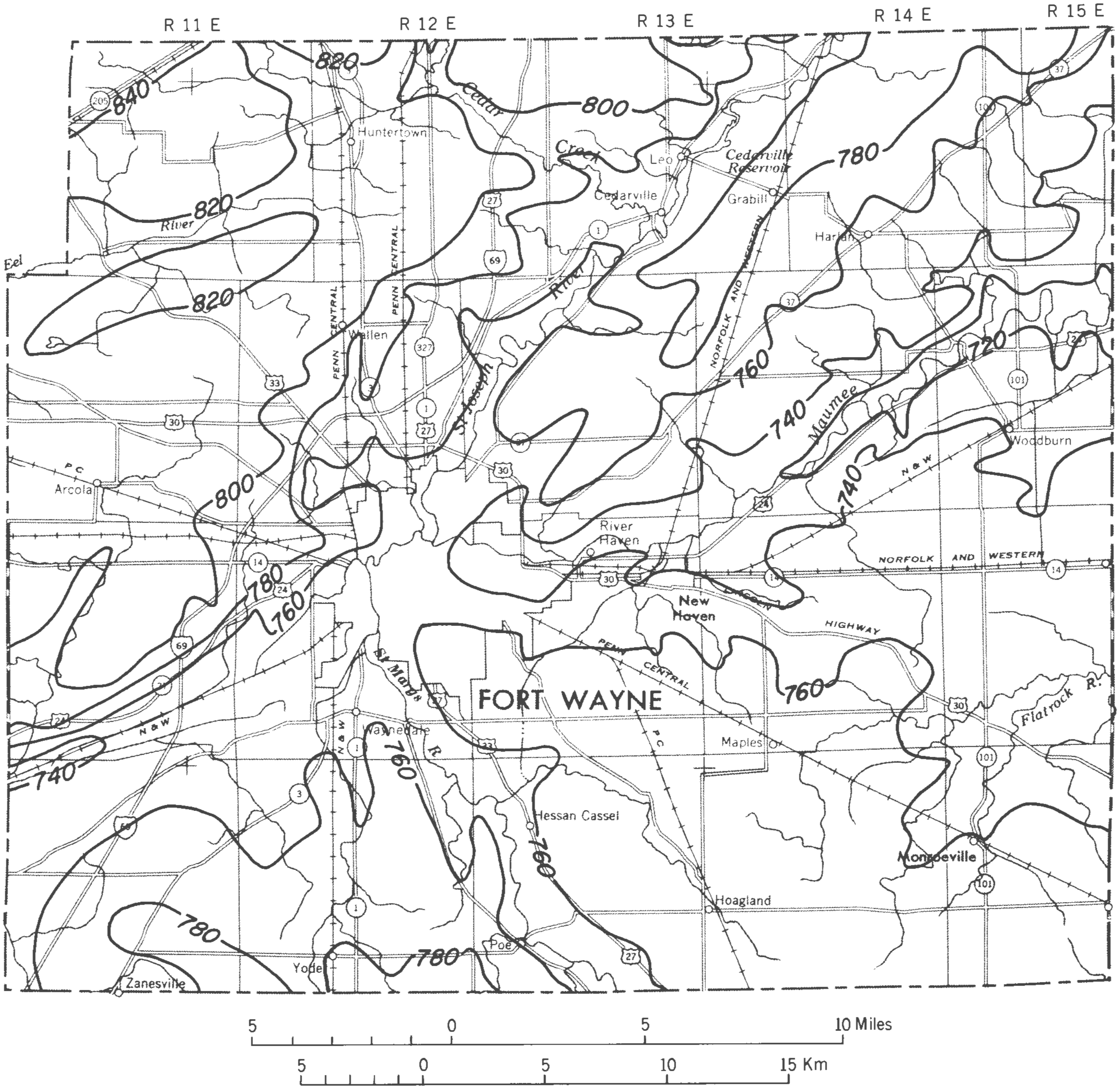


Figure 20. Map of Allen County showing the potentiometric surface (ground-water table). From Tate and others, 1973, and Pettijohn and Davis, 1973. Contour interval is 20 feet. Datum is mean sea level.

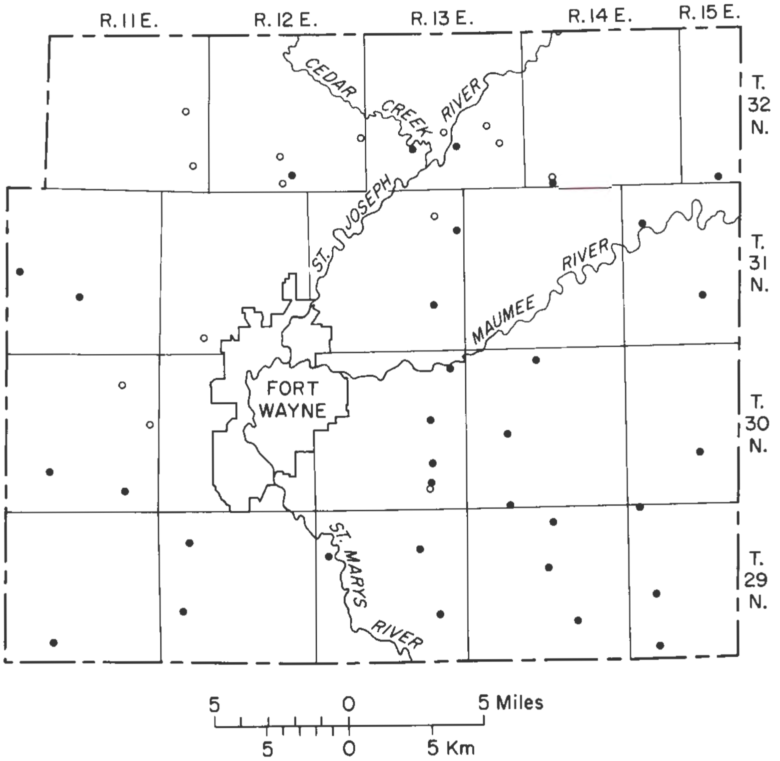


Figure 21. Map of Allen County showing locations of wells sampled for water quality study. Dots represent bedrock wells; open circles represent sand and gravel wells.

WATER QUALITY

By N. K. Bleuer and William C. Herring

SAMPLING AND ANALYSIS

Of 47 water wells sampled specifically for this study in June 1971 (fig. 21), 14 are from glacial aquifers and 33 are from the bedrock aquifer. The sampled glacial aquifers are in the northern part of the county and the bedrock aquifer is in the southern part. Analytical procedures are described in detail and the results are discussed in Foley and others (1973).

WATER QUALITY IN DRIFT AND BEDROCK AQUIFERS

Water derived from glacial sand and gravel aquifers and from the carbonate bedrock aquifer is similar in natural quality in most respects. In seven of 12 statistical tests, no significant difference was found between the grouped bedrock aquifer and glacial aquifer data. In the five remaining tests, comparisons of iron, sodium, zinc, strontium, and bicarbonate (also qualitatively determined hydrogen sulfide, H_2S) showed significant differences between grouped samples from bedrock and glacial aquifers. Concentrations of iron, zinc, and bicarbonate were greatest in waters derived from glacial aquifers, and concentrations of strontium and sodium were greatest in bedrock waters. The variation in quality, as seen in comparisons of standard deviations in table 6, is generally greater in water derived from sand and gravel aquifers than in water derived from bedrock, but there are exceptions. Although exceedingly variable, waters from glacial aquifers contain what can be thought of as normal concentrations of most dissolved constituents. Iron, sulfate, and strontium content appears to be relatively high.

Table 6. Statistical summary of dissolved constituents in ground water

Constituent	Aquifer	Mean (ppm)	Standard deviation	Statistically significant difference? (Student's t test at 0.005 level)
H_2S	Glacial	(1)		
	Bedrock	(2)		
Calcium	Glacial	106	41	No
	Bedrock	86	34	
Magnesium	Glacial	49	18	No
	Bedrock	46	12	
Iron	Glacial	3.7	3.3	Yes
	Bedrock	0.9	0.6	
Sodium	Glacial	26	10	Yes
	Bedrock	41	15	
Potassium	Glacial	7.0	2.3	No
	Bedrock	8.0	1.6	
Chloride	Glacial	3.8	5.4	No
	Bedrock	7.1	8.1	
Sulfate	Glacial	148	136	No
	Bedrock	240	183	
Dissolved solids	Glacial	836	285	No
	Bedrock	694	269	
Hardness	Glacial	505	179	No
	Bedrock	430	153	
Zinc	Glacial	.64	.63	Yes
	Bedrock	.30	.30	
Strontium	Glacial	5.1	3.2	Yes
	Bedrock	8.2	4.0	
Bicarbonate	Glacial	452	62	Yes
	Bedrock	296	104	

(1)Not present.

(2)Scattered occurrences.

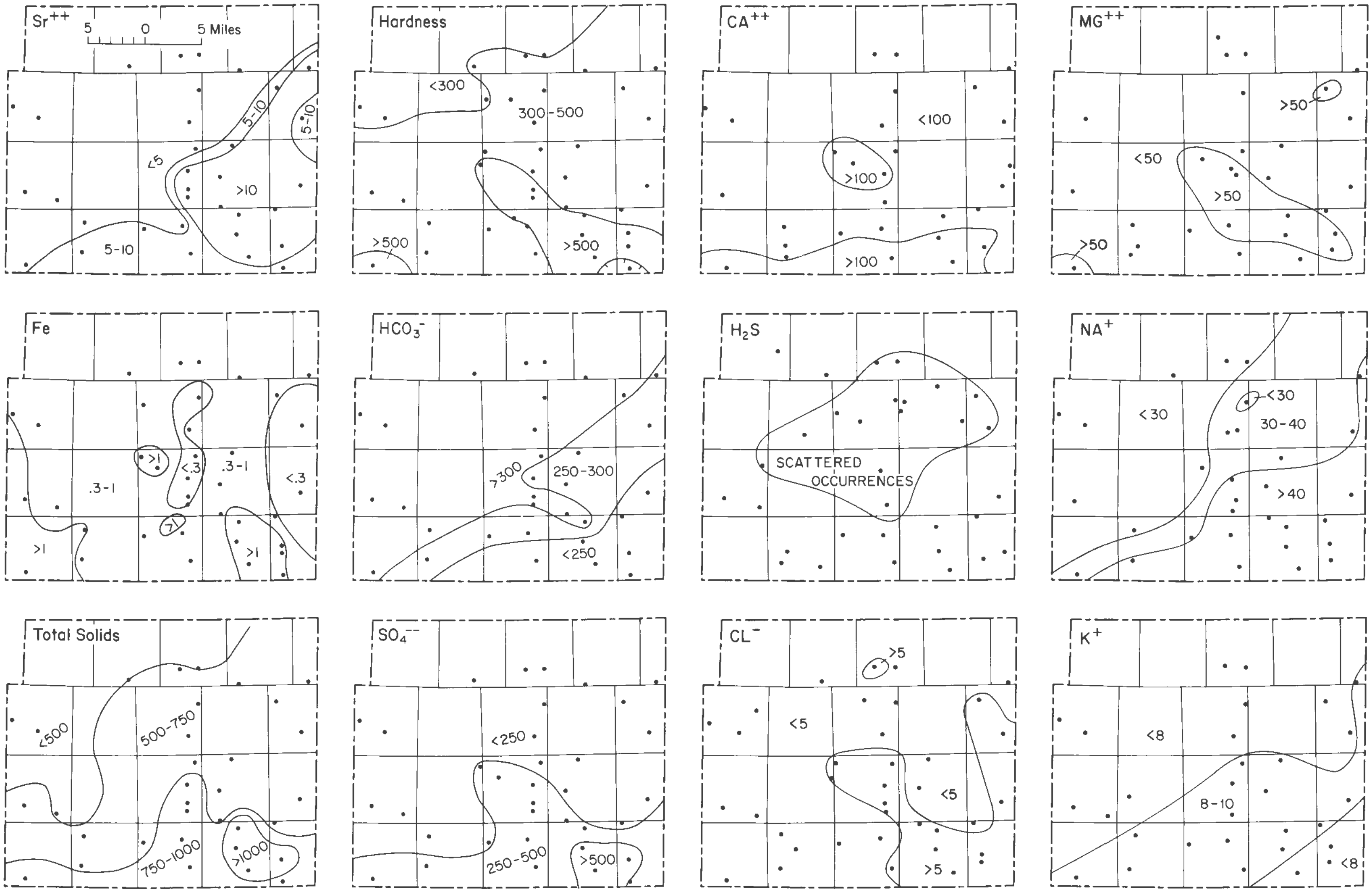


Figure 22. Maps of Allen County showing concentrations in parts per million (ppm) of dissolved constituents of ground water in the bedrock aquifer. Dots represent datum points.

Table 7. Recommended maximum concentrations of dissolved materials for drinking water (U.S. Public Health Service, 1962) and summaries of other significant properties (Rosenshein and Hunn, 1964)

Constituent	Recommended maximum (ppm)	Significance
Iron	0.3	Oxidizes to reddish-brown sediment on exposure to air. More than about 0.3 ppm stains laundry and utensils reddish brown. More than 0.5 to 1.0 ppm imparts objectionable taste to water. Larger quantities favor growth of iron bacteria. Objectionable for food processing, textile processing, beverages, ice manufacturing, brewing, and other purposes.
Chloride	250	Gives salty taste to drinking water when present in large amounts in combination with sodium. Increases the corrosiveness of water when present in large amounts.
Sulfate	250	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process.
Dissolved solids	500	
Zinc	5	
Bicarbonate	—	Bicarbonate in conjunction with carbonate (CO_3) produces alkalinity. Bicarbonate of calcium and magnesium decomposes in steam boilers and hot water facilities to form scale and release corrosive carbon dioxide gas.
Hardness	—	Hard water increases amount of soap needed to make lather. Forms scale in boilers, water heaters, and pipes. Leaves curdy film on bathtubs and other fixtures and on materials washed in the water.

WATER QUALITY VARIATIONS WITHIN THE BEDROCK AQUIFER

Although sufficient water quality data are not at hand to map stratigraphic or areal quality variation in the glacial aquifers, the quality of bedrock-derived water does vary systematically over the county.

Amounts of many dissolved constituents in bedrock-derived ground water are highest in southern and southeastern Allen County, and only bicarbonate has a clearly opposite distribution (fig. 22). Most of the variation appears to parallel the distribution of bedrock units regionally but is affected by flow directions locally. (See Foley and others, 1973.)

The concentrations of hydrogen sulfide, sulfate, and strontium, the amount of dissolved solids, and the hardness (ppm $CaCO_3$) in general are high in comparison with normal ground water. Several constituents are in excess of maximums suggested for drinking water (table 7) and are higher than can be tolerated without treatment in many industrial uses.

Table 8. Ground-water yield and transmissibility ranges for drift and bedrock aquifers

Aquifer	Median well yield[1] (large diameter wells) (gallons per minute)	Average thickness sand and gravel aquifers (ft)	Coefficient of transmissibility (gallons per day per foot)
Drift (sand and gravel)	250 20 - 600 range[2]	25[2]	50,000[2] 25,000-50,000[3]
Bedrock	175[2] 35 - 500 range[5]		15,000[4]

[1] Most of these wells are for public supply; no domestic wells were considered.

[2] For Maumee basin (Herring, 1969).

[3] Tate and others, 1973; Pettijohn and Davis, 1973.

[4] Range of coefficients is great (Herring, 1969; Pettijohn and Davis, 1973).

[5] Maximum yield where several feet of sand or gravel is present above bedrock surface.

GROUND-WATER DEVELOPMENT

By N. K. Bleuer and William C. Herring

The ground-water resources of Allen County include sufficient water in storage to allow considerable future development (table 8), particularly for individual home use. In most parts of the county well fields can be developed for suburban housing and industrial uses, but the cost of such development must be weighed against the cost of buying water from the existing surface-water source. Industrial users in particular must also consider the natural quality variations of the ground water (discussion in following paragraphs) and the cost of treatment.

Only rough estimates have been made of the long-term potential yield of ground water in Allen County. A yield of 150,000 gallons per day per square mile is considered to be a reasonable value for much of the county (Herring, 1969). In those parts of the county where an unconfined sand and gravel aquifer is at the land surface, the potential yield could be greater because of more recharge from precipitation. Also, in such areas the use of recharge induced from the streams and artificial recharge pits, canals, etc., could mean the development of considerably more ground water.

The Eel River lowland of northwestern Allen County, where thick sections of sand and gravel are present over a rather wide area, appears to have potential for large yields of water. The lowland has a natural regional ground-water discharge, but water tables have been lowered through artificial drainage for agricultural uses. Parts of the Wabash-Erie Channel might provide large water capacities. Thick sections of gravel, gravel pits, and quarries are present in places in the channel. The pits will someday be abandoned, and their future could be planned with water resources in mind. The use of water from either the Eel River lowland or the Wabash-Erie Channel by Fort Wayne, of course, would involve a diversion of water from one drainage basin to another, and the ramifications of such a transfer would require study.

Deep-Well Disposal

INTRODUCTION

Most industrial processes result in the accumulation of some waste products which, in their initial, untreated state, may be detrimental to the environment. These materials must be treated either to eliminate or to neutralize objectionable components, or they must be removed entirely from the human

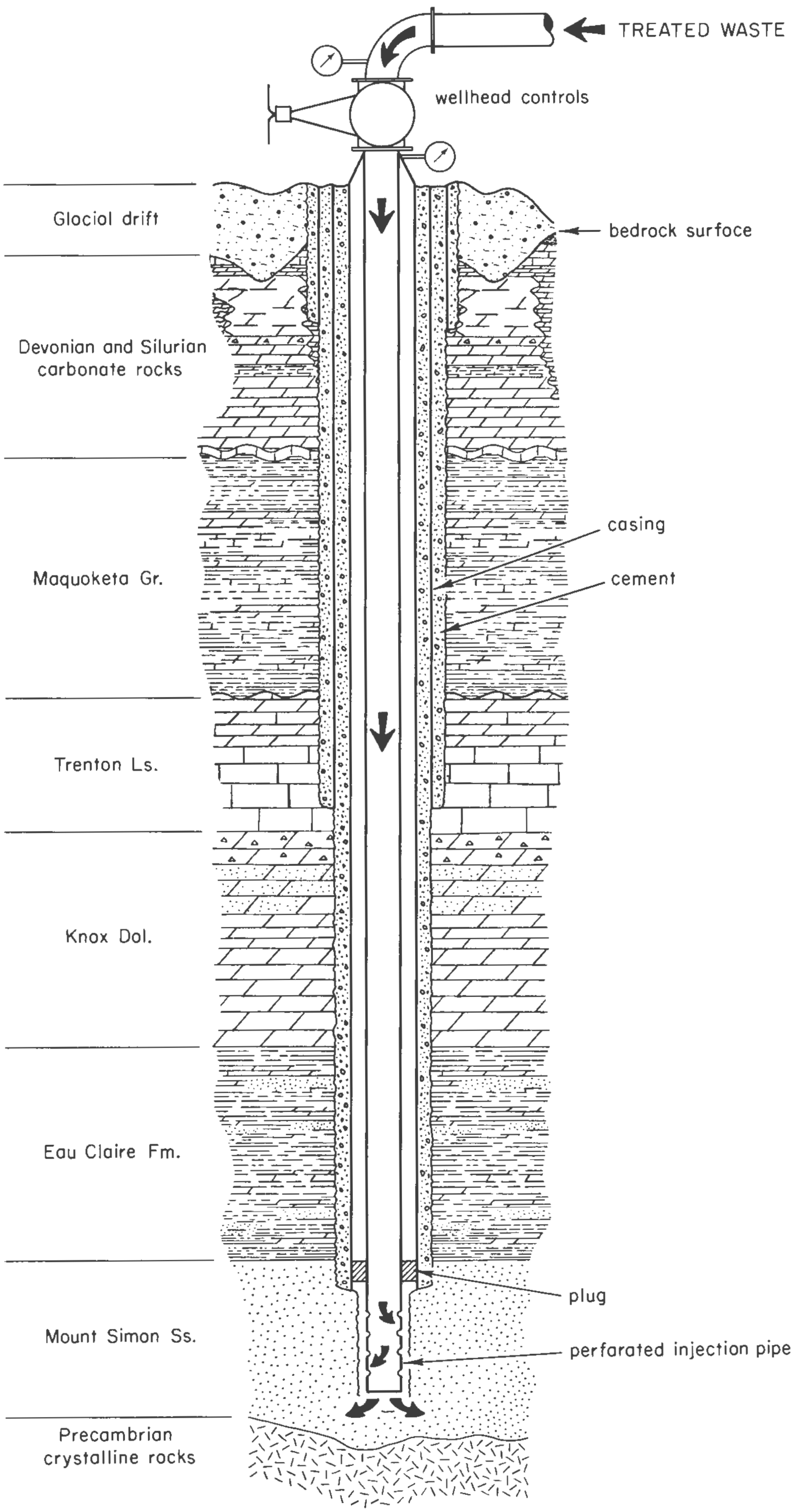


Figure 23. General configuration and geologic relationships of a potential disposal well.

environment for so long as they remain objectionable. The latter solution may be required when treatment is economically or technologically out of the question.

In some places certain liquid wastes can be disposed of (stored) by pumping them into a well down to a deeply buried permeable stratum that is suitably isolated from overlying and underlying aquifers by impervious strata (fig. 23). The geologic factors to be considered in siting a disposal well are as varied as the geology involved. Necessary for all sites, however, are the following conditions:

1. A reservoir formation with suitable porosity and permeability within a great enough volume of rock to contain and distribute the effluent.
2. A formation fluid of suitable chemistry and under sufficiently low pressure to permit economical injection.
3. A uniform flow under conditions of full saturation providing control of rate and direction of effluent travel.
4. Unfractured impermeable strata above and beneath the reservoir of sufficient strength to contain the additional pressure of injection.
5. Overlying rocks such that an economical drilling and completion program can be set up.

In general, wastes suitable for deep-aquifer disposal are greatly diluted, but the volume of dilutent is great. Fluids disposable in deep aquifers must have specific characteristics, or they must be easily converted to a specific form. Subsurface waste disposal should be done only if it is the most environmentally sound means of disposal (Environmental Protection Administration, 1974; see also ORSANCO, 1973, 1974, and references therein).

DEEP-WELL DISPOSAL POSSIBILITIES

Only one of the sedimentary rock units underlying Allen County, the Mount Simon Sandstone (figs. 11 and 23), is known to be suitable for deep-well disposal. The Mount Simon is being used in nine of the 13 presently operative disposal wells in Indiana. In Allen County the Mount Simon directly overlies the basaltic basement rocks and is in turn overlain by 600 to 675 feet of shales and siltstones of the Eau Claire Formation (figs. 11 and 23).

These two rock units form substantial aquicludes which should adequately isolate the reservoir formation. The Eau Claire is overlain by a thick shale and carbonate-rock sequence of Ordovician through Devonian age which contains no reservoir suitably isolated for disposal. In addition, the rock units above the Trenton Limestone of Ordovician age were heavily drilled in the early 1900's, and the possibility of escape through unrecorded wells is high.

The Mount Simon thickens rather uniformly to the northwest from 350 to 600 feet (fig. 11). It has adequate porosity and permeability and is deep enough and stratigraphically well positioned for deep disposal of liquid wastes. The Eau Claire aquiclude presents a thick, impermeable, and unbroken cover. Also, the Allen County area is not one of active oil and gas development or of tectonic activity, which enhances the potential for deep-well disposal.

The Mount Simon Sandstone, present throughout Indiana, is probably cleaner and coarser and therefore more porous and permeable in northern Indiana than in southern Indiana (Dawson, 1960). On the basis of limited data, porosity and permeability of the Mount Simon in Allen County appear to increase northwestward. Permeability at any given point seems to be equal in all directions. Thus, under hydrostatic conditions, a waste fluid with a density greater than that of the natural brine would tend to move downdip, displacing brine upward and updip. Little is known of the deep flow patterns in the Mount Simon Sandstone of Allen County. Nevertheless, the natural fluids might be expected to move updip in the confined aquifer. Although the Mount Simon does not crop out along the axis of the Cincinnati Arch, it comes as near to the surface as 2,200 feet in eastern Ohio.

The water within the Mount Simon is not potable; no economic use or demand exists for the rock or brine; the Mount Simon would probably not leak and allow contamination of other formations. Brines, acids, and most chemical wastes would not adversely affect the rock in most applications, but extremely toxic or radioactive materials could remain unknown dangers for a very long time.

Although the Mount Simon is geologically attractive and technically feasible as a disposal reservoir, deep-well disposal remains an "out of sight, out of mind" proposition. It is not a form of pollution abatement but only one of many possible choices of pollution distribution. Thus great care must be exercised and all possible factors must be considered before any waste disposal program is initiated.

Surface Waste Disposal

Waste materials disposed near the land surface consist of solids and liquids and of chemically or bacteriologically active as well as relatively inert materials. These different wastes require different disposal systems. The design of such systems must consider surface topography and drainage and the workability of the near-surface materials. The system must assure protection of water-bearing strata from direct contamination from liquid waste or from contamination by leachate derived from solid waste.

SANITARY LANDFILLS

Design of solid waste disposal sites should provide for the fact that leachates from landfills contain solutes that are relatively unaffected by their passage through some earth materials. For this reason, earth materials at the base of a landfill should be relatively impermeable, particularly if aquifers are close beneath the fill. Similarly, precautions must be taken that surface-leachate discharges do not become a hazard or a nuisance. In some situations it may be necessary to collect the leachate.

Some areas in Allen County with high water table or ponding due to the slowly permeable till of the Lagro Formation have basic landfill design problems (fig. 24). If possible, a landfill base should be above the highest seasonal level of the water table. Cover material should be slowly permeable when well packed and sloped to decrease the amount of water entering a fill and lessen the problem of a perched water table within the fill. Seepage springs at the base of a ramp- or area-method fill are expectable in Allen County and must be accommodated, possibly by diversion of drainage entering a site and by interception of discharge below the site. Sufficient material of low permeability (for example, till of the Lagro Formation) must separate the base of the fill from an aquifer. Aquifers are generally but not everywhere well below the surface in Allen County.

Commonly, landfills can be operated in marginal geologic and hydrologic situations if remedial engineering measures are used. Tile lines, underdrains, and holding and infiltration lagoons allow the collection and even the treatment of leachate, but simple use of existing geologic and hydrologic flow conditions to control the rate and direction of leachate movement and to assure its sufficient renovation seems to be a generally more desirable alternative.

A study using available regional geologic data (appendix) should be an early step in the planning and engineering of a modern landfill. Further information on landfill requirements and techniques are available from the Indiana State Board of Health. (See also Bleuer, 1970, and Bleuer and Hartke, 1971.)

SEPTIC SYSTEMS

Septic systems, in contrast with landfills, make use of earth materials to absorb liquid waste and to filter biologic and solid materials from the waste. Earth materials must be sufficiently permeable that great amounts of liquid can be absorbed and transmitted through them. Indeed, the extent of drainage fields is based on the percolation rate of the soil. The U.S. Public Health Service considers that soils in which the water percolation rate

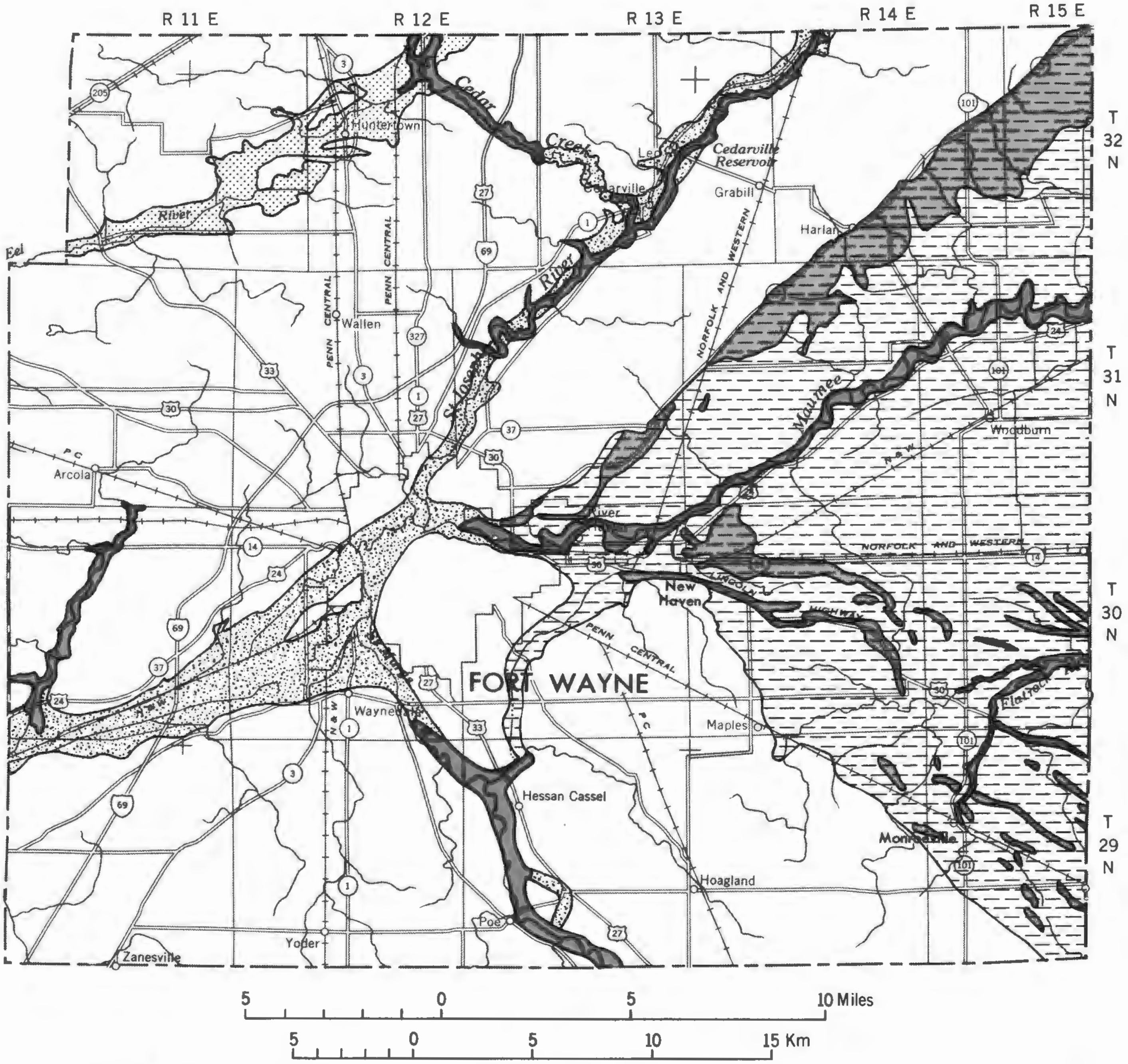


Figure 24. Map of Allen County showing limitations for surface waste disposal. Explanation is on the following page.

	SANITARY LANDFILL	SEPTIC SYSTEMS
□	**FORT WAYNE AND WABASH MORAINE AND TILL PLAIN AREAS** Generally more than 50 ft of slowly permeable silty clay loam till (Lagro Formation) lies at the surface, above any used aquifer. Only in places are surface or near-surface sand or gravel lenses sufficiently thick to be continuous with a significant aquifer; thus possibilities of contamination of ground water are small. Major problems are the locally high water table and clayey nature of soils and geologic materials, and possibly accompanying workability and drainage problems. Good to excellent opportunities exist for use of trench, ramp, or area with fills, or of these methods in combination.	Most of the area of Allen County is underlain by soils that are too impermeable and (or) too wet to accept septic effluent properly (Kirschner and Zachary, 1969, soil survey report). Most of this unacceptable area is underlain by very slowly permeable clayey soils. Clearly, extensive closely spaced suburban development on the clayey soils or any of the poorly drained soils can only lead to problems of effluent breaking to the surface and repeated failure of individual systems.
▤	**MAUMEE LAKE PLAIN** Generally more than 40 ft of silty clay loam till, clay, or thin sand lies at the surface, above the sand or bedrock aquifer. Only in the axis of the plain in a band about 2 miles wide along the Maumee River are there continuous sections of gravel which might act as a conduit to the bedrock aquifer. The gravel aquifers are scattered and are not nearer than about 30 ft to the surface except beneath the topographically low Maumee River floodplain terraces. But in general, many of the surface materials in this area are probably sticky and water retentive. Except for scattered low sand ridges, few natural areas exist from which ramp-method fills can be built. Area-method fills are feasible, for which cover material could be taken from shallow excavations at the outward-expanding periphery of the fill. Trench-method landfills could be operated seasonally or in some areas throughout the year with some pumping. High water tables alone do not necessarily preclude landfilling in an area if the aquifers are relatively deeply buried by slowly permeable material.	
▦	**LAKE PLAIN MARGINS** In some places within or along margins of the ancient lake plain, sand or gravelly materials form ancient beach ridges, deltaic deposits, and glacial outwash deposits of a few feet to more than 20 ft in thickness and cap the glacial till or lake clay. These surface materials, though generally permeable, are not sources of water supply. They are commonly separated from the deeper aquifers by fine-grained material that is commonly more than 50 ft thick, although in places within the northernmost areas of these materials, T. 32 N., for example, thick sand deposits are present relatively near the top of a lower buried aquifer. Particular caution should be exercised, therefore, in siting a landfill in these areas. The route of the movement of near-surface leachate along the sand-clay interface is difficult to predict, but some such movement must be anticipated in such situations. Sources of fine-grained cover material are common near many of these areas, and fair to good sites with potential for several design types could be found.	At the opposite extreme, a much smaller total area is underlain by sandy and more permeable surficial deposits. In most places these are underlain by much less permeable clayey materials, but in a few areas surficial sand or gravel is continuous in depth with a water-supplying unit. Where permeable materials do extend to depth over a sizable area, as in the Huntertown area of the Eel River lowland and parts of the Wabash-Erie Channel (see column to left), and particularly where the water table is high and effluent is continually under anaerobic conditions, any extensive closely spaced suburban development using both wells and septic systems runs a risk of pollution of the ground water and of directly feeding water wells with little-purified septic effluent.
▨	**ST. JOSEPH AND ST. MARYS RIVERS AND WABASH-ERIE CHANNEL** The valley terraces of both the St. Joseph River and parts of the Wabash-Erie Channel are underlain by gravel deposits and are not generally suitable for surface waste disposal. Some of these deposits thinly overlie glacial till, some of the thicker deposits are interspersed with lenses of till and clay, and some are thick gravel underlain by till whose lateral continuity is not known. At the surface is typically 6 to 10 ft of sandy loam, silty loam or clay, and in some places peat or muck. Wells typically extend beneath sand and gravel aquifers to bedrock. The critical variable is the thickness and continuity of intervening till layers. Therefore, just how much fine-grained material caps and protects aquifers in these areas cannot be generally predicted. Exceedingly detailed engineering and geologic studies should be conducted prior to waste disposal activities in these areas, and use of sites in such areas may require remedial measures.	
░	**EEL RIVER VALLEY** Thick deposits of surficial sand and gravel are present in the lowland of the Eel River in and around Huntertown in northwestern Allen County. These deposits form an unconfined surficial aquifer that is rather widespread (fig. 4; appendix), but its exact distribution has not been determined. Although this is an area of general ground-water discharge, its lateral extent is such that contamination of ground water from a landfill operation would be a distinct possibility. The geologic conditions of northwestern Allen County are particularly complex, so that acceptable sites might be found in this area, but extreme caution and detailed engineering and geologic study should be conducted.	
■	**FLOODPLAINS** Periodically flooded or scoured floodplains are not generally suitable for landfilling.	
	QUARRIES AND GRAVEL PITS Certain sites should not be considered for disposal of anything but nearly inert waste. These include limestone quarries, which have breached significant aquifers. Such quarries, if filled with materials capable of producing objectionable leachate, would become sources of extreme ground-water contamination. Large, deep sand and gravel pits scattered throughout the county may well cause similar concern, depending on the composition and lateral extent of finer grained materials at the base of the pits and the continuity of the deposit with the local aquifers.	

Figure 24--Continued

is slower than 1 inch in 60 minutes are unsuitable for any type of soil-absorption system. Furthermore, in order that aerobic percolation can prevail, the base of the absorption trenches should be at least 4 feet above the highest seasonal level of the water table (U.S. Public Health Service, 1967).

Septic problems in Allen County stem largely from the wide distribution of slowly permeable soils and surficial geologic materials. Most of the county is underlain by soils that are either too wet or too slowly permeable to accept septic effluent properly (Kirschner and Zachary, 1969). Other potential problems stem from intensive development of those few areas in which materials are too permeable to too great a depth (fig. 24).

Engineering Geology

Many types of construction require subsurface engineering and soil exploration data that must be considered in the design. It may be a design of the type of foundation necessary to support a given load on a given soil, of the treatment and arrangement of materials in embankments or subbases, or of the slope at which to make a cut. Much of this information must be derived from the engineer's own testing program, but preliminary planning information can be obtained from a combination of soil survey data (Kirschner and Zachary, 1969) and regional geologic data. Soil survey reports describe in detail the nature and distribution of only the uppermost several feet of weathered material. But to the soils engineer the term soil encompasses all unconsolidated materials at any depth and therefore includes in large part the subsurface geologic materials. Thus geologic and surface soils information complement one another.

Tests that are summarized in this section were performed according to standard procedures, AASHO (American Association of State Highway Officials) for Atterberg limits and grain size (using, however, a 0.004-mm silt-clay division) and FHA (Federal Housing Administration) for potential volume change ratings.

ENGINEERING PROPERTIES AND CONSTRUCTION CONSIDERATIONS

Construction conditions vary considerably across the county as to the engineering properties of geologic materials and as to the moisture conditions of the materials (fig. 25).

Excellent foundation conditions are to be found throughout the areas of the Wabash and Fort Wayne Moraines and in the large areas underlain by till of the Lagro Formation. In places, however, surface soils are poorly drained, such as in those areas underlain by Blount and Pewamo soils and those areas that are underlain by soft clays, saturated loose sands, or compressible organic soils. The Maumee lake plain presents similar restraints, although strong material (till of the Lagro Formation) is usually found immediately beneath the soft plastic soil zone in the central lake plain and the well-drained sandy soils that are in places in and peripheral to the plain.

Problem areas for construction are those underlain in places by peats and mucks (figs. 4 and 25), thick soft clays, and very loose wet sands as found in the Wabash-Erie Channel, the Eel River valley, an area north of Arcola, the Fort Wayne Outlet, and smaller alluvial areas (figs. 4 and 26). Other problem areas exist where the difficult-to-excavate till of the Trafalgar Formation is near the surface (fig. 27). Overall, strengths of geologic materials below the few feet of surficial weathered material are in most places sufficient for small residential construction. In most places materials of sufficient strength are to be found at depth for the construction of larger structures without the necessity of undue foundation expense (fig. 25; appendix).

SURFACE STORAGE OF LIQUIDS IN RESERVOIRS AND PONDS

Surface storage lagoons are geologically practical in much of Allen County, particularly where the surficial material is the till of the Lagro Formation (Qte, Qt, Qtl; fig. 4) or other deposits which are relatively impermeable in the undisturbed state (Qcl, some Qsa; fig. 4). Small farm ponds are constructed mostly within the soil zone with a minimum of excavation, and their planning requires only the information contained in the soil survey report for the county. Larger structures definitely require a detailed engineering appraisal. Projects involving considerable stripping of floor material for construction may cut into or near confined aquifers, which are zones of potential leakage. Even limited pockets of such material within a tight till may lead to piping failure.

The thickest and most persisent zone of potential piping failure is the intersequence sand (fig. 5), the surface of which is most commonly a few feet to 15 feet above the top of the Trafalgar till (fig. 6). Thin, less extensive and less predictable sand and gravel lenses may be present higher within the Lagro till (appendix).

GEOLOGIC CALAMITIES

Except for flooding, the causes and control of which are currently under study by other agencies, the geologic hazards that plague many areas of the United States are of relatively little concern in Allen County. The risk of massive landslides is nil on the natural slopes of the overconsolidated till of Allen County, although improperly founded structures on steep slopes in the clayey drift could creep downhill under the right hydrologic conditions.

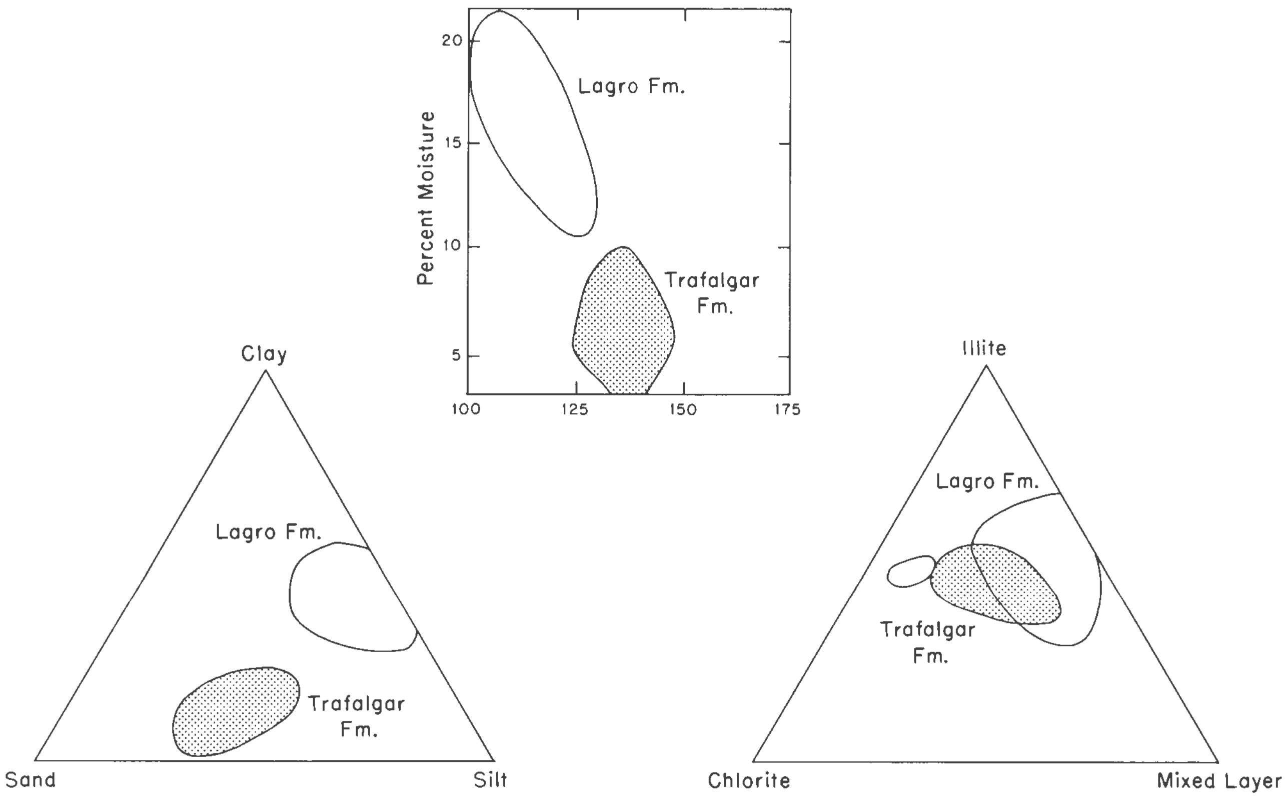
Allen County is within a seismic (or earthquake) risk zone in which very few shocks of modest to high intensity are ever to be expected. Most earthquakes are associated with active fault zones deep in the earth's crust. No fault of any age, active or inactive, has been recognized in the subsurface of Allen County.

Formation	Related surface soils associations	Distribution	Texture
LAGRO (Qte, Qt, Qtl, fig. 4; appendix)	Morley-Blount-Pewamo (ground moraine and end moraine areas) Hoytville, Nappanee, Pewamo (lake plain)	Underlies at some depth most soils and surficial geologic materials (loam till in northwestern Allen County associated with scattered Miami soils).	Clay loam to silty clay loam (unsorted pebbly till) (fig. 5). ANALYSIS: 10%-20% sand; 40%-50% clay.
TRAFALGAR (subsurface only) (appendix)		Underlies at varying depths most of Allen County; relatively near surface only in a few areas (fig. 8).	Loam to sandy loam (unsorted pebbly till) (fig. 5). ANALYSIS: 35%-45% sand; 15%-20% clay.
ATHERTON (Qsl, Qgv, Qsb, Qmp, Qcl, fig. 4; appendix)	Martinsville-Belwine-Fox Carlisle-Willette Lenawee-Montgomery-Rensselaer Rensselaer-Whitaker	Scattered: lake, surficial outwash, slack-water, swamp, and dune deposits; sand and gravel widespread in the subsurface. Typically thin, but more than 100 ft of sand and gravel and up to 70 ft of soft clay known in places.	Variable according to origin.
MARTINSVILLE (Qsa, fig. 4)	Eel-Martin-Genessee	Flanking river and stream channels.	Medium- to fine-grained silt of floodplain origin, overlying sand, and fine shelly gravel.

FOUNDATION AND EXCAVATION CONDITIONS	COMMENTS
LAGRO Provides excellent foundation conditions and may be readily excavated with small equipment. Large boulders occur in the drift in places, but these are not common. Natural slopes may range as high as 80°, and artificial vertical cuts 15 to 25 ft or more in height in homogeneous material may be expected to remain open for short periods. However, the problem to be anticipated with any open cuts, especially permanent ones, is the common *in*homogeneity of this material. Small sand lenses or blebs within the till may drain water and lead to the undercutting of the overlying till. Small seeps through such coarser layers, no matter how thin, may lead to elevated pore-water pressures in slope-covering materials and may increase the possibility of slumping.	Uppermost till unit (fig. 5; appendix), stressed by great thicknesses of glacial ice, overconsolidated throughout except weathered surface of several feet. Profiles through the upper 25 ft or so commonly display similar variations in consistency. The upper 2 to 3 ft has quite variable, but still generally low, consistencies ranging from medium to stiff. This is a function of weathering, frost, and variations in drainage. The till reaches a maximum stiff to very stiff consistency in the range of 7 to 15 ft, commonly at about 10 to 12 ft. This is probably a function of periodic dessication to this depth, or perhaps in part, deposition of carbonate from downward percolating water. Consistencies decline slightly below this zone, but rise again at about 20 ft in inherently stronger material. Thus, except for surface weathered material, the Lagro Formation has stiff to very stiff consistency and unconfined compressive strengths in the range of 2 to 4 tons per sq ft.
TRAFALGAR Not often encountered in smaller engineering works, but when it is present, it commonly presents a problem of exceedingly difficult excavation of the hard till, particularly where the use of small equipment is planned. Even the use of larger equipment at relatively great depths has been known to be hampered by boulder concentrations in the lower till. The most efficient method of excavation in quaries is reported to be the scraping down from the front of a vertical face rather than undercutting the base. Blasting has been resorted to in the stripping of this till in local quarries. Vertical cuts in this till may be expected to stand for relatively long periods, except where sand lenses are numerous.	Buried till unit extremely overconsolidated by ice load; hard as some solid rock types. Near the surface (with attendant construction problems) in several areas (figs. 6 and 8; appendix). An estimate of the nearness of unit or suprajacent sand, gravel, or hard silt obtained by comparing elevation taken from map of Trafalgar Formation surface (fig. 6) with surface elevation.
ATHERTON/MARTINSVILLE Bearing strengths of these materials, which range from gravel and dense sand to quick sand, clay, or peat, are exceedingly variable and cannot be generally predicted. Natural slopes of the granular materials of the Atherton Formation are relatively low. Artificial cuts in dry sand or gravel should allow for this degree of slope or less. In many areas in the terraces of the St. Joseph River and the St. Marys River and in the Fort Wayne Outlet or the Wabash-Erie Channel, saturated sand or gravel is to be expected (fig. 4). Slopes in this material may have to be exceedingly low; caisons and dewatering apparatus are put to use in many projects. In places high pore-water pressures may reduce the bearing capacity and the excavatable slope considerably.	Saturated granular materials, under conditions of upward ground-water flow within regional discharge areas, can be expected in parts of the St. Joseph valley, the Fort Wayne Outlet, and the Wabash-Erie Channel (fig. 3). Exceedingly soft, nearly "quick" sands are present in places (fig. 3).

Figure 25. Engineering data and foundation and excavation conditions for unconsolidated materials.

Consistency/Density	Dry density	Moisture	L. L.	P. L.	P. I.	P. V. C.	Classification
Medium to very stiff.	~110 lb per ft^3 in upper 7.5 ft (excluding surface soil horizons) ~126 lb per ft^3 in 7.5-15 ft	15-20%	High 30's	15-20	15-20	Neglible (absence of clay mineral montmorillonite and low content of mixed-layer minerals; fig. below).	CL A-6 to A-7
Hard to very hard.	135-145 lb per ft^3	5- 6%	15	10	5	Neglible (clay mineralogy as Lagro Fm.; slightly more chlorite; fig. below).	CL A-4
Variable according to sediment type, position in landscape, hydrologic characteristics, and history. Near surface sands and gravels commonly loose to medium dense, increasing with depth; units sandwiched between tills in subsurface or exhumed, commonly medium to very dense. Peat, muck, and organic sands to clays are soft to very soft. Lake clays soft except where dessicated.							Variable according to sediment type
Variable according to sediment type, hydrologic characteristics, and history.							SM to ML, CL A-1 to A-3; to A-7



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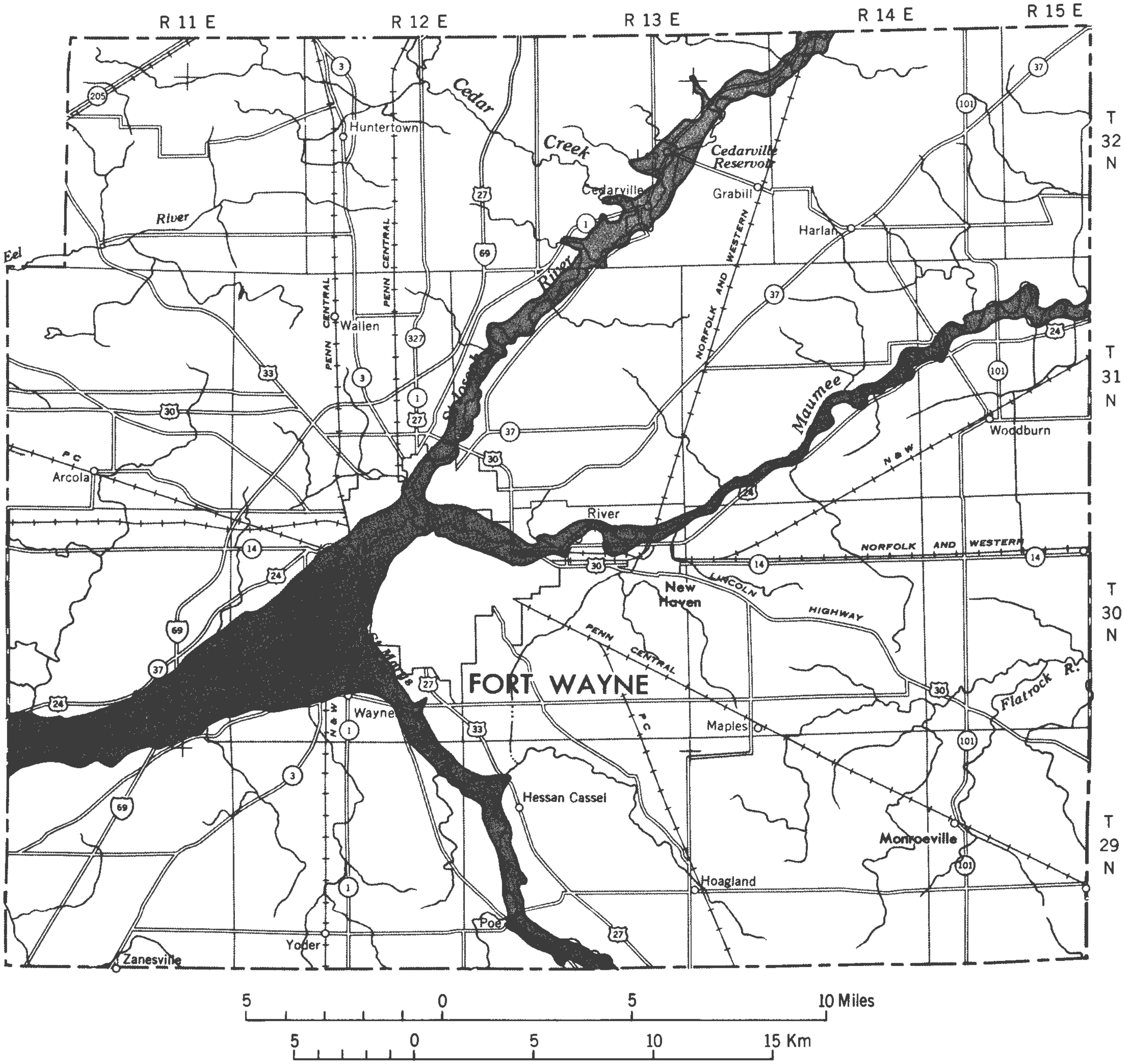


Figure 26. Map of Allen County showing areas that may be underlain by runny wet sand that may require caissons or dewatering for excavation. Included are some areas of quicksand under high pore-water pressures.

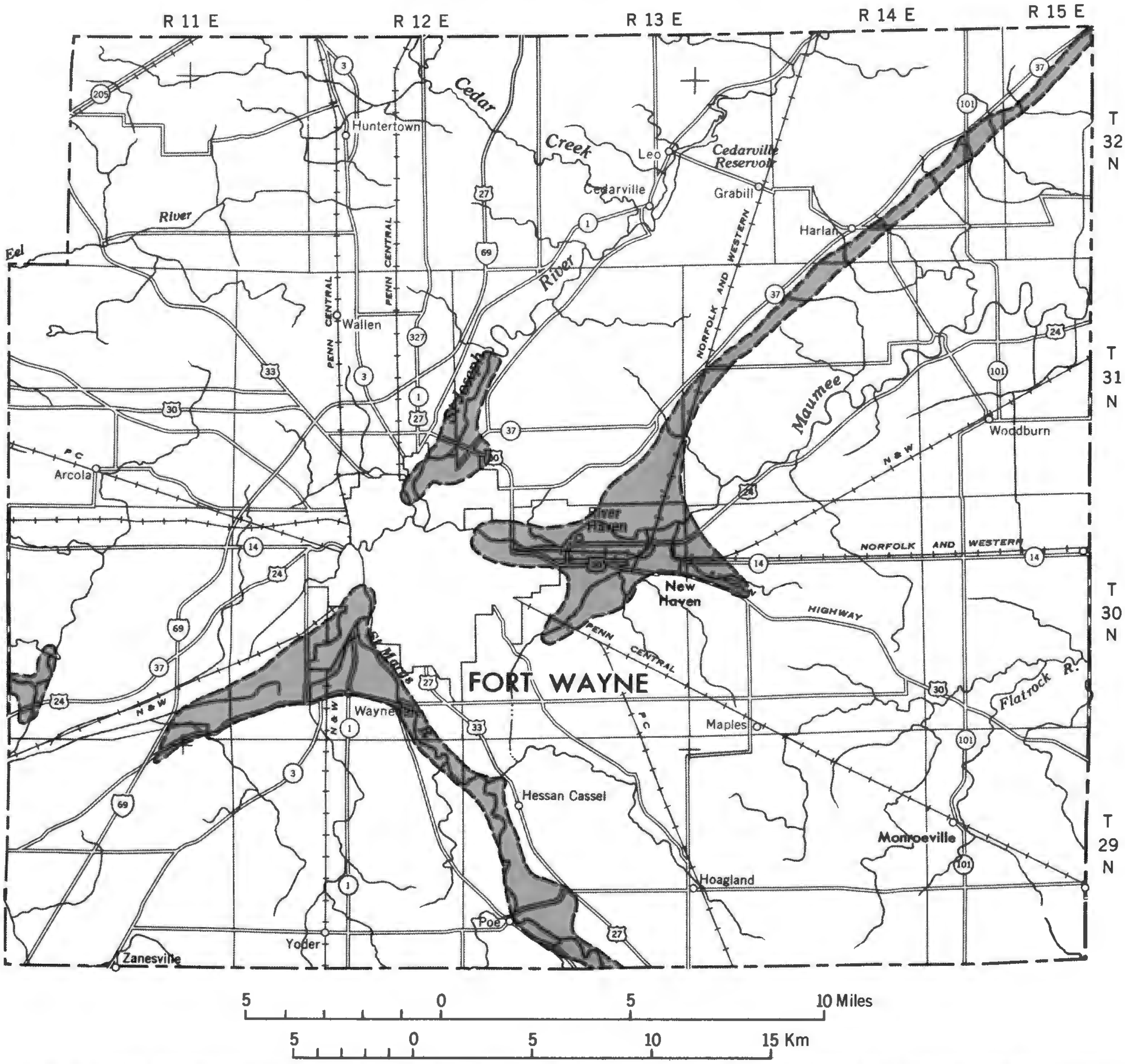


Figure 27. Map of Allen County showing areas in which shallow excavation may encounter hard till of the Trafalgar Formation or silt of the Atherton Formation. Till may be thinly interlayered with sand and gravel, particularly in the Wabash-Erie Channel and the Fort Wayne Outlet areas.

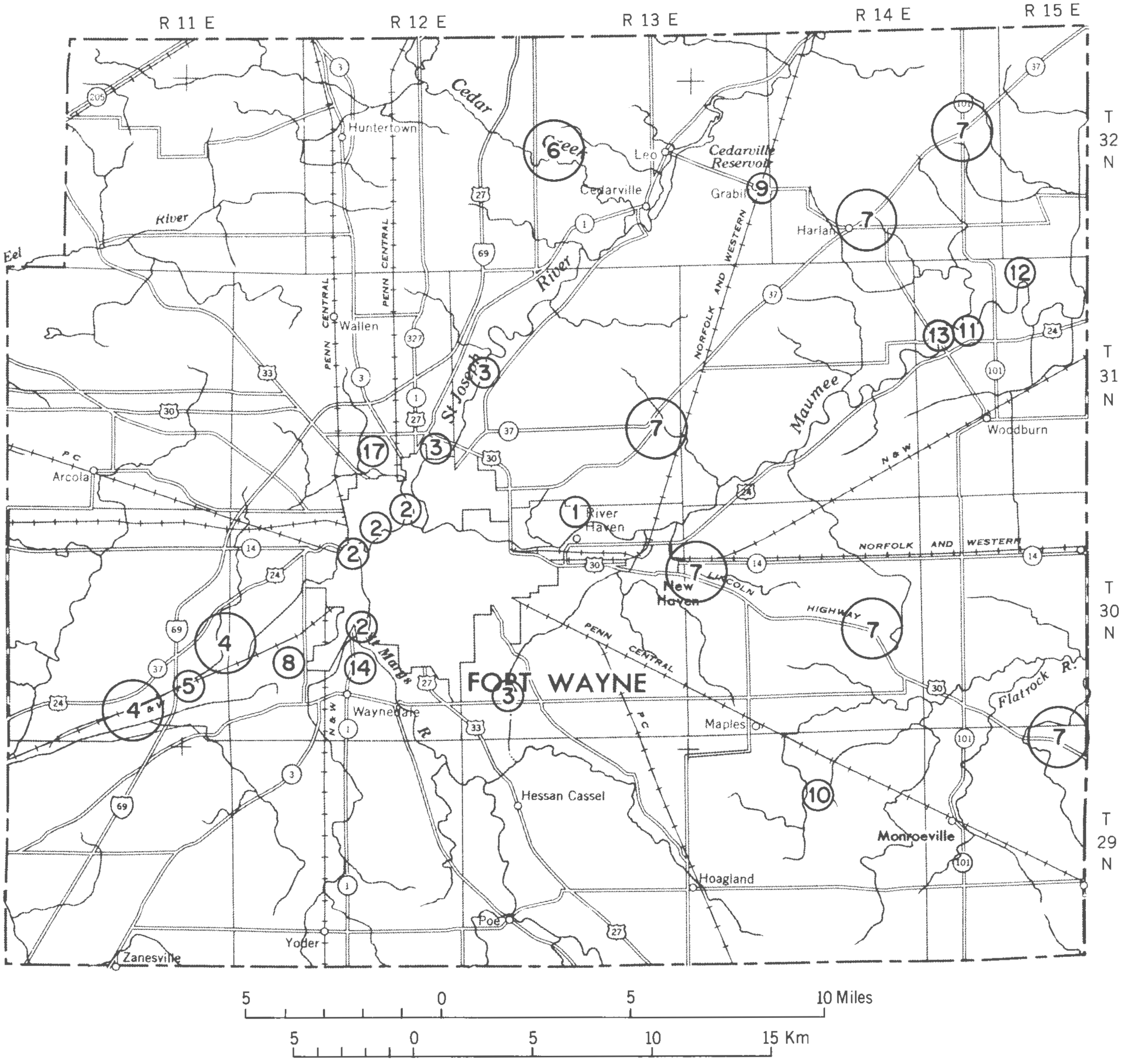


Figure 28. Map of Allen County showing scenic and historic geologic sites. See table 9 for a list of sites.

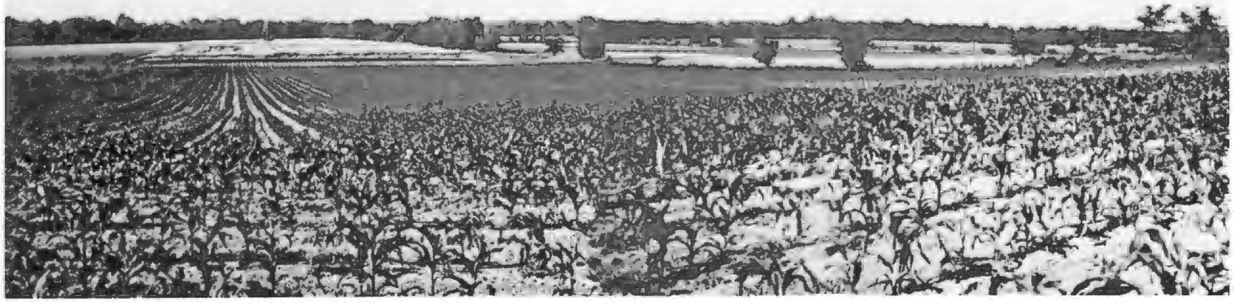


Figure 29. Panoramic view southward into the Fort Wayne Outlet from the Lake Avenue-Maysville Road.

Some Scenic and Historic Geologic Sites

Many geologic features of Allen County were described in the earliest geologic reports in the Midwest, and some of these features are world famous. The significance of the area is due largely to the fact that three major geologic elements, moraines, lakebed, and drainage routes, converge at Fort Wayne (fig. 3). Some of these landforms are now particularly significant because urbanization has virtually obliterated comparable features elsewhere in the Midwest. Because of their geologic form, some features surely were important to early man. Thus, with an eye toward the enhancement of their educational value as well as preservation for posterity, these resources should be considered in the same manner as historic sites of the recent past. Some could be incorporated in the expanding park system in Allen County or could be explained in interpretive roadside displays.

The purpose of this section is to point out the geologic and historical importance of some features (fig. 28; table 9) whose subtle beauty should be more widely appreciated. Our descriptions of the geologic sites should be useful in planning interpretive displays, nature tours, and class field trips. (See Ault and others, 1973.) We have diagrammed and described several points where the views of geologically significant features are unexcelled.

FORT WAYNE OUTLET

EAST LAKE AVENUE (IN THE ONE-HALF MILE WEST OF ITS INTERSECTION WITH MAYSVILLE ROAD) (1, FIG. 28; TABLE 9)

As one drives eastward on Lake Avenue from Coliseum Boulevard, a truly spectacular view unfolds to the south. This is the head of the Fort Wayne Outlet of glacial Lake Maumee (figs. 3 and 29). Lake Avenue runs along the crest of beach deposits on the north shore of the former lake. The Maumee lake plain is clearly visible to the east, and the Fort Wayne Outlet, cutting through the morainal uplands, is visible to the south and southwest. Lakes dammed between the Fort Wayne Moraine on the west and retreating ice front on the east stood at elevations of 800, 780, and 760 feet and emptied westward into the Fort Wayne Outlet at this point. (The elevations of the terraces representing the scoured surface of the lake outlet stand at about 750 feet.) The several lake levels are classically thought of as reflecting the opening and closing of an additional outlet in Michigan, but there is some evidence to suggest that the levels could have been controlled by progressive downcutting right here in the Fort Wayne Outlet,

Table 9. Some scenic and historic geologic sites in Allen County

Site	Status	Significance
1 East Lake Avenue; Maysville Road	Agriculture	Scenic-historic view; head of Fort Wayne Outlet of glacial Lake Maumee.
2 Existing city parks	Urban developed	Located in axis of Fort Wayne Outlet of glacial Lake Maumee.
3 Six Mile Creek Channel	Agricultural; encroaching suburbia	"Scenic"-historic view; former subsidiary discharge route for glacial Lake Maumee.
4 Wabash-Erie Channel	Agricultural; encroaching industry	Little-spoiled low area, the former route of glacial meltwater and three levels of glacial lake discharge; potential restoration to seminatural wetland.
5 Fox Island	Nature preserve	Unspoiled area of dune sand, in axis of Wabash-Erie Channel (glacial and lake discharge route), on south edge of last glacial lake exit.
6 Cedar Creek canyon	Little-developed scenic river	Located in valley cut by glacial meltwater flowing westward; creek now flows eastward.
7 State Highway 37; old U.S. Highway 30	State and federal right-of-way; agricultural surroundings	Traverse crest and margins of beaches of 780-ft level of glacial Lake Maumee. Excellent lengthwise views of ancient beach profiles and of Maumee lake plain.
8 Ardmore Avenue quarry	Active quarry with accessible viewing stand	Indicative of man's great need for industrial minerals. Limestones deposited in warm shallow seas 400 million years ago.
9 Grabill tile kiln	Shutdown kiln and factory	Historic sites with kilns and machinery; tile as made here paved way to agricultural growth in the area.
10 Hoagland tile kiln	Shutdown kiln	
11 Bluecast Spring	Forest; proposed regional park	Natural spring issuing from sand and gravel bed that is smaller but probably equivalent to bed at Bull Rapids.
12 Oxbow Bend	Agricultural; proposed regional park	Located on lake plain and floodplain–terrace of Maumee River.
13 Bull Rapids	Agricultural	Scenic stretch of Maumee River, where downcutting has been hung up on lag boulders atop buried glacial outwash channel.
14 Waynedale gravel pits	Active pits with surrounding urban development; potential urban park	Developed in terrace of glacial outwash that flowed from glacier snout standing at Fort Wayne Moraine.

first through the till of the Lagro Formation, then through the till of the Trafalgar Formation (Bleuer and Moore, 1972). The Maumee River now drains in the opposite direction, down the eastward-sloping axis of the bottom of that ancient lake, whose form was initially molded by ice of the extinct Erie Lobe. The view across the valley bottom (which in part now includes the flood plain of the Maumee River) therefore is significant geologically in terms of preservation. This area could easily be marked by an interpretive display or could be included in a self-guided tour of historic Allen County.

LAWTON PARK, SHERMAN PARK, AND SWINNEY PARK (2, FIG. 28; TABLE 9)

These city parks are on the flat channel bottom of the Fort Wayne Outlet, and although views are not spectacular, the parks occupy an interesting geologic setting that also could be noted with educational displays. When the ice stood last in what is now eastern Fort Wayne, meltwater discharged down the St. Joseph and St. Marys valleys and into the Wabash-Erie Channel. The parks are in the line of earliest discharge of glacial meltwater down the St. Joseph River valley to the Wabash-Erie Channel; thus earliest drainage was westward, not eastward as it now is. Later when ice retreated farther to the east and Lake Maumee formed, its discharge torrent passed over these sites, again westward. Finally, sometime after Lake Maumee ceased to exist, the Maumee River came into being, flowing eastward down the axis of the old lake. For some time the St. Marys and the St. Joseph Rivers continued to flow westward, but eventually the Maumee captured the St. Marys and St. Joseph drainges, and both subsequently drained to the east. This recurving of drainage lines is a classic example of barbed drainage, and this particular example is shown in several textbooks.

SIX MILE CREEK CHANNEL (3, FIG. 28; TABLE 9)

The Six Mile Creek Channel (Trier Ditch) follows an arcuate course across southeastern Fort Wayne. It and the main Fort Wayne Outlet were the only gaps in the Fort Wayne Moraine through which the waters of Lake Maumee could have drained. Its north end opens into a wide sandy plain between Fort Wayne and New Haven, and the south end terminates at the St. Marys River.

The recent history of the Six Mile Creek Channel appears to have been as an overflow route for the St. Marys River, but this does not preclude the possibility that the channel originated as a lake discharge route. This channel could have been significant in the draining of the two high lake levels and could have barely helped drain the lowest level lake.

Indeed, the U.S. Corps of Engineers has proposed construction of a deepened, channelized flood diversion route through the bottom of this old stream course. Much of the bottom of this channel is now being urbanized, but in 1913 it carried 5 feet of water from the St. Marys River to the Maumee River, 8½ miles to the north.

The channel and its walls may be viewed from Tillman Road, Maples Road, and Paulding Road where they cross the channel. Interpretive displays at one of these views, or at a nearby school, would have considerable educational value.

WABASH-ERIE CHANNEL (4, FIG. 28; TABLE 9)

West of Fort Wayne and extending to Huntington is the Wabash-Erie Channel, the great glacial spillway that first carried direct glacial drainage and that then carried water from Lake Maumee westward into the Wabash valley. Its geologic history is complex. Most of the channel is a scoured surface, a surface cut into preexisting glacial tills and gravels by the torrential discharge of glacial Lake Maumee. The billions of gallons of frigid lake waters that discharged daily down the Wabash-Erie Channel produced a stream similar to today's Niagara River. During the discharge of the earliest and highest of the Maumee lakes most of the Wabash-Erie Channel was occupied by a huge river. During the latest and lowest stage of the lake,

Figure 30. Aerial view eastward, upstream in the deep north half of the Wabash-Erie Channel (left background). Fox Island lies in the wooded area near the upper center of the photograph, just beyond Interstate Highway 69.

however, only the Fort Wayne Outlet was in significant use, and only the north half of the Wabash-Erie Channel (figs. 28 and 30) was occupied by a much smaller river. As much as 20 feet of fine-grained alluvial fill in this deep north channel has brought its present level up to that of the shallower scoured floor of the main part of the channel to the south. The great channel can be viewed well from the north-south roads crossing the channel and from some places along U.S. Highway 24 and Interstate Highway 69. Interpretive displays could be placed at any of several sites, and a traverse of the valley could easily be incorporated in any self-guided tour.

Potentially most unique is the north passage of the Wabash-Erie Channel, particularly that part north of Fox Island, where conflicts between development, agriculture, and the natural environment will become more and more severe. Agriculture has already taken the place of the natural marshland that man first encountered here, and some development, including mineral extraction industries, will continue to take the place of agriculture. But the question of the best use of this land remains open. The use for which it is uniquely suited was, and perhaps could be again in part, its original (non) use, that is, as a natural area.

FOX ISLAND (5, FIG. 28; TABLE 9)

Fox Island, a linear dune complex, lies at the south edge of the deep north channel within the larger Wabash-Erie Channel. Such dunes as those comprising Fox Island may form where there is a steady prevailing wind and a continuing sand supply. At Fox Island, and several spots just to the east, sand was derived from the floor of the older scourway to the south and west, was sorted by the wind, and was blown into its dune forms. Boulders of crystalline rocks around the base of Fox Island, and along fence rows to the south and west, are a lag deposit (or residue from the glacial deposits) resulting from the removal of fine material–first by the torrential lake discharge water, then by the removal of the sand blown by the wind.

We do not know just when the Fox Island dunes formed. They were where they are now, under forest cover, when white man came on the scene. They were probably formed soon after the waning of glacial Lake Maumee, after the gravel terrace to the south (the sand source) was drained but before vegetation was established. The northern boundary of the dunes could have been determined by a small river that conceivably was the latest and lowest Lake Maumee discharge. If this is true, the dunes are about 13,000 years old. Of course, they could have formed much more recently.

The ecology of Fox Island is well known to be unique and in a delicate state of balance. Vegetation on the loose fine sand is easily removed through overuse, most easily by gouging by motorcycles. Furthermore, it is the nature of the fine dune sand to move once the stabilizing vegetative cover is removed. It is erodible by wind and water and perhaps least fit of any geologic material for the punishment of off-road vehicle use.

CEDAR CREEK CANYON (6, FIG. 28; TABLE 9)

The valley of Cedar Creek in the north-central part of Allen County is one of the most striking physiographic features in the area. It cuts almost perpendicularly across the Wabash Moraine and carries water from upper Cedar Creek to the St. Joseph River instead of to the Eel River into which it once flowed. This creek is a classic example of stream piracy, the capture of the headwaters of one stream by another.

As the last glacier melted and the ice front receded to the northeast, great quantities of debris-laden meltwaters flowed from it, following courses determined by the snout of the glacier and by the arcuate morainal ridges that it had left behind (fig. 31). Such a stream flowed down the outer edge of the Wabash Moraine, down the Eel River sluiceway to the Wabash River. The St. Joseph River was a similar stream flowing in a narrow groove between the inner edge of the Wabash Moraine and the outer edge of the Fort Wayne Moraine, its waters finally entering the Wabash-Erie Channel and merging with the discharge of glacial Lake Maumee.

When the glacier stood on the Wabash Moraine, before the development of the channel of the St. Joseph, a subice channel probably discharged westward across the west half of the moraine (fig. 31), perhaps at the position of an existing sag in the topography. After the ice had left and the St. Joseph River was established, a tributary began headward erosion on the east side of the moraine, opposite the previously cut channel (fig. 31).

After the ice mass feeding the Eel River sluiceway had diminished, the Eel was no longer competent to move its massive bedload and a riffle developed near the point where Cedar Creek now turns to the southeast. Seasonal floodwaters rose high enough to spill over the divide in the middle of the Wabash Moraine, and the Eel drainage was thus rapidly pirated. Nature preserves or parks developed in Cedar Creek canyon could make use of geologic information in interpretive displays or nature guides.

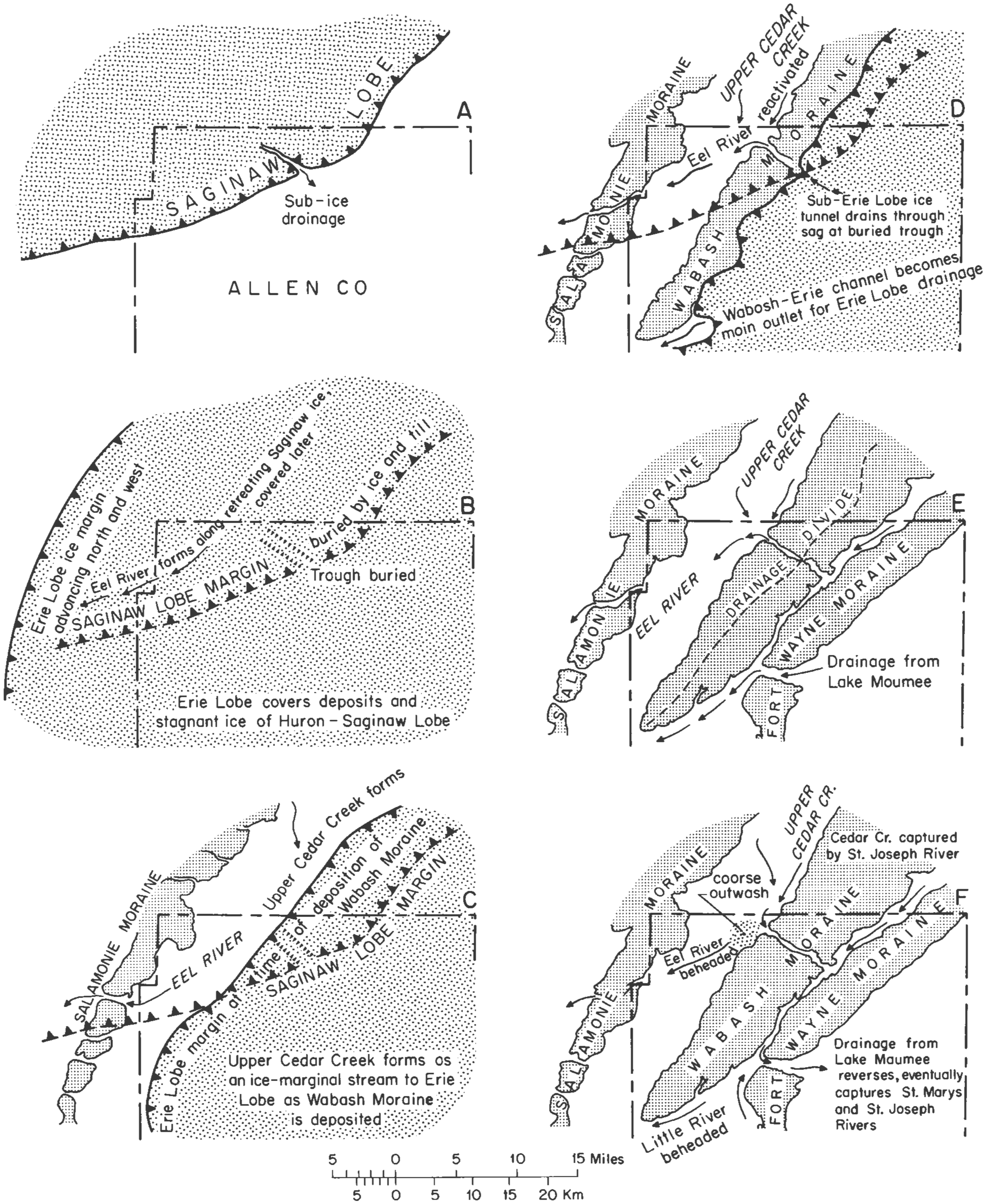


Figure 31. Diagrams showing the sequential development of Cedar Creek canyon.

Figure 32. View of a beach profile, the shore of the 780-foot level of Lake Maumee, just east of New Haven. Waters lapped against the base of the scarp.

STATE HIGHWAY 37 NORTH;
OLD U.S. HIGHWAY 30 EAST (7, FIG. 28; TABLE 9)

From the point where the pavement turns northeastward and becomes Maysville Road, Highway 37 passes along the crest of the best developed of the three beach levels of glacial Lake Maumee, the one that stood at about 780 feet. As one drives northeastward there are many excellent views of the flat lake bottom to the east interrupted here and there by very low swales that are ancient offshore sandbars. The road mostly parallels the gently sloping, concave-upward scarp that was cut by waves into the clayey glacial till of the east face of the Fort Wayne Moraine and parallels sand ridges that were formed when storm waves drove sand high up onto the beach. This route parallels one of the most distinct topographic discontinuities to be found in the Midwest. The lake plain is a result of wave scour of an initially ice-scoured surface and the deposition of waterborne sand and clay. The morainal topography is a result of deposition of material that chaotically melted out of the glacier at the glacier margin.

From the New Haven High School eastward on U.S. Highway 30 the road passes first along the crest of the beautifully sculptured, smoothly sloping wave-cut shoreline of the 780-foot Lake Maumee. Farther east and as far as the state line, the route is over wave-cut scarp and sand accumulations of beach and offshore bar origin (fig. 32). Both of these routes have had a long and interesting history. These high well-drained beach-line routes along the shore of the swampy remnants of Lake Maumee undoubtedly served both the Indians and early whites as important thoroughfares. Along Highways 37 and 30 there are many scenic views that might well

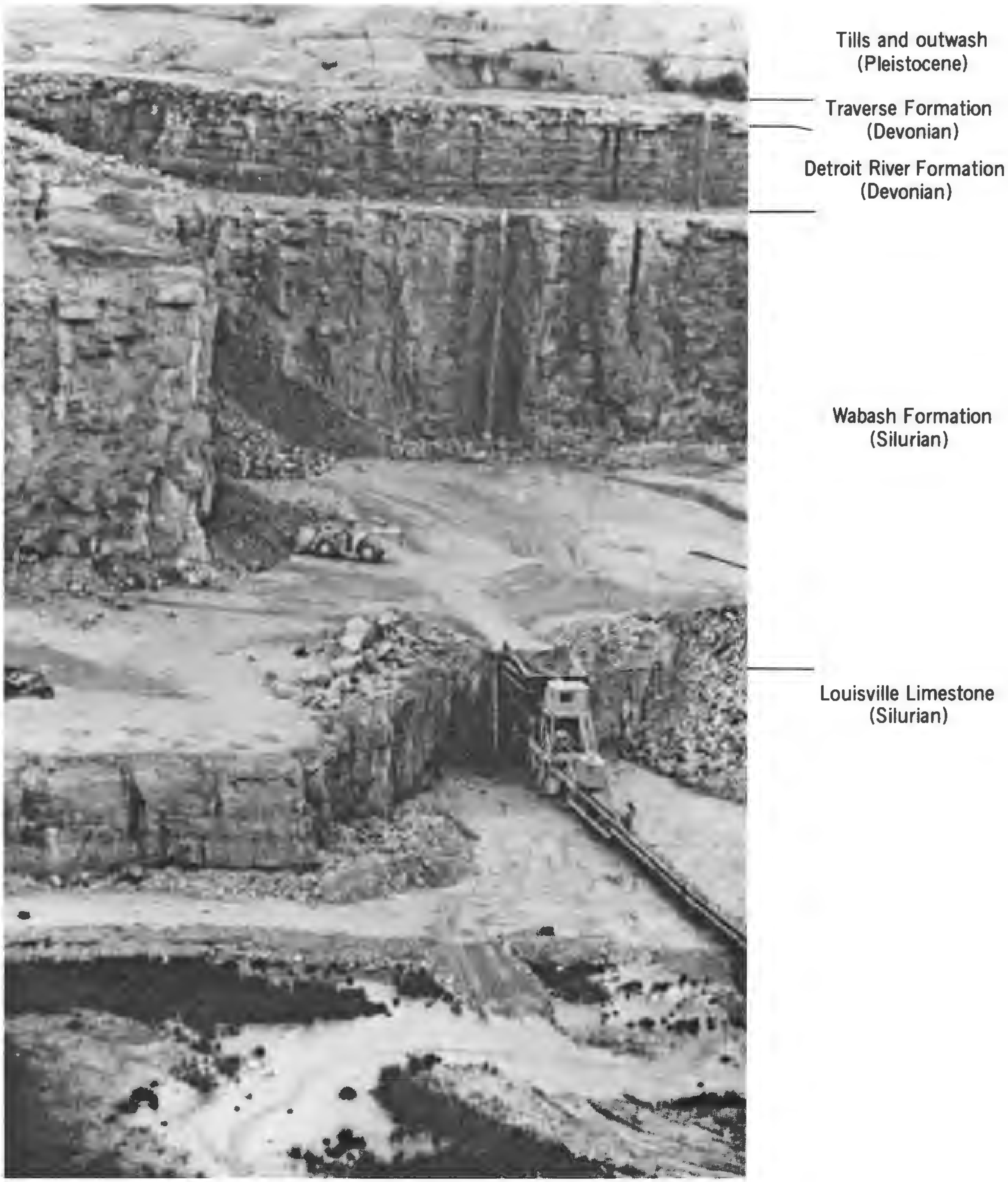


Figure 33. View of the May Stone & Sand, Inc., quarry on Ardmore Avenue, from the viewing stand atop the north wall, just off Sand Point Road.

be preserved as park or pulloff with interpretive displays. Both routes could be included in a self-guided driving tour of historic Allen County.

QUARRIES (8, FIG. 28; TABLE 9)

Among the geologically significant areas are some that represent a past or present dependence on natural resources for economic growth. The presently operating May Stone & Sand, Inc., quarry on Ardmore Avenue, which may be viewed from an observation platform just south of Sand Point Road, displays the immense void where a tremendous volume of stone has already been removed and attests to man's need for mineral aggregate. Four other quarries are being worked within Allen County, and some of them will doubtless reach this size.

Visible from the viewing stand at the May quarry (fig. 33) is one of the most complete pictures of the geologic history to be found in northeastern Indiana. Most of the rock has been removed from the heart of an ancient reef, or bank of carbonate rock, composed mostly of the remains of bottom-dwelling organisms, such as corals, bryozoans, and brachiopods. The creatures whose fossil remains are sparsely scattered through the rocks today thrived in the warm shallow Silurian seas about 400 million years ago. Shoreward, behind the reef and generally to the south in shallower, less turbulent waters during Silurian time, calcareous silt was deposited in thin laminae, while in front of the reef to the north in quieter, deeper water more clay and less lime slowly settled. Occasionally, shifts of current patterns brought both of these environments into the Fort Wayne area.

Above the massive reefal dolomite of Silurian age is a thin sequence of sparsely fossiliferous rocks of middle Devonian age that represent a restricted, more salty than normal sea. The break between these beds and those reefal rocks beneath is only a plane, but it represents a very marked change in the depositional environment and the passing of a substantial period of time, the rock record of all of early Devonian time being absent. The restriction of the sea that caused the middle Devonian rocks to be unfossiliferous eventually ended, and the topmost bedrock units of middle Devonian age contain fossils indicative of a normal, perhaps subtropical sea.

The break between the Silurian reef rocks and the 350-million-year-old Devonian rocks above, though great, is tiny compared with the hiatus represented by the contact of unconsolidated glacial sediments with the bedrock surface (fig. 33).

Hundreds of millions of years passed and many events went unrecorded before the great sheets of ice advanced from the northeast. The surficial glacial materials consist (top to bottom) of outwash gravel, which occurs as a high terrace remnant of a once greater body that filled the Wabash-Erie Channel. The outwash was derived from the melting ice of the Erie Lobe when it stood at Fort Wayne. Beneath this gravel are glacial till, an unsorted clayey mixture of the type known to melt out of glacial ice masses, gravel, more till, and a basal gravel. Thus here in two till sheets is evidence of two glacial advances, each followed and preceded by melting ice and abundant sand and gravel deposits. Ice stood here last between 20,000 and 13,000 years ago.

Quarries are such interesting places that they are often labeled "attractive nuisances." Long after the lumbering machines have abandoned their labors, the fascination of these deep holes remains. In a glaciated area, such as northeastern Indiana, they lure the rockhounds and fossil and mineral collectors. The May quarry has only a limited selection of fossils, but quartz, calcite, dolomite, pyrite, fluorite, and sphalerite have been reported from the rocks in this 350-foot-deep hole.

The limestone removed here is used as aggregate in concrete and asphalt mix and as a road base material. Holes are drilled along the margin of the excavation and loaded with

Figure 34. View of the Klopfenstein tile kiln at Grabill.

explosives, and a high wall of rock is blasted down. Care is taken that as much energy as possible goes into breaking rock and not for shaking the ground. Loaders then take the fragmented rock to the crusher which further reduces the size. The crushed rock is conveyed to the sizing plant, where further crushing and screening are carried out. Various grades of crushed stone can be made, depending on the customers' specifications. Material is conveyed up tall stackers and deposited in stockpiles until it is sold.

TILE KILNS (9, 10, FIG. 28; TABLE 9)

Geodesic domes are now seen in many cities. Aside from certain structural advantages they have, these domes are the mark of progress and symbols of the space age. Allen County has two similarly distinctive domed (not geodesic) buildings that were once functionally beautiful and that now have great historical interest. These structures are tile kilns, windowless, circular brick buildings about 30 feet in diameter with domed roofs and a separate smokestack. They are called downdraft kilns and are periodic in their operation.

The green (molded but unfired) tile or other ware are stacked within the building and fires are kindled around the perimeter. The temperature, brought up slowly at first and then more rapidly to the peak, is controlled by dampers and by the rate of hand feeding the fire mouths. Hot gases from the fire mouths pass up through the material being fired and are reflected from the domed

Figure 35. View of the Stringtown tile kiln and works west of Monroeville.

roof to pass back down through the ware and out flues in the floor to the stack. A single cycle could take as long as a month. The round shape and domed roof aid in controlling gas flow and also reduce heat loss.

One kiln (fig. 34) is in the southeastern part of Grabill (SE¼NE¼ sec. 25, T. 32 N., R. 13 E.). It was operated by Mr. Aaron Klopfenstein, who still lives nearby, and produced such wares as farm draintile, building block, common brick, and flowerpots. The raw material used by Mr. Klopfenstein was the upper 5 feet of soil developed on bluish-gray glacial till (Lagro Formation) found near Grabill. Below that depth the content of limy concretions became too high. This operation closed sometime between 1960 and 1965.

Mr. Walter Bolyard owned the tile factory 3 miles west of Monroeville (SE¼SE¼ sec. 10, T. 29 N., R. 14 E.). This kiln (fig. 35), too, is of the periodic type and could make a cycle in a week or so. In 1955 the company was known as Stringtown Tile, had six employees, and could produce as much as 7,000 tile per day. Operations ceased in 1961.

At the time of the first comprehensive study of the clay resources of Indiana, compiled by George Whitlatch in 1933, the ceramic industry of Allen County had dwindled to these two tile plants and a single brick plant. By 1948 the brick plant had gone out of business and the Klopfenstein tile works was listed as a manufacturer of common brick as well as tile. Apparently this venture was not successful, as the brick was not mentioned by Murray's directory of producers and users of clay in 1955, although the plant still employed five persons and ran eight cycles per year.

Both the Klopfenstein and Bolyard kilns are still in good condition. These sites would make excellent county historical parks and as part of self-guided tours of historic Allen County. Exhibits could be prepared as well, since much of the old equipment is still there. The development of agriculture in much of Allen County was a direct result of drainage of the land, and tile, of course, played a part in this endeavor.

Grabill, the center of an Amish-Mennonite settlement, is already noted as the focal point of an area of Americana. Handcraft furniture is the major industry and examples of harness tack abound in the town. The Klopfenstein plant is in the industrialized part of the small town by the railroad tracks.

Stringtown Tile is in a slightly rolling ground moraine area in the southeast corner of Allen County. Except for the lower reach of Flatrock Creek valley and some low sandy beach ridges northwest of Monroeville, there is little that is scenic or of historical interest in the vicinity.

If these properties were to be purchased by the county or by suitable local or private authority, a modest investment in trees, picnic benches, and perhaps a well and sanitary facilities would make them fine picnic areas.

OTHER AREAS

Several other interesting areas are summarized in table 9. All those listed above are areas that can be appreciated from a particular viewing spot. But there are large-scale interesting geologic features to be found throughout Allen County. Among these are the massive hilly morainal areas and their linear ridge crests and bogs and lowland drainageways within them. And at an opposite extreme is the amazingly flat expanse of the bed of glacial Lake Maumee.

Literature Cited

Ault, C. H., and others
    1973 - Guidebook to the geology of some Ice Age features and bedrock formations in the Fort Wayne, Indiana, area: Indiana Geol. Survey Guidebook, 62 p.

Bleuer, N. K.
    1970 - Geologic considerations in planning solid-waste disposal sites in Indiana: Indiana Geol. Survey Spec. Rept. 5.
    1974 - Buried till ridges in the Fort Wayne area, Indiana, and their regional significance: Geol. Soc. America Bull., v. 85, p. 917-920.

Bleuer, N. K., and Hartke, E. J.
    1971 - Diagrammatic cross-sections of Indiana geology in relation to solid-waste disposal sites: Indiana Geol. Survey Spec. Rept. 5 [Supp.].

Bleuer, N. K., and Moore, M. C.
    1972 - Glacial stratigraphy of the Fort Wayne area and the draining of glacial Lake Maumee: Indiana Acad. Sci. Proc., v. 81, p. 195-209.
    1975 - Buried pinchout of Saginaw Lobe drift in northeastern Indiana: Indiana Acad. Sci. Proc., v. 84, p. 362-372.

Burger, A. M., and others
    1971 - Geologic map of the 1° X 2° Muncie Quadrangle, Indiana and Ohio, showing bedrock and unconsolidated deposits: Indiana Geol. Survey Regional Geol. Map 5.

Dawson, T. A.
    1960 - Deep test well in Lawrence County, Indiana: Drilling techniques and stratigraphic interpretations: Indiana Geol. Survey Rept. Prog. 22, 36 p.

Dawson, T. A., and Carpenter, G. L.
    1963 - Underground storage of natural gas in Indiana: Indiana Geol. Survey Spec. Rept. 1, 29 p.

Dryer, C. R.
    1889 - Report upon the geology of Allen County: Indiana Dept. Geol. and Nat. History, Ann. Rept. 16, p. 105-130.

Environmental Protection Administration
    1974 - Subsurface emplacement of fluids, Administrator's Decision Statement No. 5: Federal Register, v. 39, p. 12922-12923.

Foley, C. F., and others
    1973 - Strontium and other notable chemical constituents of well-water of Allen County, Indiana: Indiana Acad. Sci. Proc., v. 82, p. 274-280.

Gray, H. H.
    1972 - Lithostratigraphy of the Maquoketa Group (Ordovician) in Indiana: Indiana Geol. Survey Spec. Rept. 7, 31 p.

Herring, W. C.
1969 - Reconnaissance of the ground-water resources of the Maumee River basin: Indiana Div. Water Rept. 7 [open-file report].

Johnson, G. H., and Keller, S. J.
1972 - Geologic map of the 1° X 2° Fort Wayne Quadrangle, Indiana, Michigan, and Ohio, showing bedrock and unconsolidated deposits: Indiana Geol. Survey Regional Geol. Map 8.

Keller, S. J.
1973 - Map of Indiana showing oil, gas, and products pipelines: Indiana Geol. Survey Misc. Map 18.

Kirschner, F. R., and Zachary, H. L.
1969 - Soil survey of Allen County, Indiana: U.S. Dept. Agriculture, Soil Conserv. Service, 76 p.

Leverett, Frank
1902 - Glacial formations and drainage features of the Erie and Ohio basins: U.S. Geol. Survey Mon. 41, 802 p.

Leverett, Frank, and Taylor, F. B.
1915 - The Pleistocene of Indiana and Michigan and the history of the Great Lakes: U.S. Geol. Survey Mon. 53, 527 p.

Moore, M. C., and Bleuer, N. K.
1973 - An exposure of pre-Wisconsinan drift near Fort Wayne, Indiana [abs.]: Indiana Acad. Sci. Proc., v. 82, p. 265.

Murray, H. H.
1955 - Directory of producers and consumers of clay and shale in Indiana: Indiana Geol. Survey Directory 3, 42 p.

Ohio Department of Natural Resources, Division of Water
1970 - Groundwater for planning in northwest Ohio: 63 p.

ORSANCO Advisory Committee on Underground Injection of Wastewaters
1973 - Underground injection of wastewaters in the Ohio Valley region: Cincinnati, Ohio Rivery Valley Sanitation Comm., 63 p.
1974 - Registry of wells for use in underground injection of wastewater in the Ohio Valley region: Cincinnati, Ohio River Valley Sanitation Comm., 101 p.

Owen, Richard
1862 - Report on a geological reconnoissance of Indiana. . .: Indianapolis, H. H. Dodd and Co., 365 p.

Pettijohn, R. A., and Davis, L. G.
1973 - Water resources of the Maumee River basin, northeastern Indiana: U.S. Geol. Survey Hydrol. Inv. Atlas HA-493.

Price, J. A.
1906 - The roads and road materials of Allen County: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 30, p. 275-314.

Rosenshein, J. S., and Hunn, J. D.
1964 - Ground-water resources of northwestern Indiana, preliminary report: Newton County: Indiana Div. Water Bull. 26, 69 p.

Soper, E. K., and Osbon, C. C.
1922 - The occurrence and uses of peat in the United States: U.S. Geol. Survey Bull. 728, 207 p.

Tate, C. H., and others
1973 - Water resources of the upper Wabash River basin, northeastern Indiana: U.S. Geol. Survey Hyrol. Inv. Atlas HA-433.

Taylor, A. E.
1907 - The peat deposits of northern Indiana: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 31, p. 73-278.

U.S. Public Health Service, Department of Health, Education, and Welfare
1962 - Public Health Service drinking water standards: Public Health Service Pub. 956, 61 p.
1967 - Manual of septic-tank practice, revised: Public Health Service Pub. 526, 92 p.

Whitlatch, G. I.
1933 - The clay resources of Indiana: Indiana Dept. Conserv. Pub. 123, 298 p.

Other Sources

Doheny, E. J., Droste, J. B., and Shaver, R. H.
1975 - Stratigraphy of the Detroit River Formation (middle Devonian) of northern Indiana: Indiana Geol. Survey Bull. 53, 86 p.

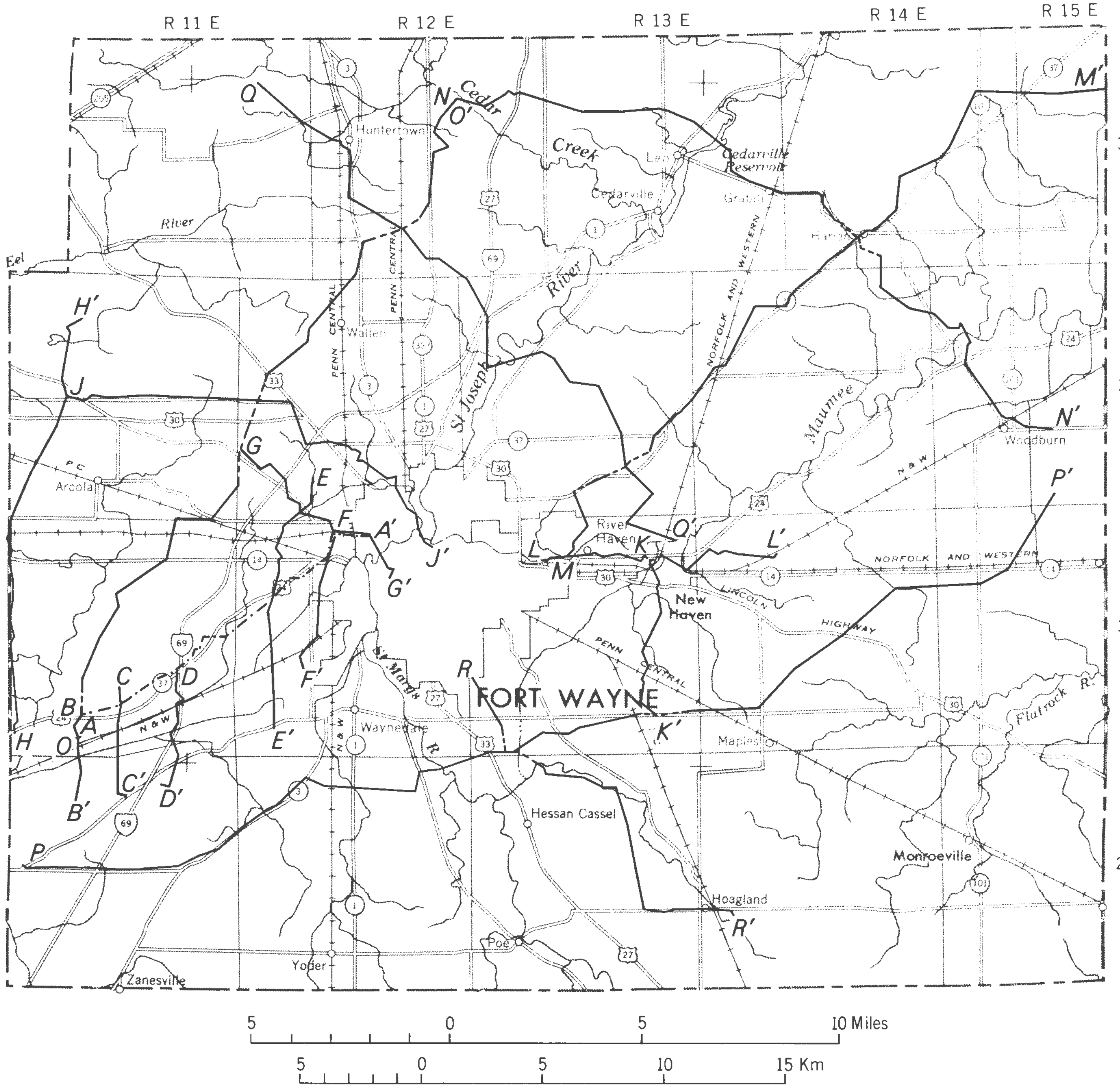
Gooding, A. M.
1973 - Characteristics of late Wisconsinan tills in eastern Indiana: Indiana Geol. Survey Bull. 49, 28 p.

Greenberg, S. S., and Vitaliano, C. J.
1962 - Basalt from a deep well in Lawrence County, Indiana: Jour. Geology, v. 70, p. 482-488.

Gutstadt, A. M.
1958 - Cambrian and Ordovician stratigraphy and oil and gas possibilities in Indiana: Indiana Geol. Survey Bull. 14, 103 p.
Kottlowski, F. E., and Patton, J. B.
1953 - Precambrian rocks encountered in test holes in Indiana: Indiana Acad. Sci. Proc., v. 62, p. 234-243.
Pinsak, A. P., and Shaver, R. H.
1964 - The Silurian formations of northern Indiana: Indiana Geol. Survey Bull. 32, 87 p.
Rooney, L. F.
1969 - New mineral wealth upstate: Outdoor Indiana, v. 34, no. 9, p. 25-28.
Rooney, L. F.
1970 - High-calcium limestone and high-magnesium dolomite resources of Indiana: Indiana Geol. Survey Bull. 42-B, 20 p.
Rooney, L. F., and French, R. R.
1968 - Allogenic quartz and the origin of penemosaic texture in evaporites of the Detroit River Formation (middle Devonian) in northern Indiana: Jour. Sed. Petrology, v. 38, p. 755-765.
Wayne, W. J.
1963 - Pleistocene formations in Indiana: Indiana Geol. Survey Bull. 25, 85 p.

Appendix

CROSS SECTIONS A-A′ THROUGH R-R′ SHOWING GLACIAL MATERIALS IN ALLEN COUNTY, INDIANA



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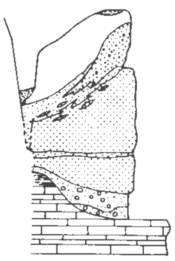

EXPLANATION OF SYMBOLS USED IN CROSS SECTIONS

⁘ Sand and gravel	☐ Till (New Holland)	░ Till (Trafalgar)
░ Silt and clay	▓ Till (unnamed)	▨ Bedrock

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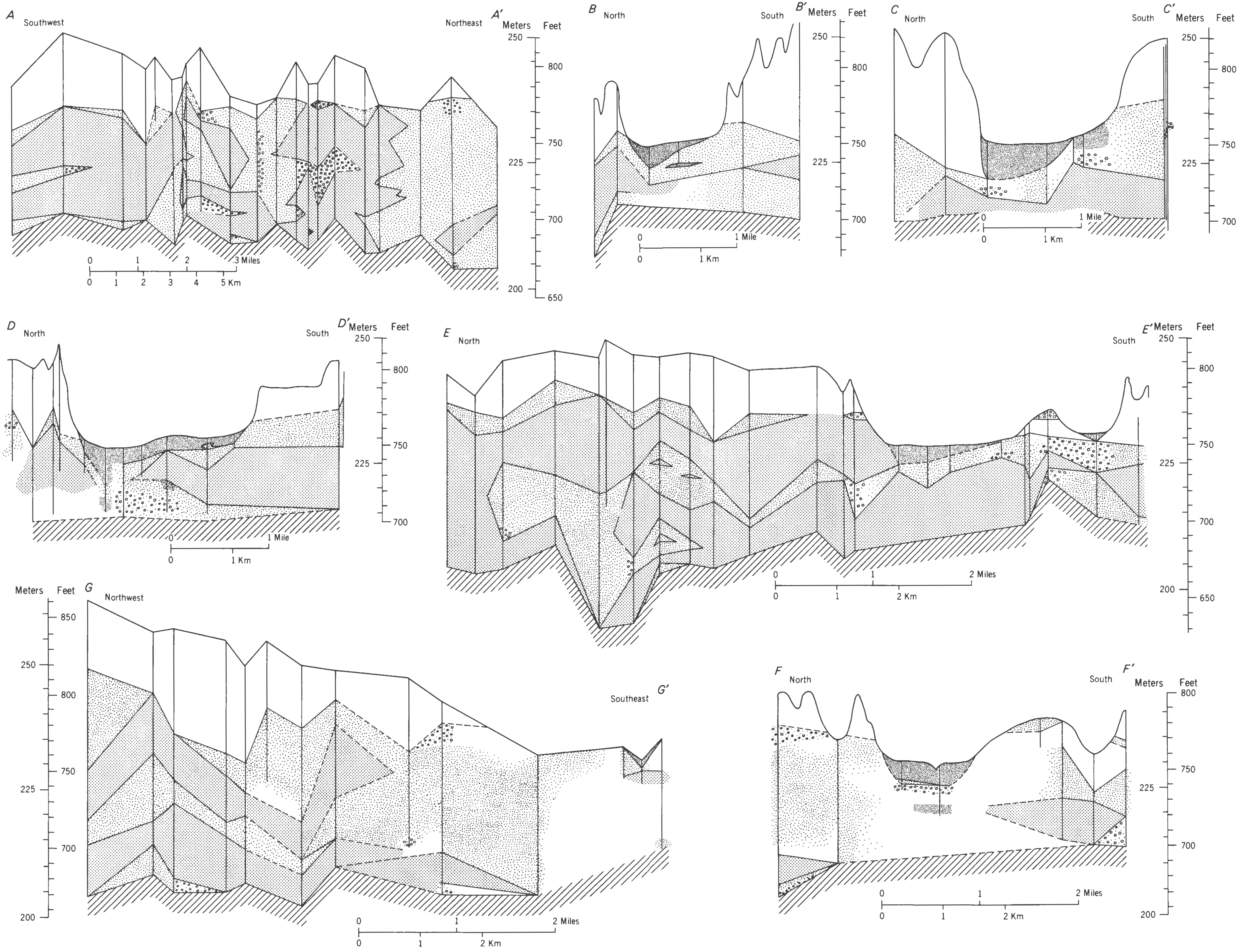
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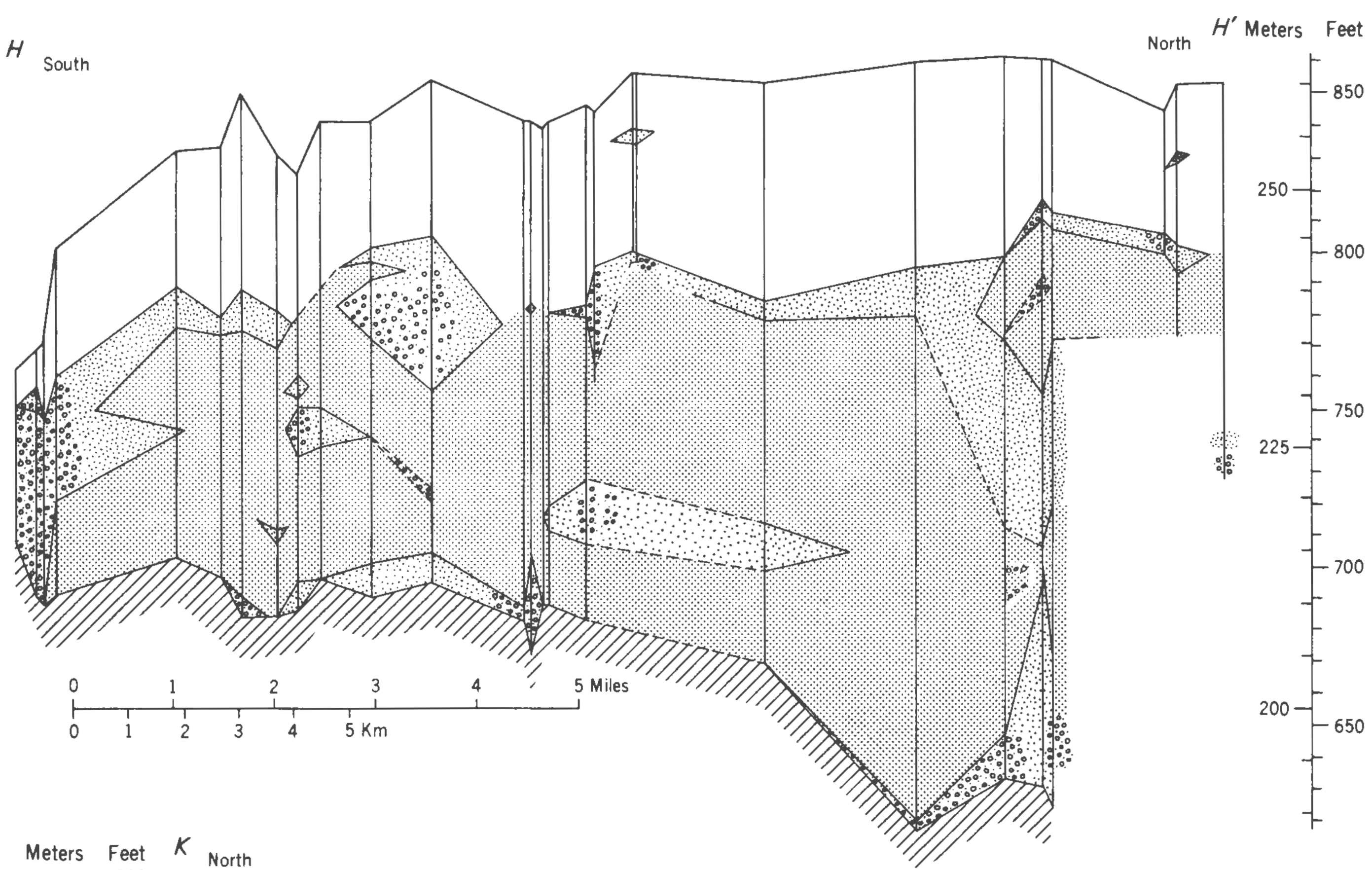
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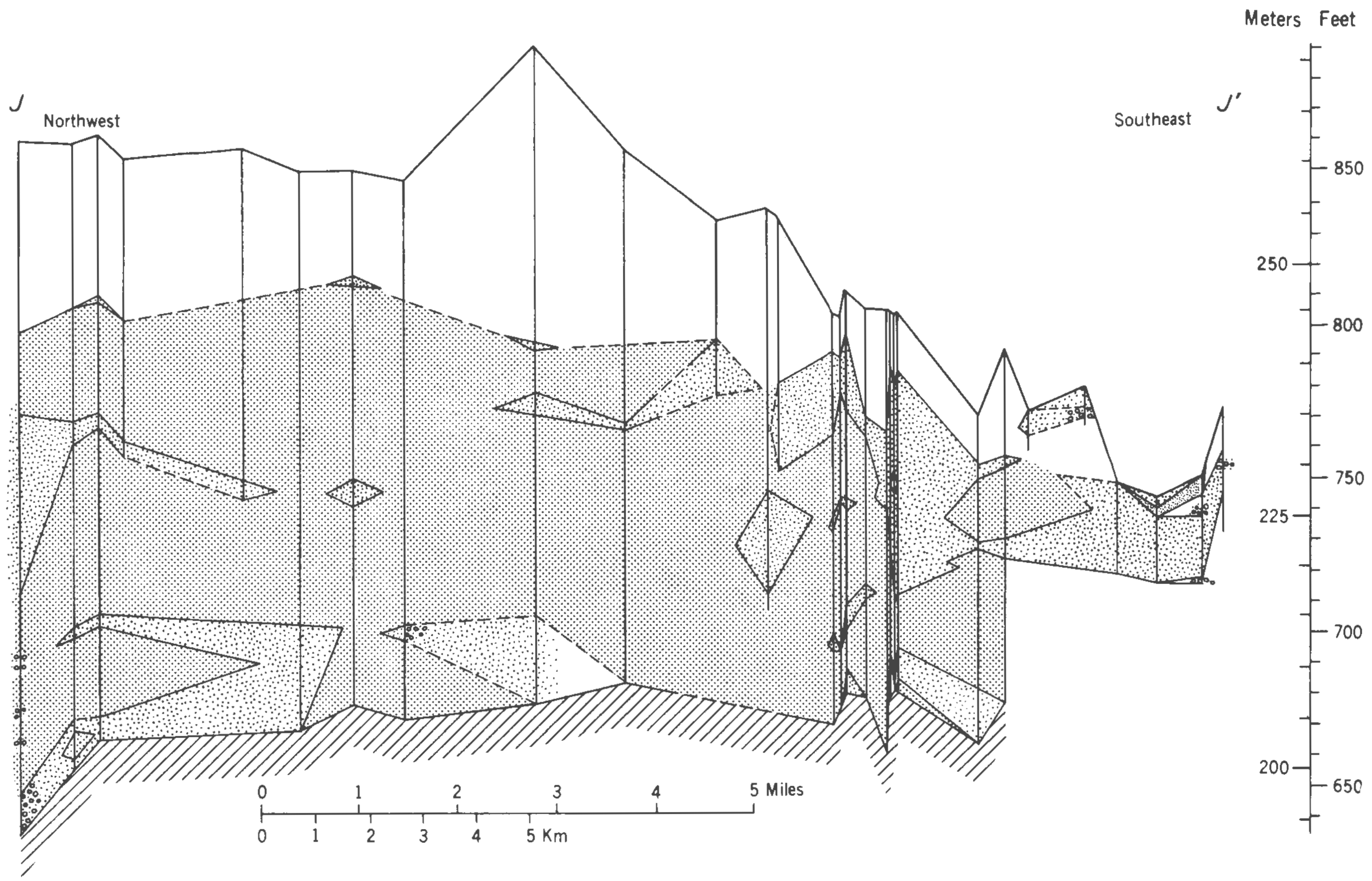
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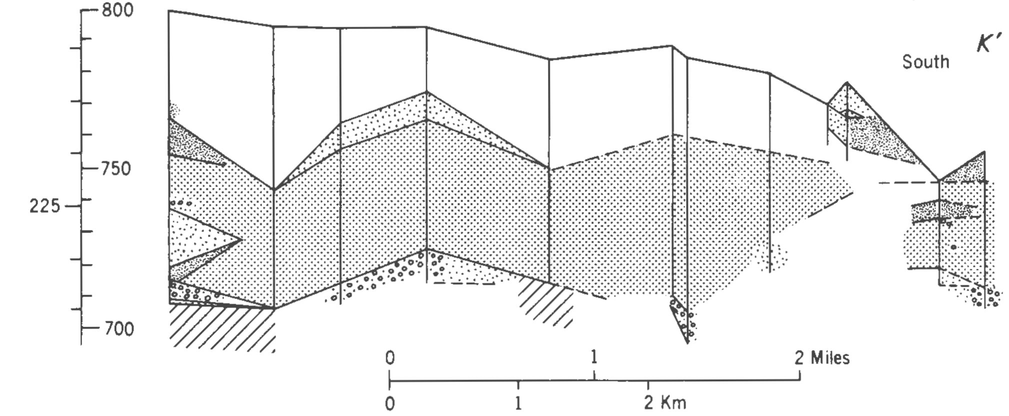
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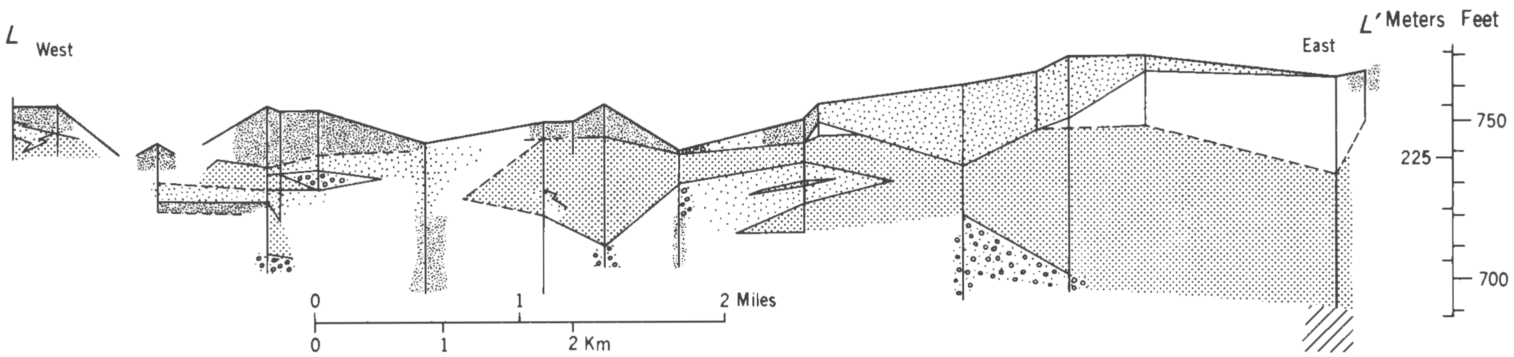
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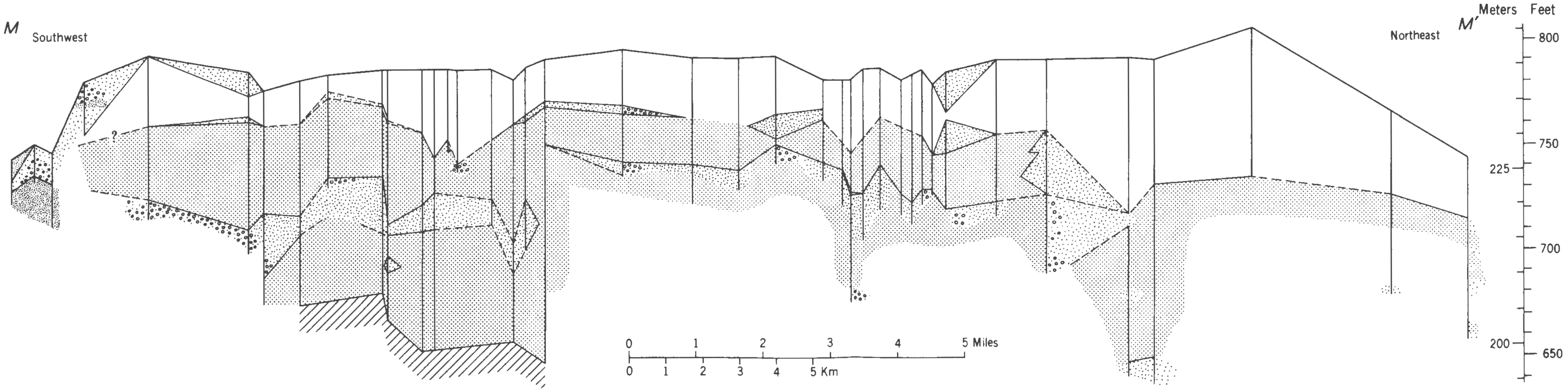
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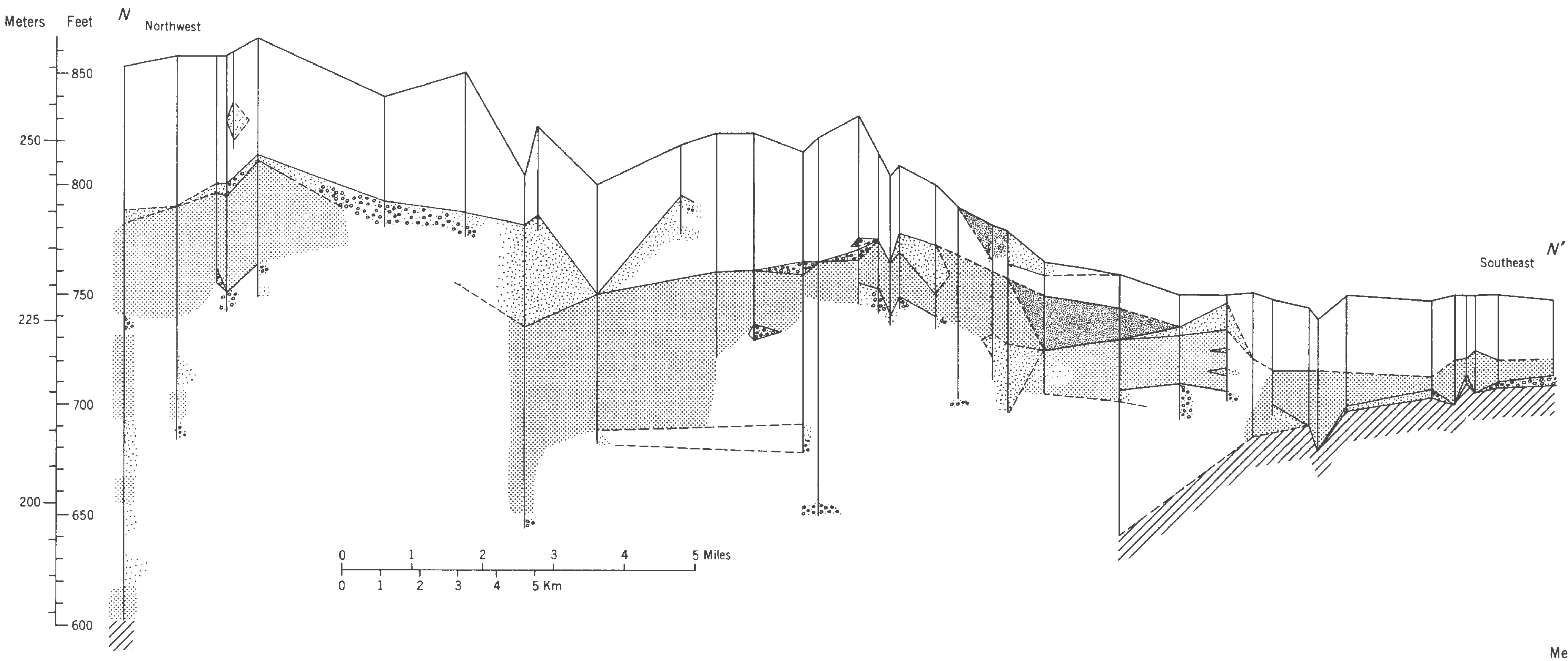
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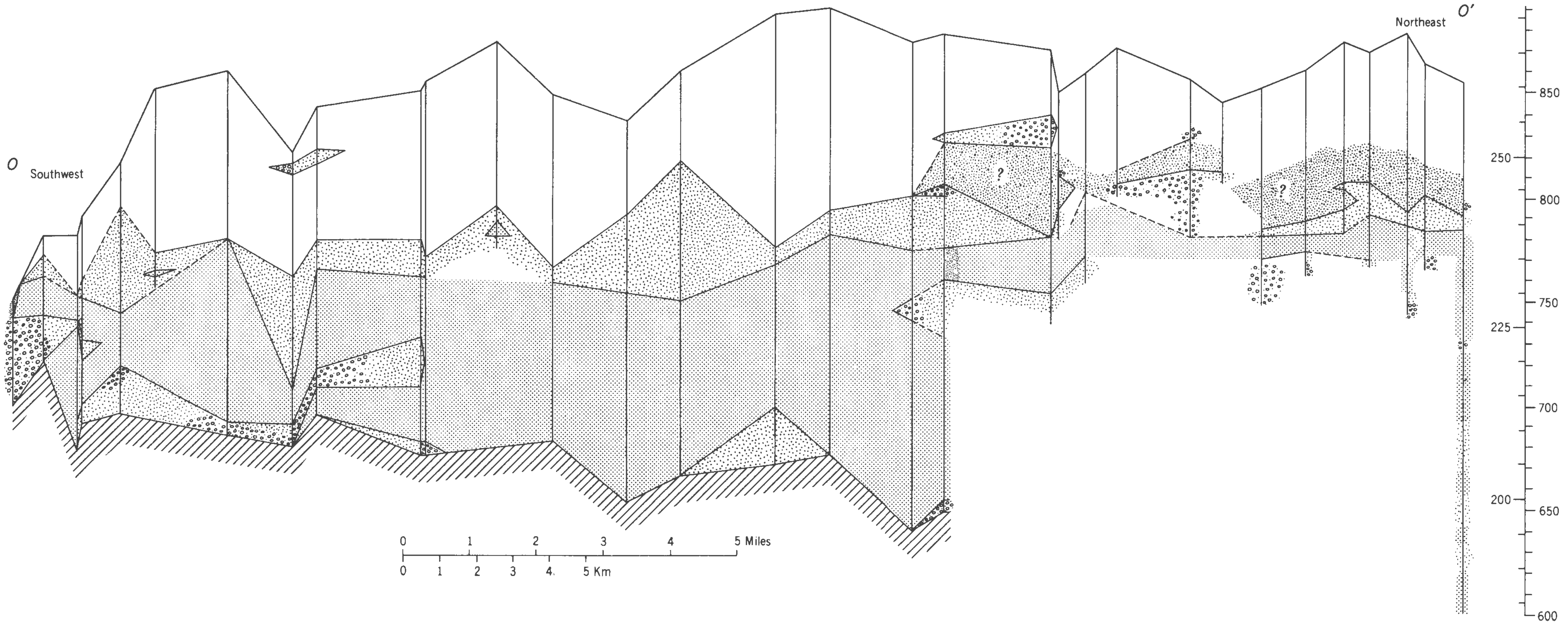
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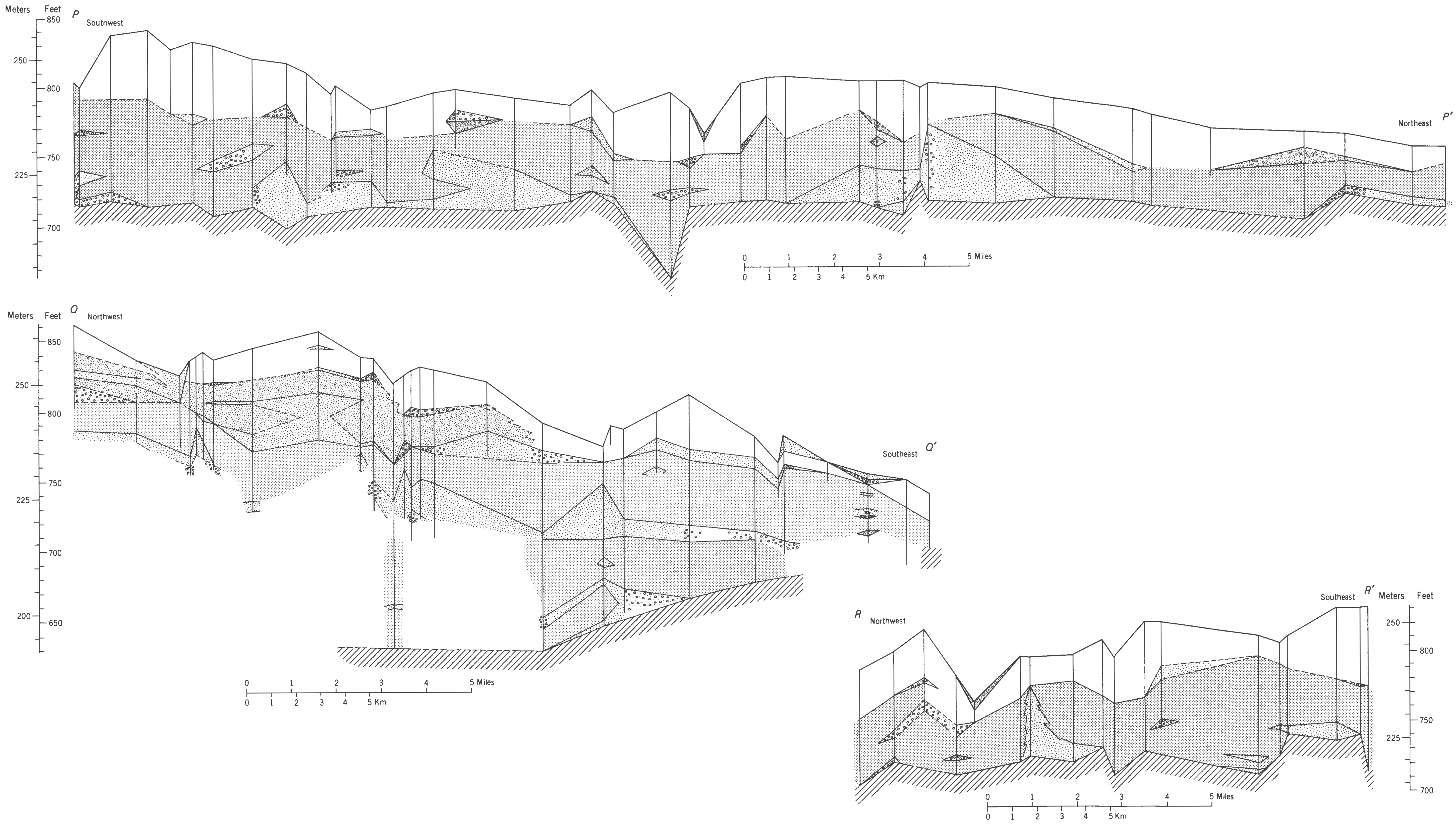
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