1975

Urban Geology of Madison County, Indiana: Special Report 10

William J. Wayne
University of Nebraska-Lincoln, wwayne3@unl.edu

Wayne—URBAN GEOLOGY OF MADISON COUNTY, INDIANA   Indiana Geological Survey   Special Report 10

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Special Report 10

State of Indiana
Department of Natural Resources
GEOLOGICAL SURVEY

Urban Geology of Madison County Indiana

By WILLIAM J. WAYNE

ENVIRONMENTAL STUDY 7

DEPARTMENT OF NATURAL RESOURCES
GEOLOGICAL SURVEY SPECIAL REPORT 10

PRINTED BY AUTHORITY OF THE STATE OF INDIANA
BLOOMINGTON, INDIANA: 1975

STATE OF INDIANA
Otis R. Bowen, *Governor*
DEPARTMENT OF NATURAL RESOURCES
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For sale by Geological Survey, Bloomington, Ind. 47401
Price $1.25

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Urban Geology of Madison County, Indiana

By WILLIAM J. WAYNE [1]

Introduction

During recent years many of the population centers of Indiana have undergone growth that has resulted in expansion of urban uses into land that has been largely rural. As a result of that expansion, conflicts have arisen between expanding urban uses and the agricultural and mineral resource uses of land that lies near the centers of population. In addition, uncontrolled use of flood plains, steep slopes, and areas of soft sediments and high water tables has caused inconvenience and financial loss to individuals and industries that unknowingly have built structures in those places. Generally, these situations have developed as a result of a lack of information or understanding about the geologic materials or processes that exist in the area involved.

PURPOSE OF REPORT

This report was prepared to bring together information on the geologic features of Madison County, Ind., that are likely to affect the urban development of land in the county. Information of this kind is of greatest value in areas where land use is changing, because as the population density of a developing community increases, all factors likely to limit the most effective use of the land must be considered in preparing comprehensive planning studies and ordinances (Wayne, 1969). The information in this report is intended to serve as a guide in land use planning and engineering planning but is not sufficiently detailed to replace specific site evaluation studies.

SOURCES OF DATA

The surficial geologic map (pl. 1) and bedrock map (fig. 2) were prepared from a set of U.S. Geological Survey topographic maps, scale 1:24,000, on which geologic contacts had been drawn for compilation of the Muncie and Cincinnati sheets in the Regional Geologic Map series of the Indiana Geological Survey (Burger and others, 1971; Gray and others, 1972). Fieldwork for the Madison County study was done by William J. Wayne in 1950, 1952, 1953, 1967, and 1968. Aerial photographs were used extensively in the mapping.

The map showing thickness of glacial drift (fig. 3) was prepared from water well data and seismic records and represents revision of both data and interpretation from published reports (Wayne, 1956; Burger, Keller, and Wayne, 1966).

To present information about the geologic materials and resources in a form that might be readily usable in land use planning, interpretive maps have been prepared to show prospective mineral resource areas, groundwater sources, solid-waste disposal areas, and areas of hazardous construction conditions. All of these interpretive maps have been produced from the surficial geologic map, the bedrock geologic map, and the map showing thickness of glacial materials.

Although some aspects of the geology of Madison County have been presented in several regional geologic reports, the only existing review of the geology of the county as a whole was prepared more than three-quarters of a century ago (Brown, 1884). Most of that report now has little more than historical value.

Descriptive studies of the Silurian and Devonian rocks that underlie the cover of glacial drift and that crop out in a few places were presented by Cumings and Shrock (1928), Shaver and others (1961), Pinsak and Shaver (1964), and Kindle (1901). The glacial deposits were reviewed by Leverett and Taylor (1915) and Wayne (1956, 1963, and 1968). The water supply of the county was the subject of reports by Capps (1910), Biggs and Wayne (1953), and Steen (1970). A recent soil study provided extensive and detailed information on the soils of the county and on their capabilities (Schermerhorn and others, 1967).

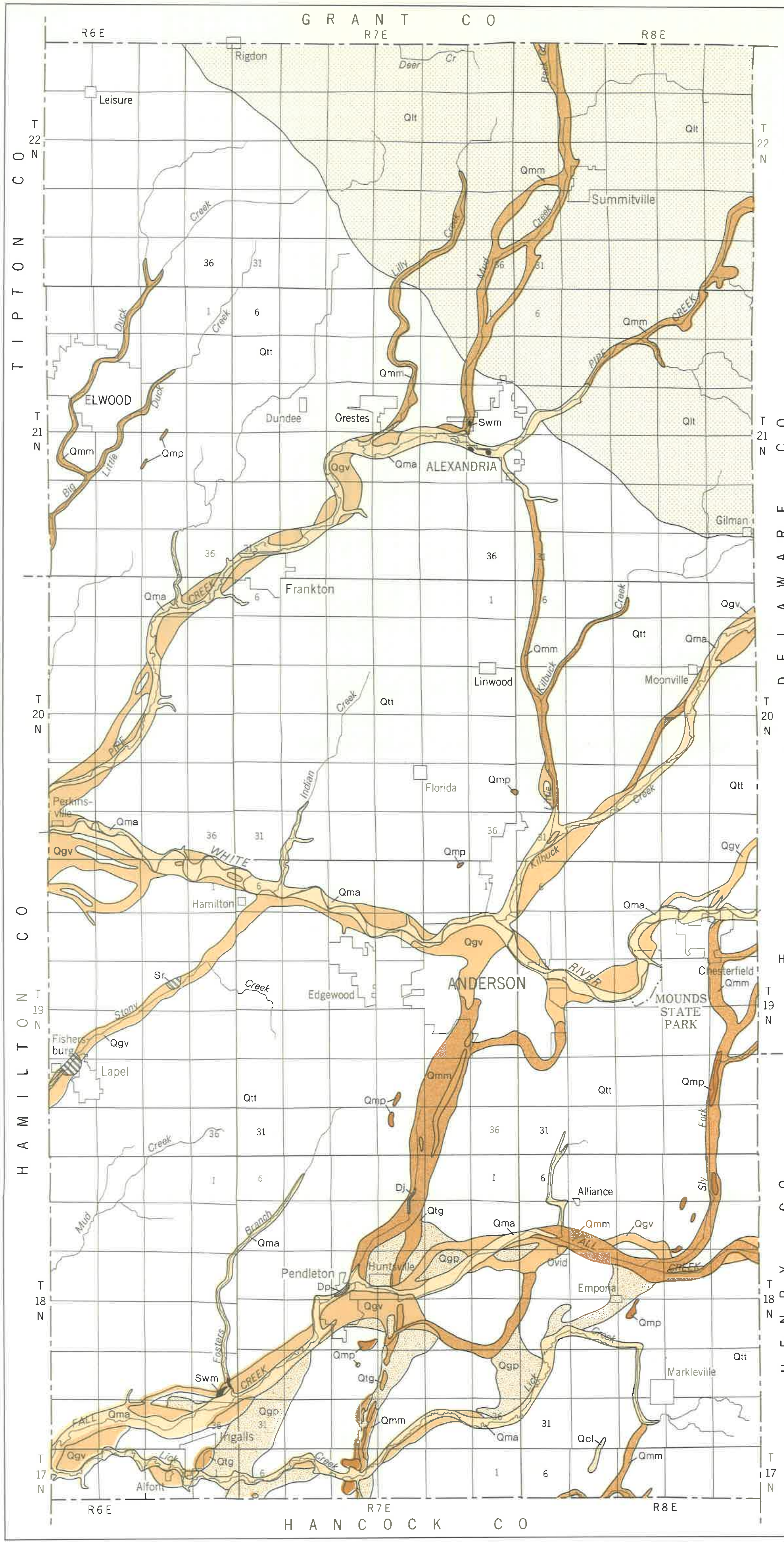
Physical Features of the Land

Madison County is in the part of Indiana that was blanketed with glacial drift, so that the present landforms are wholly a result of glacial deposition except for the relatively minor erosion that has taken place since the ice sheet melted. This part of Indiana, in

[1] Professor of geology, University of Nebraska, Lincoln.

ERAS	PERIODS	APPROXIMATE LENGTH IN YEARS	ROCK TYPES IN INDIANA	PRINCIPAL MINERAL PRODUCTS
CENOZOIC	QUATERNARY (PLEISTOCENE EPOCH)	1 MILLION	*Glacial drift: till, gravel, sand, silt (including loess), clay, marl, and peat (Till and gravel contain boulders of many kinds of sedimentary, igneous, and metamorphic rocks)* Thickness 0 - 500 ft	*Sand and gravel Clay Marl Peat Ground water*
CENOZOIC	TERTIARY	60 MILLION	*Cherty gravels, Sand and clay* } *Scattered deposits* 0-80 ft	*Glass sand*
MESOZOIC	CRETACEOUS JURASSIC TRIASSIC	70 MILLION 35 MILLION 30 MILLION	No deposits in Indiana	
PALEOZOIC	PERMIAN	25 MILLION	No deposits in Indiana	
PALEOZOIC	PENNSYLVANIAN	20 MILLION	*Shale (including carbonaceous shale), mudstone, sandstone, coal, clay, limestone, and conglomerate* 1,500 ft	*Coal Ceramic clay, shale Oil and gas Crushed stone Building sandstone Refractory gravel*
PALEOZOIC	MISSISSIPPIAN	20 MILLION	Upper Part: *alternating beds of shale, sandstone, and limestone* 500 ft Middle Part: *limestone, dolomite; beds of chert and gypsum* 300 ft Lower Part: *shale, mudstone, sandstone; and some limestone* 600 ft	*Oil and gas Building limestone Crushed stone Gypsum Ceramic shale*
PALEOZOIC	DEVONIAN	60 MILLION	Upper Part: *carbonaceous shale* 100 ft Lower Part: *limestone, dolomite; a few sandstone beds* 40 - 80 ft	*Oil and gas Crushed stone*
PALEOZOIC	SILURIAN	40 MILLION	*Dolomite, limestone, chert, siltstone, and shale* 100 - 300 ft	*Crushed stone*
PALEOZOIC	ORDOVICIAN	70 MILLION	*Shale, limestone, and dolomite* 700 ft *Limestone, dolomite, and sandstone* } Not exposed at the surface in Indiana	*Crushed stone Oil and gas*
PALEOZOIC	CAMBRIAN	80 MILLION	*Sandstone and dolomite* } Not exposed at the surface in Indiana	
PRECAMBRIAN ERAS		3 BILLION	*Granite, marble, gneiss, and other igneous and metamorphic rock types* } Not exposed at the surface in Indiana	

Figure 1. General geologic time scale and rock chart for Indiana.



EXPLANATION

MARTINSVILLE FORMATION

Qma — Alluvial sand, silt, and gravel
Flood-plain deposits

Qmm — Colluvial silt, clay, and muck overlying gravel or till

Qmp — Paludal muck, peat, and marl

ATHERTON FORMATION

Qcl — Silt and clay of Pleistocene lakes

Qgv — Sand and gravel
Valley train deposits

Qgp — Gravelly sand
Outwash plain deposits

LAGRO FORMATION

Qlt — Till
Silty and clayey; almost impermeable

TRAFALGAR FORMATION

Qtg — Gravel and sand of kames and eskers

Qtt — Till
Silty and sandy; permeability slow to moderate

Dj — Jeffersonville Limestone
Dolomite, dark gray to light yellowish-brown; medium bedded

Dp — Pendleton Sandstone
Sandstone, medium grained, white; medium to thick bedded, massive

Swm — Mississinewa Shale Member, Wabash Formation
Siltstone, calcareous and dolomitic limestone

Sr — Huntington Lithofacies (reef facies), Wabash Formation
Dolomite, thick bedded. Bedding planes dip away from central unbedded core

INDEX MAP SHOWING LOCATION OF MADISON COUNTY

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

TOWNSHIP DIAGRAM

SURFICIAL GEOLOGY MAP OF MADISON COUNTY, INDIANA

Compiled by William J. Wayne, 1968.
Drafted by Roger L. Purcell.

which the underlying bedrock formations exert virtually no effect on the present topography, is called the Tipton Till Plain (Malott, 1922, p. 104).

Most of the surface of Madison County is a flat to gently rolling plain that is crossed from east to west by Fall Creek, White River, and Pipe Creek and from north to south by a series of shallow troughs, most of which are no longer occupied by streams. One end moraine crosses the northeastern part of the county. Called the Union City Moraine, it is a low, glacially formed ridge that rises only about 30 feet above the till plain to the south. Alexandria is along the southwest edge of the moraine, and Summitville stands on the crest.

Although the interstream areas of the southern four-fifths of Madison County can be characterized as a nearly level plain, many small relief features are present on it. Isolated patches of undulating topography can be found at many places in the county, but none of them are part of a recognizable end moraine. Most of the undulating patches resulted from irregular deposition by glacial ice and by streams of meltwater that flowed across and under the melting ice mass. The esker system at Anderson, in particular, is a discontinuous gravel ridge that begins at the south edge of Anderson and can be traced southward across Fall Creek into Hancock County (pl. 1).

In spite of the level appearance of much of the landscape, the total relief in Madison County is 225 feet. The highest land in the county is in the southeast corner and is slightly more than 1,010 feet above sea level; the lowest point, where White River enters Hamilton County, is about 785 feet in altitude. The maximum local relief is at Mounds State Park, where White River is about 835 feet, and the upland 1,000 feet to the south rises slightly above 920 feet, a difference of 85 feet.

Geologic (Stratigraphic) Units

Although most of the materials that lie directly beneath the surface in Madison County are unconsolidated sediments of Quaternary (Pleistocene) age (pl. 1), bedrock stratigraphic units that range in age from Ordovician through Silurian to Devonian are at the surface in a few places and underlie the unconsolidated sediments (figs. 1 and 2). The dip of the rocks is so slight that it is scarcely perceptible—about 20 feet to the mile. The variation in the depth to bedrock is the result of relief on the bedrock surface and is reflected in the thickness of glacial drift (fig. 3).

ORDOVICIAN ROCKS

The oldest rocks that underlie sediments of the Ice Age of Madison County are dark-gray to pale greenish-gray shale that is part of the Ordovician System (fig. 2; table 1). The top of the shale is about 250 feet beneath the present surface; it is the first bedrock penetrated in drilling along buried valleys where the glacial drift is thickest. The shale is known only from well records, and knowledge of its distribution at the bedrock surface is based on the interpretive map showing thickness of glacial drift (fig. 3).

SILURIAN ROCKS

Silurian limestones and dolomites more than 250 feet thick overlie the Ordovician shale and comprise the bedrock that lies beneath the glacial drift in most of Madison County. These rocks reach the surface at several places in the county where glacial or postglacial erosion has removed the drift, and they lie within 25 feet of the present surface in about 30 square miles, or 7 percent of the area of the county (fig. 3).

WABASH FORMATION: The Wabash Formation (Pinsak and Shaver, 1964) is the only Silurian rock unit exposed in Madison County, but others lie just beneath the drift cover. The Wabash Formation has two members that are identifiable in Madison County. The upper one, the Liston Creek Limestone Member, is a thin-bedded cherty limestone present only in the southwestern part of the county. It is exposed in a few places along Fall Creek below Pendleton, including the reformatory quarry.

The lower part of the Wabash Formation, the Mississinewa Shale Member, is a massive gray calcareous to dolomitic siltstone that lies beneath the glacial drift throughout much of the county. It was once quarried at Alexandria for use in manufacturing mineral wool. In central Madison County the Mississinewa contains many layers of thin- to medium-bedded limestone interbedded with the more typical calcareous siltstone or shale. The limestone beds were once quarried at Anderson, near Frankton, and along White River west of Hamilton for foundation blocks.

The Silurian rocks of northern Indiana are well known to geologists because they contain the lithified remains of ancient organic reefs. Most of the reefs are roughly circular in plan, the central part of which is a massive unbedded core of dolomite. Thick flank beds of fossil-fragmental dolomite or limestone slope in all directions away from the core and pinch out or thin greatly where they merge with the horizontally bedded limestones and shales between the reefs.

The reef rock is massive and resistant to erosion; therefore, many reefs remained on the interstream

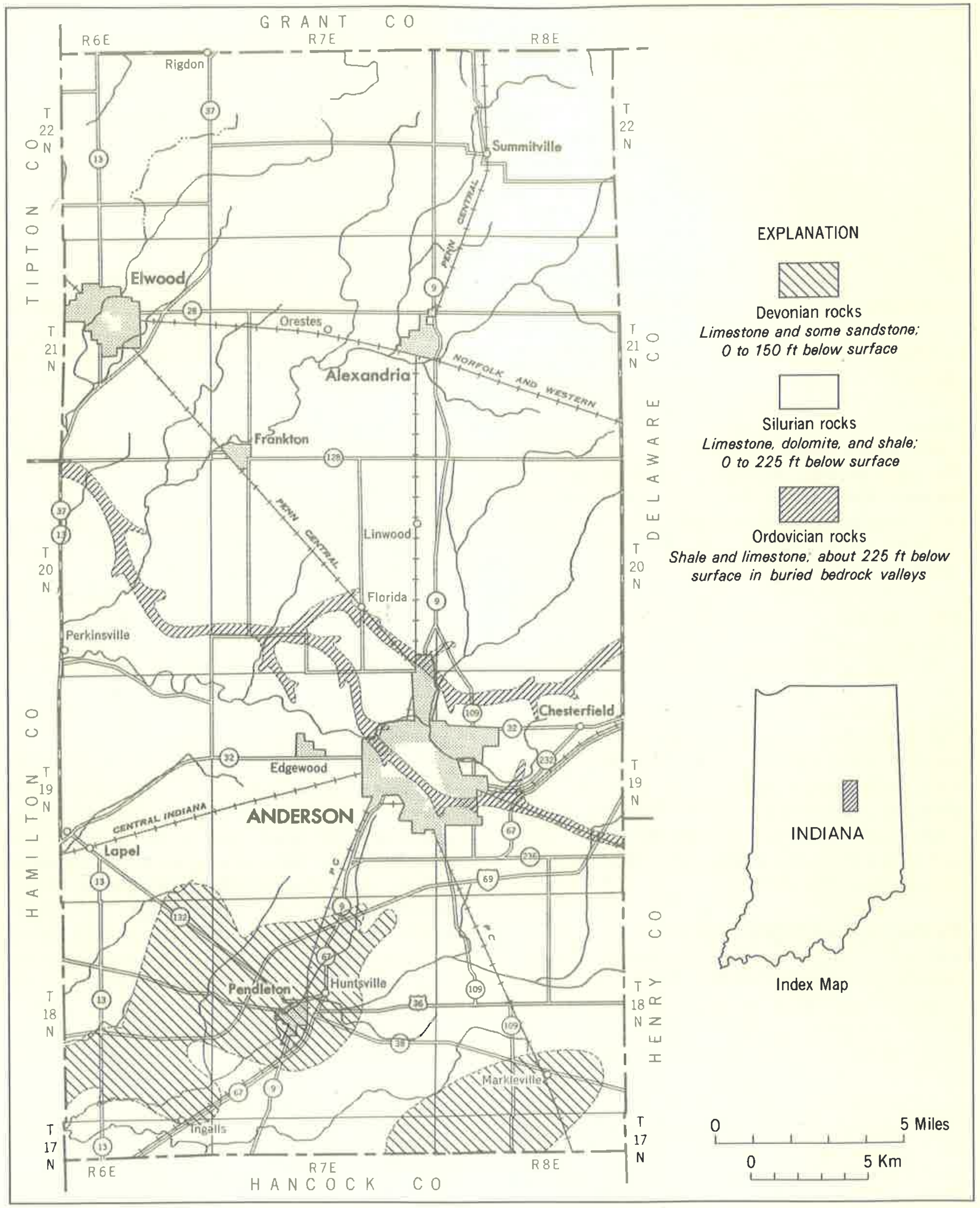


Figure 2. Bedrock geology of Madison County. Geologic contacts from Burger and others, 1971, and Gray and others, 1972.

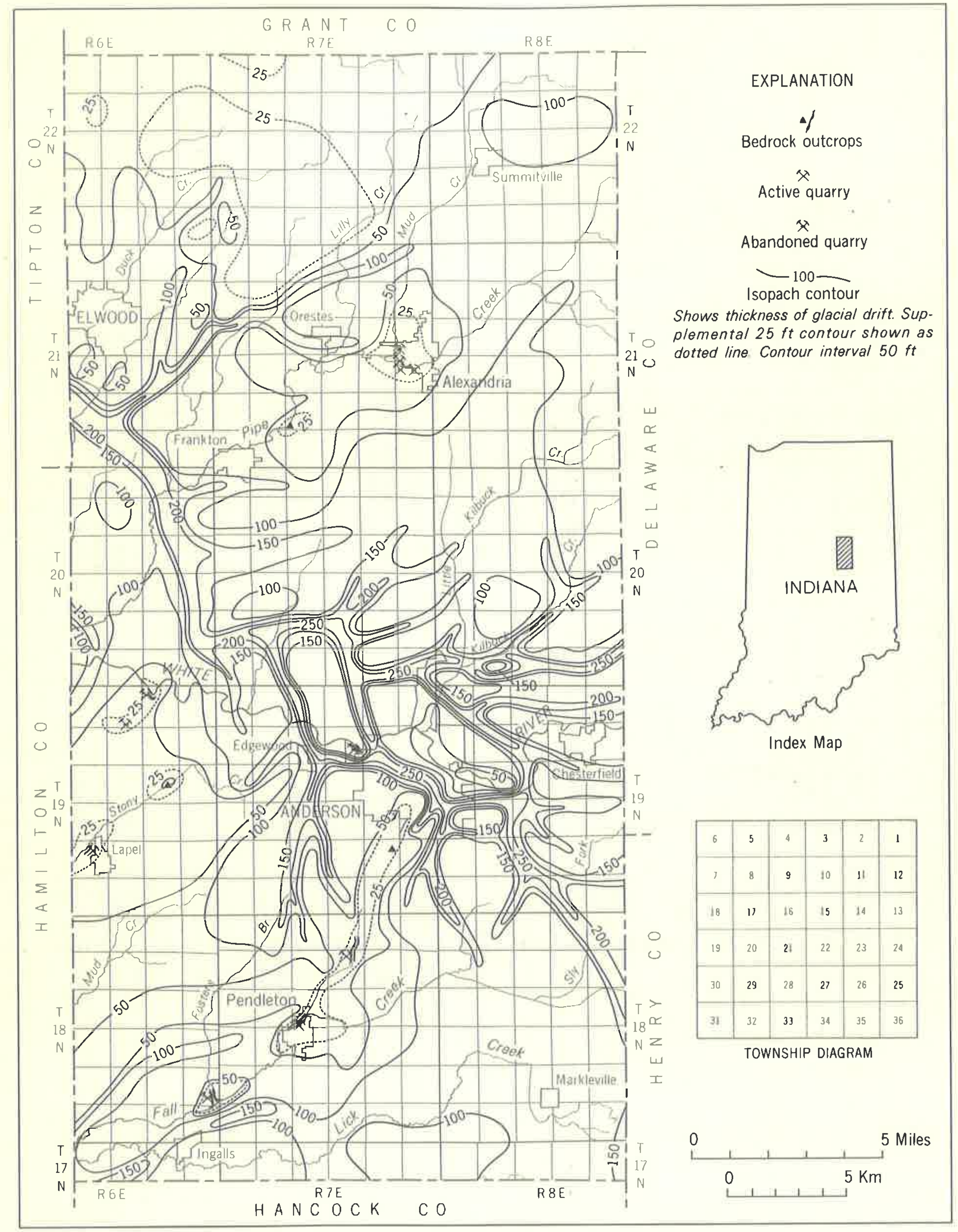


Figure 3. Thickness of glacial drift in Madison County.

Table 1. Characteristics of rock units in Madison County

Rock unit	Map symbol	Lithology, thickness	Topography	Groundwater characteristics	Economic value	
Martinsville Formation	Qma	Silt, sand, and gravel, 3 to 30 ft	Flood plain, level	Saturated at shallow depth	Sand and gravel in some	Flood susceptible, high water table, low bearing strength
	Qgm	Muck or clay, 3 to 10 ft, over gray sand or clay	Floors of streamless or ditched valleys	Saturated at shallow depth	Sand and gravel in some	Flood susceptible, high water table, low bearing strength
	Qmp	Muck over peat or marl, 5 to 30 ft	Depressions	Water table at or near surface	Peat, marl	Flood susceptible, high water table, low bearing strength
Atherton Formation	Qcl	Clay, silt, or fine sand, 5 to 20 ft	Flat, poorly drained	Aquitard		
	Qgv	Sand and gravel, as much as 50 ft	Generally level, well drained	Aquifer where below water table; recharge area	Sand, gravel	
	Qgp	Sand and gravelly sand, generally as much as 20 ft	Level to rolling, well drained	Very shallow aquifer; good recharge area	Sand, gravel	
Lagro Formation	Qlt	Clayey silt or silty clay, slightly pebbly (till), as much as 30 ft	Gently rolling to nearly flat	Aquitard	Weathered zone has been used for clay tile manufacture; stable for foundations of most structures	
Trafalgar Formation	Qtk	Bouldery gravel, as much as 40 ft	Hills, ridges, slopes (kames, eskers)	Permeable, generally above water table	Sand, gravel	Stable for foundations
	Qtt	Till, sandy, pebbly, silty, as much as 100 ft	Flat to gently rolling, locally steep	Slowly permeable		Stable for foundations
Jeffersonville Limestone	Di	Dolomite, medium bedded, as much as 25 ft present		Aquifer, shallow, probably subject to contamination	Dolomite for aggregate and agricultural stone	
Pendleton Sandstone	Dp	Sandstone, white, well cemented to friable, lenticular, 0 to 15 ft		Aquifer, too local to be of importance	Formerly used for dimension stone; too local to be developed again	
Wabash Formation: Liston Creek Limestone Member		Dolomitic limestone, cherty, thin bedded, as much as 30 ft?		Aquifer, present only in southwest corner of county	Formerly used for aggregate (Pendleton)	
Wabash Formation: Mississinewa Shale Member	Swm	Siltstone, dolomitic or calcareous, massive but containing thin limestone beds, 100 ft		Weak aquifer	Formerly used for mineral wool at Alexandria, foundation stone at Anderson	
Wabash Formation: Huntington Lithofacies	Sr	Dolomite and limestone, thick bedded to massive; thickness variable to 100 ft		Aquifer, too local to be of importance	Aggregate and agricultural stone (Lapel)	
Louisville Limestone Waldron Formation		Dolomite and dolomitic limestone, thin to medium bedded, cherty, 60 to 75 ft	No surface outcrops	Aquifer, moderate to good	Used for aggregate and agricultural stone where exposed at Muncie	
Salamonie Dolomite		Dolomite, sugary textured, medium to thick bedded, 90 to 120 ft	No surface outcrops	Aquifer, moderate to good	Used for aggregate where exposed east of Muncie	
Ordovician rocks		Shale, gray to gray green; limestone partings	No surface outcrops	Aquitard		

areas of the preglacial land surface and now protrude through the glacial drift cover. Because of their accessibility as well as the physical properties of the rock in them, they have been used extensively for crushed limestone. Only a few reefs are known to crop out in Madison County and one of them, at Lapel, has been worked for crushed limestone for many decades.

LOUISVILLE LIMESTONE, WALDRON FORMATION, AND SALAMONIE DOLOMITE: Underlying both the reefs and the Mississinewa shale is a sequence of medium-bedded dolomites that includes the Louisville Limestone, the Waldron Formation, and the Salamonie Dolomite. All these rocks are light gray to white, hard, and porous and are likely to look sugary. Total thickness of these units is about 150 feet. The upper part of the sequence is exposed in the base of the quarry at Lapel; elsewhere these rocks do not reach the present surface in the county, but they are overlain only by glacial drift along all the buried valleys in the county.

DEVONIAN ROCKS

A thin plate of rocks of middle Devonian age caps the thick Silurian section in the southern part of Madison County. Exposed only along Fall Creek at Pendleton and in the bottom of the ditch that now parallels State Highway 67 north of Pendleton, the total section of Devonian rocks is only 30 to 40 feet thick. It consists of a basal sandstone and an overlying dolomite.

JEFFERSONVILLE LIMESTONE: The Jeffersonville Limestone in Madison County consists of about 25 feet of dolomite that is medium bedded and dark gray to light yellowish brown. The dolomite crops out above the lip of the falls in Falls Park in Pendleton, in the bed of Fall Creek above Pendleton, and in the bank of the drainage ditch north of Huntsville. About 20 feet of Jeffersonville dolomite is exposed in a quarry opened in 1967 about 2 miles north of Pendleton.

PENDLETON SANDSTONE: The lowermost rock unit of the Devonian section in Madison County is a medium-grained thick-bedded white sandstone. It is moderately well cemented to poorly cemented. Its thick beds and homogeneous characteristics cause it to form massive ledges where it is exposed at the falls of Fall Creek in Pendleton. The Pendleton Sandstone exists only as lenses beneath the Jeffersonville Limestone in central Indiana. Orr and Pierce (1973, p. 328-329) described it as a very fine-grained sandstone with dolomite cement.

The only known outcrop is the type section at Falls Park in Pendleton, where it was once quarried for building stone. Foundation blocks of bridges and buildings and some sidewalk paving slabs that came from the Pendleton quarry can still be seen in Pendleton and Anderson.

The Pendleton Sandstone evidently is present only in southwestern Madison County and perhaps in eastern Hamilton County. It has been encountered in a few wells drilled in that area. Where the Pendleton is absent, dolomite of the Jeffersonville lies directly on Silurian rocks.

The Silurian and Devonian rocks in Madison County are well indurated, and their excavation requires blasting. The limestones and dolomites stand well in their resistance to weathering processes. The siltstone facies of the Mississinewa Shale Member, however, is soft and weathers readily on exposure to flakes of calcareous siltstone. Bearing strength of all the rocks is high.

BEDROCK SURFACE

During the many millions of years that elapsed after the older rocks were deposited, streams eroded the surface. When glaciers first covered Madison County during the Pleistocene Epoch (or Ice Age), rivers had cut trenches as much as 300 feet below the limestone plain. Solution openings, including sinkholes and caverns, undoubtedly existed, but little is known about their abundance or distribution beneath the drift cover. Occasionally a water well driller reports having drilled into a cave, and a small one was exposed in a quarry a few miles to the east in Delaware County; thus, the presence of caverns should be suspected in Madison County, particularly near the buried valleys.

Because of the relatively flat surface of the till plain, the shape of the bedrock surface is reflected in a map showing thickness of glacial drift (fig. 3).

QUATERNARY (PLEISTOCENE) SEDIMENTS

The trenched limestone plain of Madison County was covered by at least three ice sheets, named in order, from oldest to youngest, the Kansan, Illinoian, and Wisconsinan. The ice-laid sediments and water-laid sediments derived from them have been grouped into stratigraphic units for mapping and discussion (Wayne, 1963).

JESSUP FORMATION: The Jessup Formation is till, an uncemented but tough and compact mixture of clay, silt, sand, and coarser rock fragments. It is not exposed at the surface in Madison County but has been encountered in wells. It is difficult to distinguish from overlying and younger tills, however, except where the weathered surface has been preserved.

TRAFALGAR FORMATION: Unweathered till of the Trafalgar Formation, shown on the geologic map (pl. 1) as *Qtt*, is a sandy and slightly clayey silty till. The Trafalgar Formation, Wisconsinan in age, has been leached of carbonates to a depth of 2 to 4 feet. The clay-enriched zone of the soil profile (B horizon of soil science terminology) is only slowly permeable, so that after heavy rains it is common for water to stand on the surface for several days. The unweathered till below the clayey soil profile is somewhat more permeable, although water passes through it fairly slowly, too.

Thickness of the Trafalgar Formation is variable. The formation consists of two or more till beds, and in some places beds or lenses of sand and gravel are intercalated. Total thickness of Trafalgar tills plus fluviatile materials may be as much as 150 feet.

Glacial drainage lines have removed the till cover in some places, thereby exposing the underlying gravel. Where it has not been removed or thinned, the upper till is generally about 30 feet thick.

The compact tills of the Trafalgar Formation have been prestressed by glacier ice; the pressures that they have undergone beneath the overriding glacier range from as low as 7 or 8 tons per square foot to about 48 tons per square foot (Harrison, 1958). Thus, the compressive strength of these tills is great enough to support most structures. Throughout much of the county, however, the uppermost few feet of the till was deposited with little or no prestressing, so that the compressive strength of this part of the till is much lower, probably not exceeding 3 or 4 tons per square foot. All the tills are rippable and do not require blasting for excavation.

TRAFALGAR FORMATION, KAME FACIES: Some of the upland gravel deposits in Madison County were at least partly deposited in subglacial tunnels; thus they are not as well sorted as other glaciofluviatile sediments. A linear ridge along the east side of the trough drained by Prairie Creek and its continuation southward through Huntsville and across Lick Creek is the only area so mapped (pl. 1, map unit *Qtg*) in the county. This unit is generally gravel and sand but characteristically contains large boulders of local bedrock and is likely to contain masses or lenses of till. Generally it stands as a ridge well above the surrounding topography and therefore tends to be well drained.

LAGRO FORMATION: The surface material in northeastern Madison County is a till mapped as the Lagro Formation (pl. 1, map unit *Qlt*). It overlies the Trafalgar Formation and is distinct from it in that it is much less bouldery and sandy but richer in clay. The Lagro ranges in thickness from a feather edge to more than 30 feet.

Because it is much richer in clay than the Trafalgar tills, the Lagro tends to be considerably less permeable. Runoff has produced a network of small drainage lines, and a smaller percentage of the precipitation infiltrates the Lagro till than infiltrates the tills in the rest of the county. The soil profile is thin; carbonates are generally leached from only the upper 2 to 3 feet. The clay-enriched subsoil (B horizon) is typically dark brown. Texture of the unweathered till is blocky, and it breaks readily into small subcubic fragments when moist. It is dark gray to olive gray.

ATHERTON FORMATION: Most of the water-laid sediments in Indiana that were deposited by glacial meltwater have been mapped as the Atherton Formation. Coarse-grained sediments (gravel and sand) have been designated the *outwash* facies; fine-grained sediments (silt and clay) are the *lacustrine* facies. Two other facies, both wind deposits, exist but are not extensive enough in Madison County to have been mapped.

Most of the outwash facies of the Atherton at the surface in Madison County is along Pipe Creek, White River, Kilbuck Creek, and Fall Creek, but broad outwash plains that drained toward the south and southwest and that are not yet dissected by surface streams are south of Fall Creek (pl. 1).

Outwash facies of the Atherton is also present as thick lenticular beds between the Trafalgar tills. Most of the now-abandoned small gravel pits in the southern part of the county were opened where dissection along Fall Creek and its tributaries had stripped away the overlying till and exposed the gravel. Another similar gravel is still lower and is encountered regularly in water wells.

Many of the areas mapped as *Qgm* are underlain by gravels or sands of the Atherton Formation that are now buried beneath muck a few feet thick, but some of these areas are underlain by silts of the lacustrine facies of the Atherton Formation. Lacustrine facies silts and fine sands are also reported from the deeper parts of some buried valleys.

MARTINSVILLE FORMATION: In Madison County the deposits mapped as the Martinsville Formation are alluvial sands and silts and quiet water or swamp (paludal) deposits, muck, peat, and marl. The alluvial facies has been mapped along all the streams in the county that are subject to overflow (pl. 1, *Qma*). Its maximum thickness is probably 20 to 30 feet along White River.

Where muck a few feet thick overlies gravel, sand, or silt, and in a few places, till, the surface material is mapped as paludal facies (pl. 1, *Qmp*). Several small depressions in the county, particularly in the southern part, are filled with peat. Marl is present in depressions within some of the troughs that are mapped with a *Qmp* cover (pl. 1).

Mineral Resources[2]

The mineral industry of Madison County (1975) consists of four active sand and gravel operations and two established crushed stone quarries and processing plants (table 2), one small peat operation, and small sand and gravel pits that are opened on demand. The industry is oriented almost entirely to the supply of mineral aggregates for construction purposes. Crushed stone is produced for concrete aggregate, roadstone, railroad ballast, riprap, and agricultural limestone. Sand and gravel are produced for concrete aggregate, fill, road material, and other building purposes. The total value of all mineral materials taken from Madison County averaged about $2 million annually during the 3-year period 1968-70 (table 3).

Crushed stone, sand, and gravel are essential raw materials of the construction industry, and local sources of supply become even more necessary as increased population causes urban expansion. Mineral aggregates are mostly commodities of large volume and low unit value that cannot be transported far before the cost of haulage doubles or triples the plant price. To deliver their products at the lowest possible price, most companies attempt to establish operations as near as possible to the population centers. (See French, 1969, p. 348.)

[2]Part of the section "Mineral Resources" of this report was written by Robert R. French, geologist, Delhi Minerals, Adelaide, South Australia.

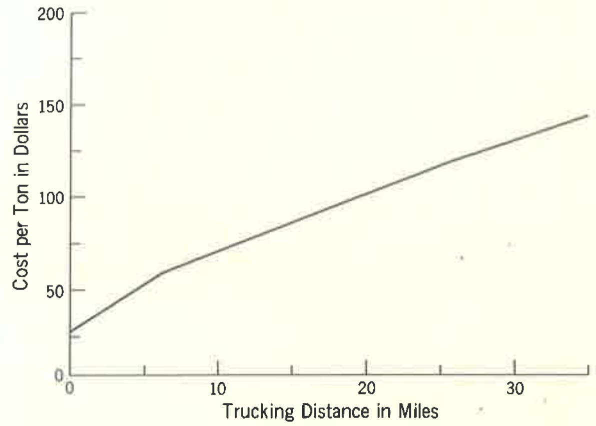


Figure 4. Graph showing approximate cost per ton-mile to haul crushed stone in Madison County in 1968.

A mineral resource is unique in that it can be removed only from those places where it has been concentrated naturally into commercially exploitable quantities. A knowledge of both those deposits that are currently being or have been exploited and those deposits that are potentially usable is important in land use planning studies. After urban uses have extended across an area underlain by a bulk mineral resource, it is no longer possible to develop that resource economically.

Figure 4 is a graph showing the cost of shipping stone in the Madison County area by a single commercial carrier in 1968. In addition to a 25 cents per ton base loading cost, a charge of 5 cents per ton-mile was made for the first 6 miles, 3 cents per ton-mile for the next 18 miles, and 2½ cents per ton-mile thereafter. If Madison County had not had local production, it would have been necessary to ship stone from the Noblesville (Hamilton County) or Muncie (Delaware County) areas. Stone delivered in

Table 2, Mineral producers in Madison County

Commodity	Producer	Address
Sand and gravel	Aggregates of Anderson	R.R. 2, Box 117, Anderson
	Myers Sand & Gravel Corp.	P.O. Box 212, Anderson
	Jerry Riddle Excavating Co., Inc.	R.R. 1, Box 240D, Anderson
	Western Materials Co.	P.O. Box 787, Anderson
Crushed stone	Anderson Rock Products, Inc.	P.O. Box 271, Anderson
	Martin Marietta Aggregates, Central Division	R.R. 1, Lapel
Peat	Filbrun Peat Moss	R.R. 2, Pendleton

Table 3. Raw mineral production in Madison County, 1960-70

[Data from U.S. Bureau of Mines Yearbooks]

Year	Value	Percentage of annual change
1970	W	
1969	$1,984,000	-4.2
1968	2,071,000	-1.6
1967	2,105,000	+21.9
1966	1,726,200	+5.8
1965	1,631,264	+6.5
1964	1,531,540	+5.9
1963	1,445,738	+26.7
1962	1,140,676	+11.0
1961	1,027,939	+0.3
1960	1,024,732	?

W – Value withheld because of confidential data.

Anderson would then have been priced to include 68 cents per ton from Noblesville, or 87 cents per ton from Muncie. Transportation of class A stone from Muncie would have raised the price by more than 68 percent.

In 1969 Madison County mineral producers processed and sold $1,984,000 worth of mineral aggregates and agricultural limestone (table 3). About 55 persons were employed full time, and additional persons were hired during seasonal peaks. The "1963 Census of the Mineral Industries" indicated that Indiana sand and gravel operators spent about 53 percent of their income for salaries, supplies, fuel, and contract work and an additional 10 percent of the total value of shipments for capital expenditures. Indiana-based crushed stone operators were estimated to spend about 61 percent of the total value of shipments for salaries, supplies, fuel, and contract work and an additional 12 percent for capital expenditures.

DOLOMITE AND LIMESTONE

Dolomite and limestone underlie most of Madison County, but they are shallow enough to be surface mined in only a few places (figs. 3, 5, and 7). Most of these areas are underlain by the Mississinewa Shale Member of the Wabash Formation, a very shaly dolomite or dolomitic shale that contains relatively little serviceable stone for crushing. The usable rock units that are near the surface include the Liston Creek Limestone Member and the Huntington Lithofacies of the Wabash Formation and the Jeffersonville Limestone (table 1). Two rock units underlying the Wabash Formation, the Louisville Limestone and the Salamonie Dolomite, are quarried from the deep open pit at Lapel (fig. 5).

The Jeffersonville is present only between Anderson and Pendleton, and the Liston Creek is limited to a small area southwest of Pendleton. The Huntington (reef) Lithofacies is likely to be present in many places but has been identified in only three, all near the west-central edge of the county. Other reefs may be present in the county but remain to be discovered.

Dolomite and limestone are now actively quarried at two places in Madison County (table 2), but there are several abandoned quarries in the county (fig. 3). Cherty rock, which is found in the Liston Creek Limestone Member of the Wabash Formation, was quarried for many years southwest of Pendleton near the reformatory. Sandstone was quarried at Pendleton for dimension stone and flagging from a site on Fall Creek that is now in the city park. Rock from quarries on the west side of Alexandria was once used as raw material for producing rock wool. Medium-bedded limestone layers from a quarry in the west part of Anderson and from a small and long-abandoned quarry along White River west of Anderson were used as an early source of stone for foundations. Both the Anderson and Alexandria quarries were in Mississinewa shale.

SAND AND GRAVEL

Sand and gravel are mainstays of the construction industry. Large volumes of the commodity are needed in all urban and urbanizing areas when it is used for road surfacing and subgrade construction and as aggregate in concrete and bituminous mixes and in standard concrete products. (See Carr and Webb, 1970.) Sand and gravel are dug from active pits in the valley of White River, Kilbuck Creek, and Little Kilbuck Creek (fig. 7). Several smaller active-on-demand gravel pits are in the valley deposits along Pipe Creek and Fall Creek and in several of the segments of the Anderson esker system. These and the more than a hundred abandoned pits in Madison County (fig. 6) show how extensively gravel has been exploited in the county.

Most of the gravel deposits opened a generation or more ago are no longer adequate by today's standards for a commercially exploitable deposit. Because of the economic demand, modern deposits must be sufficiently large to provide reserves for a decade or longer to merit development. Potentially workable deposits of this size are generally formed along the major glacial meltwater valleys, and probably underlie the major areas of the Atherton Formation along White River, Kilbuck Creek, and Pipe Creek. Smaller deposits are along Fall Creek and the esker and outwash plains mapped in the southern part of the county (pl. 1). Except for those under the trench of Little Kilbuck Creek, it is not likely that the gravels beneath the areas mapped as *Qgm* are extensive enough to support a modern gravel operation.

Figure 5. Lapel quarry of Martin Marietta Aggregates, Central Division.

One of the few places in Madison County in which high-quality limestone and dolomite lie near enough to the surface to be economically removed is at Lapel, where a quarry has been cut 221 feet (December 1971) down through steeply dipping reef flank beds of the Wabash Formation, through the Louisville Limestone, and into the Salamonie Dolomite. The company, prevented from further open pit expansion by adjacent urban land uses, has begun to extend the mine by underground methods. A portal for the underground working is visible near the center of the photograph.

Although Anderson has expanded across some of the major gravel-producing areas along White River and Kilbuck Creek, the materials were largely worked out before the city engulfed them. The present major producing areas are beyond the boundaries of the city and so are not immediately jeopardized by urbanization. The existence of additional reserves in many places in the county means that new locations probably can be found as needed for some years to come, but the threat of urban development across some major deposits is a real one, requiring that careful consideration be given now.

The large areas of worked-out gravel-pit wasteland at the edge of the city probably create more of a land use problem than does the maintenance of adequate reserves. Reclamation plans that can be carried out concurrently with gravel removal (fig. 7) will result in pit areas immediately reusable for a subsequent use on abandonment of the site (Bauer, 1965; Johnson, 1966; Klosterman, 1970).

PEAT

Few places in Madison County have accumulations of peat that are commercially workable. There are some small bogs (pl. 1), but only two probably have peat sufficiently thick to be worth considering. A bog 1 mile southeast of Pendleton (SE¼ sec. 21, T. 18 N., R. 7 E.) was being worked in 1972 (fig. 8). Stockpiled material included both sphagnum and sedge peat. Total thickness of the peat was reported to be 6 to 8 feet.

A second bog a short distance southeast of Emporia also is underlain by peat. A boring as part of a paleobotanical study (Barnett, 1937) showed that the peat was at least 31 feet thick where the sample was taken.

Peat may underlie two small bogs about 3 miles south of Pendleton, but no effort has been made to determine the nature and thickness of the material beneath the surface. Other bogs shown on plate 1 are probably too small to contain commercially workable deposits of peat.

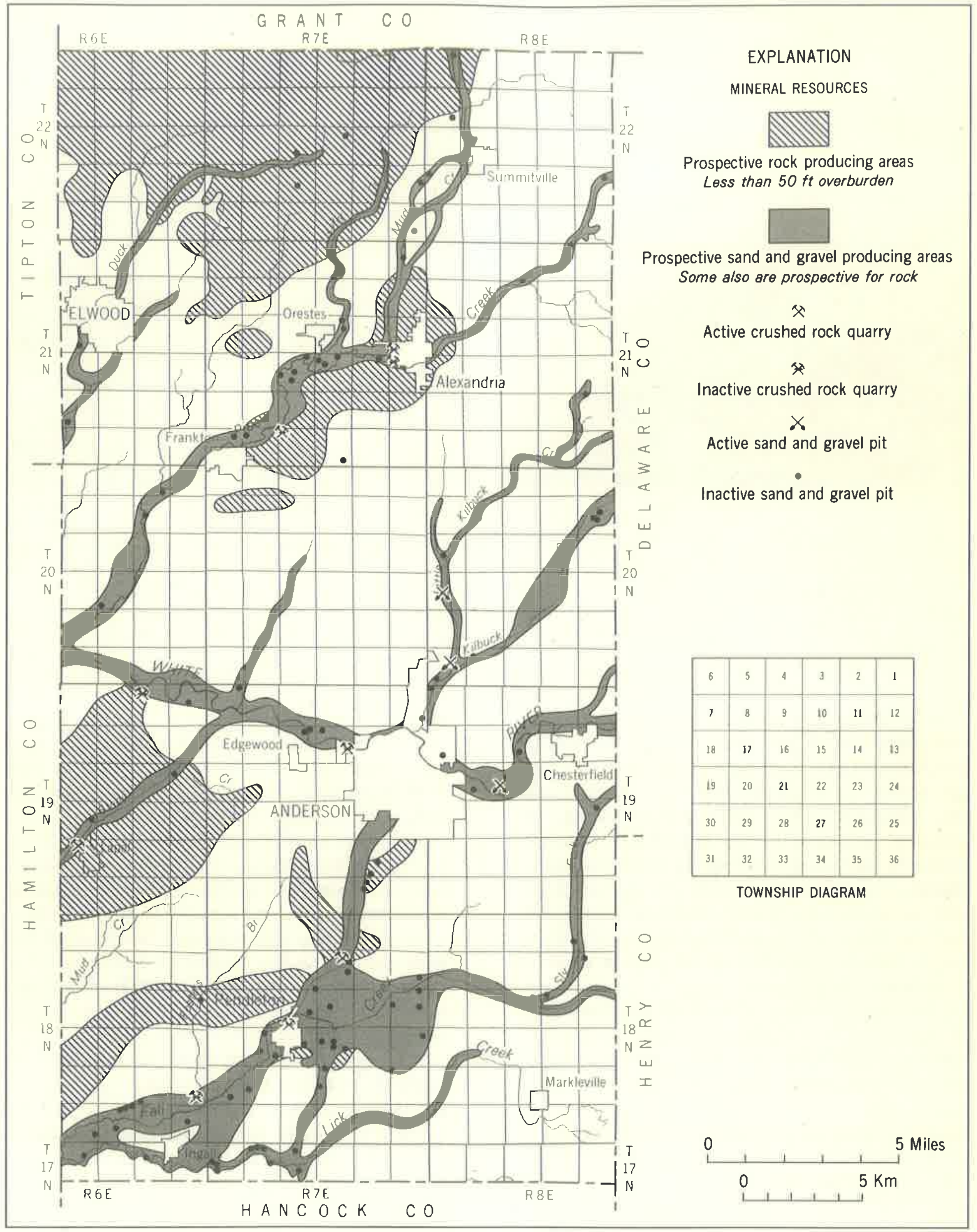


Figure 6. Prospective rock, sand, and gravel producing areas in Madison County.

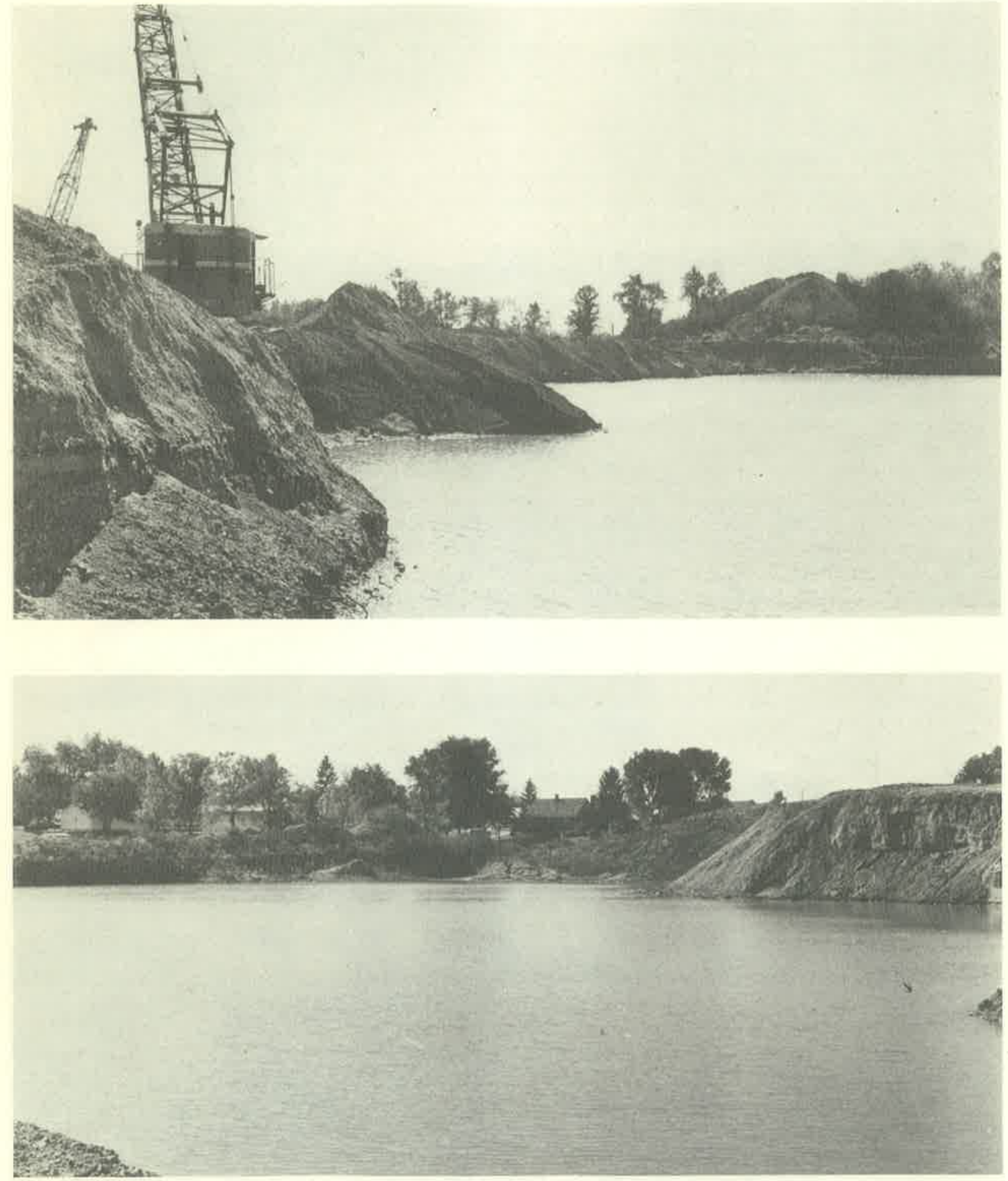


Figure 7. Gravel pit of the Myers Sand & Gravel Corp.

Extensive deposits of sand and gravel near Anderson have been used as a source of construction material for decades. Some of the worked-out pits have been left as wasteland, and others have been filled for later reuse of the land. Development for lakeside housing is taking place concurrently with excavation of gravel by the Myers Sand & Gravel Corp. at the northeast edge of Anderson. Houses on the redeveloped land beside the pit are visible in the lower photograph.

Figure 8. Excavated peat moss deposit and stockpile of Filbrun Peat Moss.

Few peat moss deposits of commercially workable size exist in central Indiana. Filbrun Peat Moss removes both sedge peat and sphagnum peat from a filled glacial lake basin 1 mile southeast of Pendleton for local sale. When the peat removal is complete, the resulting lake margin undoubtedly will have value for recreational development.

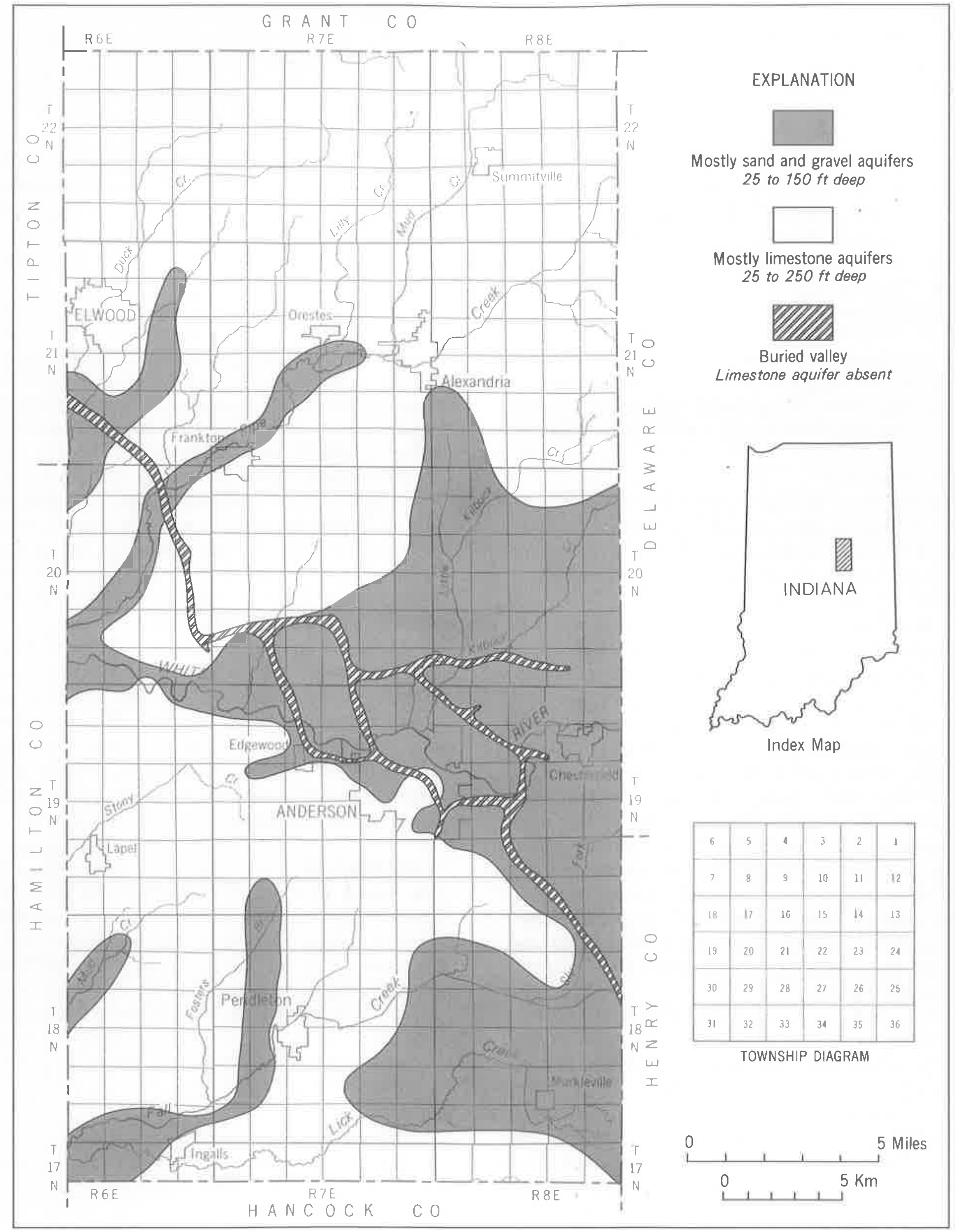


Figure 9. Principal groundwater sources of Madison County.

Water

SURFACE WATER

Because of the flat topography and lack of extensive natural drainage lines in Madison County, much of the precipitation either enters the ground or evaporates. Tile lines now intercept and carry off a substantial part of it, though, so that runoff has become much greater than it was only a few decades ago. Where urban land uses expand, the amount of precipitation that infiltrates the earth decreases and the runoff increases, thus raising the potential for flooding along streams.

Good reservoir sites are scarce in the Tipton Till Plain. Few, if any, exist in Madison County because most of the streams are shallow, and thick gravel beds are common along the valley walls. Both White River and Fall Creek valleys expose such intertill gravels, and Pipe Creek flows through a gravel-filled valley.

GROUNDWATER

Groundwater is available in moderate to large quantities throughout most of Madison County. Aquifers are both limestone and gravel (fig. 9). A map showing general groundwater availability was published by the Indiana Division of Water (Steen, 1970).

In the vicinity of Anderson, most water wells are completed at depths no greater than 150 feet. Tubular wells generally encounter gravel at about 30 feet from which some water may be pumped. A second aquifer is present in much of the area around Anderson at a depth of 65 to 100 feet (Biggs and Wayne, 1953). In some places, the intervening till is missing and both upper and lower gravels seem to be continuous. Wells in such areas are capable of very large capacities. A few deeper wells have penetrated gravel, but generally the sediments that fill the deeper parts of the buried valleys in Madison County are fine sand, silt, and clay. Thick saturated fine sand and silt, sometimes called "quicksand," has been reported from the lower part of the buried valley northwest of Anderson (figs. 3 and 9).

The rocks at the bedrock surface in Madison County are variable as aquifers (table 1). Virtually all Silurian and Devonian rocks in the county, though, are capable of yielding some water.

Dolomites of the Jeffersonville and the Liston Creek are not extensive as aquifers because they are limited to small areas in the county and are near the surface. Their performances as aquifers depend largely on their presence at the bedrock surface far enough below the water table to be perennially recharged. The Pendleton Sandstone is a lens that has very limited distribution. Its grains are sufficiently well cemented that most of its permeability is likely to be secondary (bedding planes and joints). In Madison County the Pendleton has been little used as an aquifer.

The Mississinewa is a massive shaly dolomite or dolomitic shale that has widely spaced arcuate joints and few bedding planes through which water can move. It is, therefore, not a good aquifer, although some wells have been completed in the weathered zone at the bedrock surface, and the thin limestone beds in the lower part of the unit may yield some water.

The Silurian limestones and dolomites that underlie the Mississinewa are medium bedded and well jointed and thus have good secondary permeability. Cavernous openings have been recorded, but little is known about their abundance. Undoubtedly many bedding planes and joints have been enlarged by solution, though, particularly near the edges of the deeper preglacial valley course (fig. 3). Most of the water wells in these units are domestic wells that are 100 to 150 feet deep and are probably drawing water from the Louisville or from the upper part of the Salamonie and perhaps from the Waldron. Yields of 100 gpm have been reported, and higher yields are probably possible. (See Steen, 1970.)

Ordovician shales that underlie the thick Silurian dolomite aquifers contain little water. The likelihood of failing to encounter a gravel or sand bed in which a domestic well can be completed is slight, but a few such localities have been reported. A few wells located over buried valleys have penetrated the shale directly below glacial drift that contained no aquifers and were reported as dry holes.

Waste Disposal

The wastes generated by an urban area must be removed regularly and disposed of in a safe and sanitary manner. Most cities and towns have built treatment plants to process liquid wastes and use landfill, perhaps with incineration of garbage and combustibles, for disposal of solid wastes. Those outside the range of these municipal services must normally rely on individual disposal methods for household wastes and garbage.

SEPTIC TANKS

The septic tank was originally designed to allow farm families far from community sewerage lines to enjoy the comforts of indoor plumbing. The septic tank functions by retaining wastes in a large waterproof tank for at least 24 hours. During that time bacteria break down solid waste materials and convert them

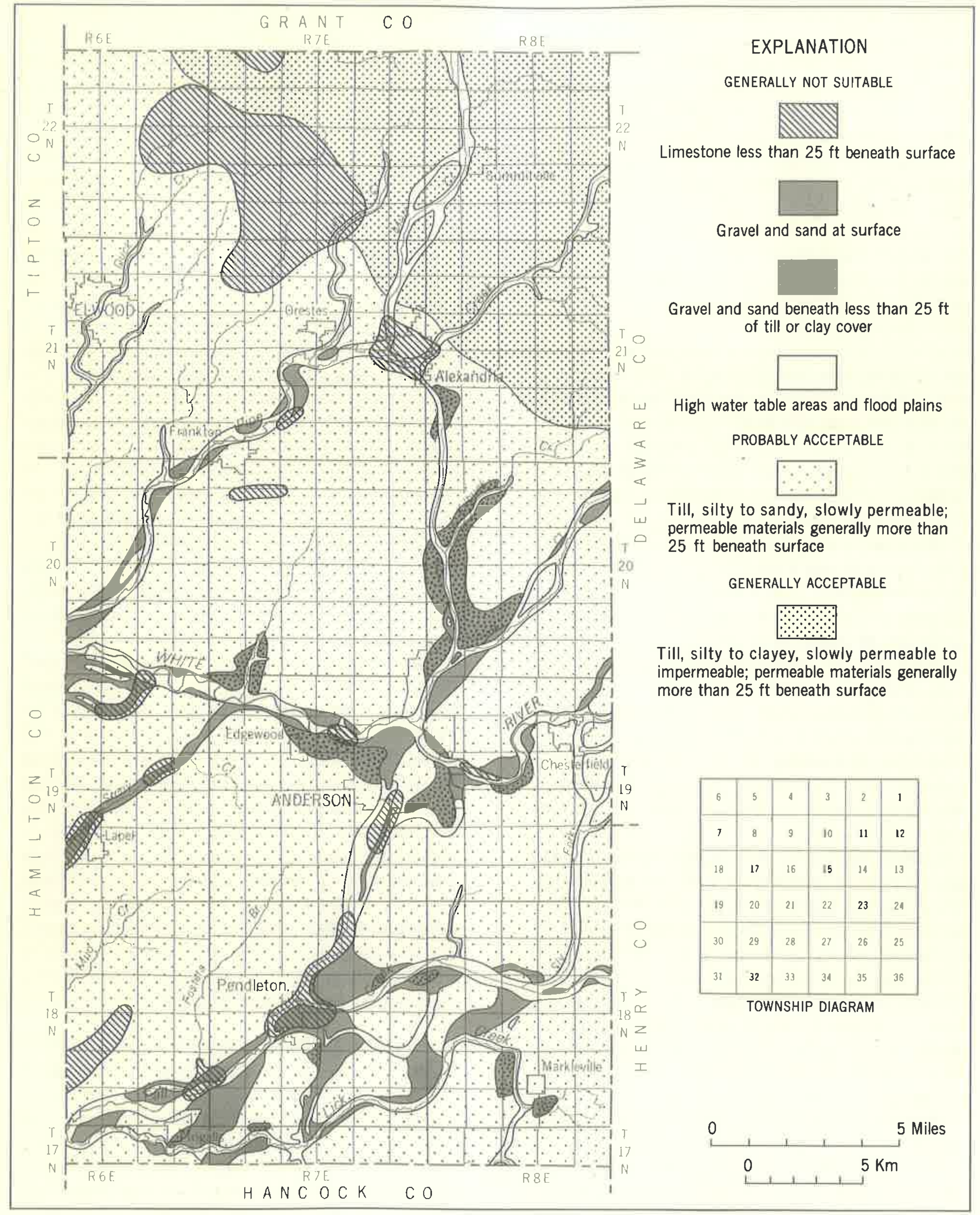


Figure 10. Suitability of surface materials for solid-waste disposal sites in Madison County.

to liquids, gases, and a solid residue. The waste liquid from the septic tank flows into field tile or perforated draintile that is laid in trenches and from there is dispersed into the soil; gases pass into the atmosphere for disposal; and the solid residue accumulates on the bottom of the tank.

The detailed soil map of Madison County (Schermerhorn and others, 1967) provides more specific data than does a geologic map (pl. 1) for evaluating any particular location for septic tank installation. Neither, of course, should wholly replace site investigation prior to installation. Nevertheless, some aspects of the geology bear directly on problems of household waste disposal.

Storm water that passes through septic tank drainage fields or over manure-covered barn lots is also likely to carry coliform bacteria and viruses as well as nitrates and other dissolved solids downward to the water table. Where underlying materials are permeable, or if openings exist in relatively impermeable surface materials, these noxious fluids may be able to pollute local water supplies.

The upper part of limestone at or near the surface generally has enlarged fractures through which fluids can move rapidly. Limestones that formerly were exposed at the surface but now are buried beneath a blanket of glacial drift are likely to have similar openings. Because many water wells are cased only a few inches into rock, wells where limestone is at shallow depths are likely to be sealed only a short distance beneath the surface. Water circulating downward through fractures in the rock can enter such a drilled well below the lower end of the casing. If that water contains contaminants, they will enter the well.

In Madison County many square miles are underlain by bedrock within 25 feet of the surface (figs. 3 and 10), and water from wells in these areas could be susceptible to this kind of pollution. Fortunately, the Mississinewa Shale Member is the bedrock in most of this area, and so solutionally enlarged fractures are likely to be rare. But the upper few feet of this rock unit is generally fractured more than it is at greater depth; therefore, to avoid possible contamination from surface water, wells should be sealed several feet into the rock.

A region that is underlain by permeable material, such as sand and gravel, and that is above the water table is more suitable than other kinds of terranes for septic tank disposal fields. Therefore, all areas mapped as the Atherton outwash facies (pl. 1) should perform well for fluid disposal. Normally, water wells in such areas will be adequately sealed from septic tank effluent if they pass through a thick clayey bed between the surface and the aquifer and if any space between the clay bed and the casing is sealed with either cement grout or a thick bentonitic mud (Indiana State Board of Health, 1966). If wells are not sealed, however, or if shallow surface aquifers are used for water supply and housing density is moderate to high, eventually some waste fluids may reach the aquifer and pollute the water.

Tills, which underlie most of Madison County, are much less permeable than sands and gravels and require larger disposal fields. In slight shallow depressions, where an accumulation several feet thick of inwashed fine-grained sediments covers the till, permeability is very low and septic tank disposal fields may fail to function or may fail in a short time. The soil profile is only 3 to 4 feet thick on most of the slight rises on the till plain; however, the permeability of the till beneath the weathered zone permits disposal of household wastes acceptably well.

Because these areas of moderate to low permeability are intimately intermixed in the area of the Trafalgar Formation (pl. 1 and fig. 10), they have not been separated on the geologic maps. Modern soils mapping (Schermerhorn and others, 1967) provides sufficient detail, however, to distinguish most of these areas of different surface permeability.

Till of the Lagro Formation, limited to northeastern Madison County (pl. 1), is finer grained and is generally less permeable than are surface tills of the Trafalgar Formation. The low permeability of this sediment will make uncommonly large disposal fields for septic tanks necessary where it is present if septic tank effluent is not to seep to the surface. Although in a completely rural situation such seeps may be unlikely to cause any problem at the time, such a situation is not desirable and will create conditions for later pollution when the surrounding land is developed. Serious stream or groundwater pollution can take place where septic tank density increases, as in a small community or a subdivision dependent on these private waste disposal facilities.

SOLID WASTE DISPOSAL

Where solid wastes are disposed of by dumping or burial, the wastes become part of the geologic environment. Even though they are compacted and covered with earth, as in a landfill, they are generally permeable. Groundwater passing through the buried wastes can produce a leachate that may contain dissolved toxic substances and is capable of contaminating ground and surface waters (Sheaffer, von Boehm, and Hackett, 1963; Schneider, 1970).

Under most conditions, time, filtration, and attenuation through dilution will make the leachate from most municipal solid waste materials relatively harmless (Zanoni, 1972), but industrial waste, much of which is disposed of in landfills, is capable of producing highly toxic leachates. The degree to which refuse is compacted and the thickness, lithology, and grading of cover materials can greatly affect the amount of leachate produced.

Early studies in California and more recent research in Illinois (Hughes, Landon, and Farvolden, 1969, 1971) indicate that the conditions most likely to result in groundwater pollution are: (1) the refuse fill is over, in, or beside an aquifer; (2) the fill is saturated much of or all the time; and (3) leached fluids are able to circulate into an aquifer. Ordinarily the water added in compaction causes no problem, but rainfall passing through the compacted wastes, or groundwater, if the landfill is partly or entirely below the water table, will provide the saturation necessary to produce a leachate that can migrate and may contaminate water supplies.

These geologic conditions are especially likely to exist at abandoned gravel pits or limestone quarries, sites often selected for waste disposal. In those parts of Madison County where either gravel or limestone is at the surface or within 25 feet of the surface (fig. 10), migration of leachate from waste disposal areas could take place readily. Elsewhere in the county, a layer of till sufficiently thick to retard movement of fluids overlies potential aquifers. In the northeastern part of the county, the nearly impermeable till of the Lagro Formation underlies the surface almost everywhere; most landfill sites there should prove to be acceptable. Testing should be undertaken at every proposed waste disposal site, however, to determine that a shallow aquifer does not underlie the area. Although no standards have yet been established for underlying materials, at least 20 feet of impermeable sediment should separate the bottom of the sanitary landfill from lower permeable materials. (See Bleuer, 1970, p. 6.)

Geologic Features and Processes Hazardous to Urban Development

Many thousands of years have been necessary to develop the present landscape features of Madison County. The county has been free of glacier ice for 15,000 or 16,000 years, and the present surface has been developed by erosion since that time. Much less time, though, is needed for the many small increments of erosion that take place in the development of a land surface. The processes of erosion are powerful, and, if unrecognized, can be hazardous to urban land uses.

FLOOD PLAINS

Rivers create the valleys in which they flow. The flat valley floor is formed by lateral erosion and by deposition of sediments carried when the river in flood overflows its banks. The channel is capable of carrying the normal flow of the stream, but at times of high runoff, the flood plain becomes the relief valve of the river, and the excess runoff spreads across the valley floor until it can slowly drain back into the channel, soak into the soil, or evaporate.

Rivers in Madison County subject to regular overflow as a result of high runoff are White River, Fall Creek, and Pipe Creek. Maps have been prepared for White River that show in detail the flood-plain surface. These maps, on file in the Division of Water offices, can be used to work out the flooding potential of the land along the river. All the land that has been subject to flooding is included in the maps with this report, however (pl. 1 and fig. 11).

For those streams with no detailed map available, such as Fall Creek or Pipe Creek, some other means must be used to delineate the land subject to flooding so that its boundaries can be recognized in planning studies. The geologic maps (pl. 1 and fig. 11) show the flood land along Pipe Creek and Fall Creek in sufficient detail for general planning, although they do not distinguish the land that is inundated annually from land that floods only once in a century. Both are part of the flood plains of these streams and have been so mapped.

HIGH WATER TABLE

Madison County is crossed by several streamless troughs that are floored with muck. Sediments beneath the muck are generally sand or gravel, but they may also be clay or marl. Many of these troughs have been drained for farming by means of buried tile lines or open ditches. All have high water tables. Hand-auger holes generally encounter water within 2 or 3 feet of the surface even in late summer. Not only is construction in such areas (fig. 11) subject to perennially high water, but the surface sediments are likely to be soft and may not support the weight of a heavy structure unless piling is used or the material is removed and replaced with stable fill.

Many very shallow upland depressions are floored with fine-grained inwashed sediment and drain very slowly. In the early months of the year standing water is common in these areas. They are not shown individually on the geologic map (pl. 1), but most of

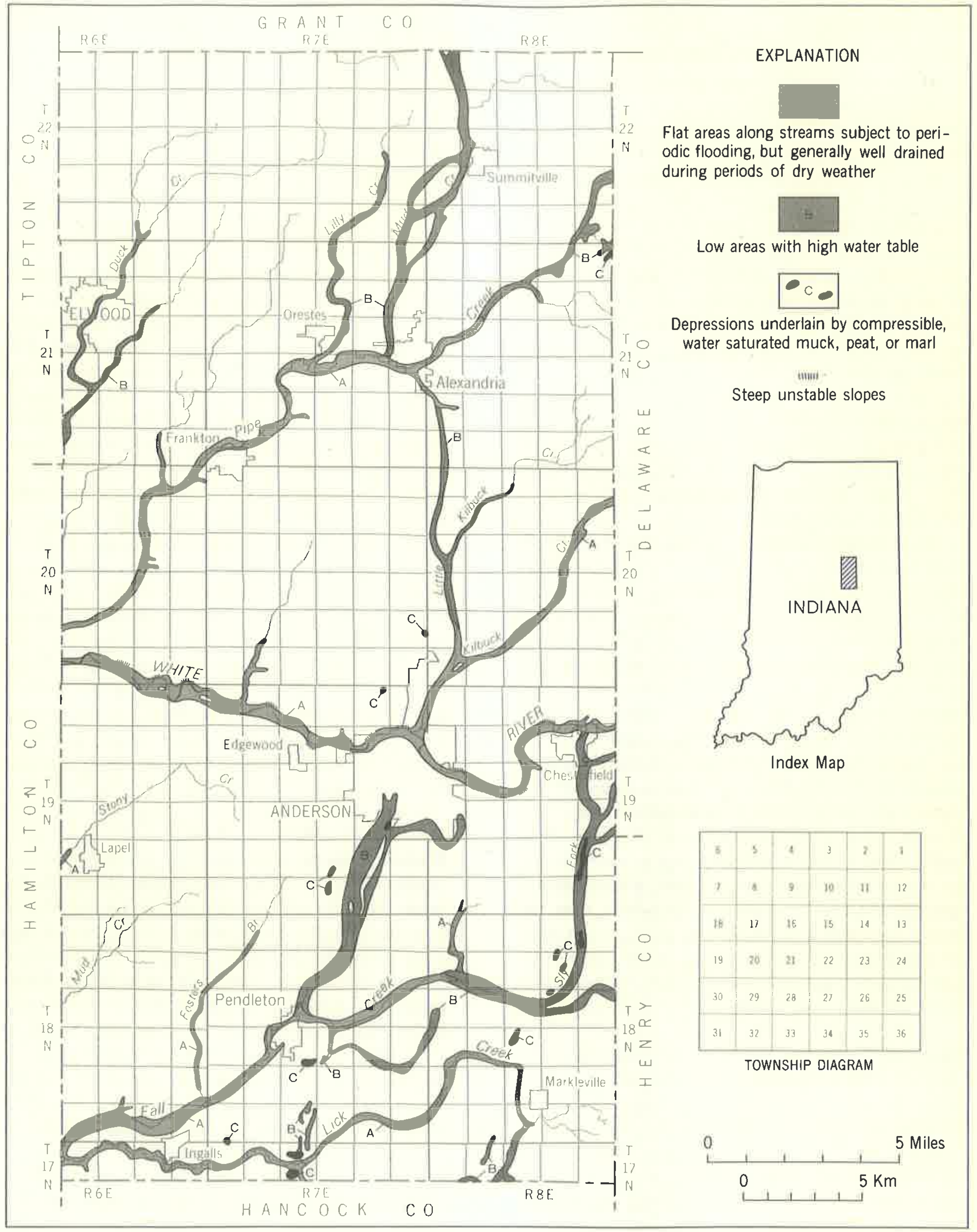


Figure 11. Areas where geologic conditions may be hazardous to land development and construction in Madison County.

them are recognizable in the field because they normally have dark-gray surface soils. Unless they are well drained by storm sewers, these areas are likely to be difficult to develop properly for homesites.

SLOPE FAILURE BY MASS WASTING

In a region as level as Madison County, few places are likely to be unstable as a result of steep slopes. Only along the edges of valleys are steep natural slopes likely to exist. In the unconsolidated tills and gravels of central Indiana, oversteepened banks tend to be reduced to a stable slope within a few decades. Only those actively undergoing cutting or along which the cutting has recently ended are likely to have not yet reached stability. Such slopes are noted in Madison County along White River (fig. 11).

The steepest slopes in the county that are likely to be undergoing no movement other than very slow soil creep are those along Sly Fork and Fall Creek in the southeastern part of the county. Little or no widening or deepening has taken place in these glacial meltwater trenches since the stagnant ice mass disappeared perhaps 15,000 years ago. Northward-facing slopes of 20 percent are fairly common and a few are as steep as 23 percent. Southward-facing slopes seem to be characteristically more gentle and generally range from 10 to 15 percent.

Most of the recent road cuts along the state and federal highways that cross Madison County are graded to a slope of 2:1, or 50 percent. These slopes in unweathered till and gravel seem to undergo little mass wasting except where drainage moisture from a field tile or a lens of silt or fine sand keeps the slope continually moist. Some downslope movement takes place in late winter when pore water pressure is high in the unconsolidated materials.

Either frequent changes in moisture content or increase in loading on stable slopes can cause the slopes to become unstable. If a house were built on an apparently stable natural slope of 20 percent or the drainage field of a household sewage system were to be installed on or just above it, the added weight or the increase in pore water pressure from the moisture could cause renewed instability and downslope movement of loose earth materials. Slopes no greater than 10 percent seem to remain stable under these changed conditions. Therefore, for construction purposes, it would be desirable to consider any slope in excess of 10 percent to be potentially unstable. Steeper slopes are to be found along virtually all drainageways adjacent to the flood plain. The only areas noted specifically in figure 11, however, are those where slopes exceed 30 percent and are actively undergoing mass wasting.

FOUNDATION SUBSIDENCE

In addition to the possibility of downslope movement of earth materials, subsidence into soft sediments can cause foundations to tilt if structures should happen to be built in areas where such materials exist. In Madison County many small boggy spots are scattered around the upland. Few of them are likely to be chosen as homesites, although as urban growth continues some may ultimately be included in subdivision development. Most of the areas of this kind are shown in figure 11.

A few larger peat- or marl-filled bogs exist in the county. Both drainage and foundation stability are likely to cause concern unless designs for future land use in these areas are accommodated to their existence. Either piling to support foundations or excavating the soft sediments and filling with stable materials would be necessary to use the land intensively. The most significant of these areas (pl. 1 and fig. 11) are along the Sly Fork trench south of Chesterfield, the bog at Emporia, south of Pendleton, and along State Highway 9 south of Anderson.

EARTHQUAKE POTENTIAL

Earthquakes of sufficient magnitude to cause structural damage rarely affect central Indiana. Since the New Madrid quakes of 1811-13, which were centered in the Mississippi Valley, few earthquakes have been recorded that should have been felt in Madison County, and none had epicenters in this part of central Indiana. The most recent was in November 1968. None of these produced sufficiently strong shocks to have damaged buildings in central Indiana.

Geologic and Other Features of Scenic or Educational Interest

Many geologically interesting features may have potential as park sites, as natural areas for educational uses, and as tourist attractions. If such areas are identified and their significance noted before they are overwhelmed by the tide of urbanization, adequate provision may be made to reserve them for such community uses.

REEFS

The Silurian rocks of northern Indiana are known to geologists throughout the world because of the remains of ancient organic reefs that they contain. The reefs have been the subject of field trips (Shaver and others, 1961, for example) and major scientific papers (Cumings, 1932; Cumings and Shrock, 1928; Pinsak and Shaver, 1964, for example). One of the finest exposures of these reefs is at Lapel, where the structure of one that has been opened by a quarrying operation can be examined. Well-preserved fossil corals and stromatoporoids, reef-building organisms, are abundant in the beds exposed in the quarry, and crystals of calcite, pyrite, sphalerite, and other minerals have been collected there. The rocks in the quarry also show well the relationships between the rocks of the reef and interreef areas of the Silurian sea. For educational purposes, it would be desirable if the quarry at Lapel, when it is finally abandoned as a stone-producing operation, could be maintained as an educational park. Landscaping would make the lower floor attractive to visitors and the walls could provide a cross-sectional view of the old reef. Instructive displays would increase the usefulness of the area as an outdoor museum.

GLACIAL FEATURES

END MORAINES: Only one end moraine, the Union City Moraine, crosses Madison County, and it is low and not particularly noticeable. Northwest of Alexandria, however, its gentle rise above the absolutely flat till plain to the southwest stands out especially well about one-half mile east of State Highway 37 and south of County Road 1800 North. (See Elwood Quadrangle, U.S. Geological Survey 7½-minute topographic map series.)

ESKERS: The esker south of Anderson was once one of the more striking glacial features in Indiana. Decades of gravel operations, though, have so completely eviscerated it that little now remains except a shell. Its continuation southward past Pendleton has been much less extensively exploited, and some fairly good eskerine topography remains. The segment that is cut by Spring Branch is probably the best of the remaining parts. It is near a shallow peat bog from which a few prehistoric bones have been collected and which might also be worth considering as a park site after the peat has been worked to exhaustion as a resource.

ICE-CONTACT TRENCHES: The last ice sheet that covered Madison County became too thin to move after it had reached its maximum extent. As the stagnant ice melted, the water drained from it through tunnels; later as the ice sheet thinned and the tunnel roofs collapsed, the meltwater coursed through ice-walled channels. The many streamless troughs that trend roughly from north to south across Madison County are the remnants of those valleys, essentially unmodified since the glacier disappeared (Wayne, 1968). Among the more striking are those followed by Sly Fork and Little Kilbuck Creek. A natural area park site may be possible within one of these trenches.

PREHISTORIC EARTHWORKS AND MOUNDS STATE PARK

Even though they are not geologic features, the prehistoric earthworks within Mounds State Park deserve mention in any report on Madison County. The mounds preserved and made available for many to see in the park are low, geometrically shaped ridges that evidently were built for ceremonial or religious purposes. Earthworks of this type have been attributed to an American Indian culture that flourished in the eastern part of the United States from about 1000 B.C. to 200 B.C. (Kellar, 1966, p. 491). The structures at Mounds State Park are somewhat different from typical mounds of this period (Adena and Early Woodland are names given by prehistorians to this culture), but archaeological studies indicate that they were probably built late in the period. Radiocarbon dates on material from Mounds State Park are 40 B.C. and A.D. 200 (Barnhart and Riker, 1971, p. 54). The mounds were built by excavating an arc-shaped trench and piling the earth outside the arc. Most mounds in the park are broken circles.

The mounds were built on a high point of ground overlooking White River and about 85 feet above it. The surface material on the upland is till, but a fairly thick (25 to 30 feet) gravel that has been cemented to form a conglomerate in many outcrops lies beneath the surface till. The gravel in turn overlies another till, which seems to extend down to the level of the river. Several springs flow from the base of the gravel directly northwest of the large mound in the park, and at one place the springs have eroded a steep-banked spring alcove. The presence of these springs on the slope beneath an overlook on the river may be the reason why this site was selected for constructing the mounds (Lilly, 1937, p. 40-41).

Mounds State Park is small, scarcely 252 acres, but it provides picnic facilities and hiking and bridle trails that fulfill some of the recreation needs of the community at a place where a significant prehistoric feature can be observed.

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