CAMBRIAN AND ORDOVICIAN STRATIGRAPHY AND OIL AND GAS POSSIBILITIES IN INDIANA

by

ALLAN M. GUTSTADT

Indiana Department of Conservation

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CAMBRIAN AND ORDOVICIAN STRATIGRAPHY AND OIL AND GAS POSSIBILITIES IN INDIANA

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ABSTRACT

Cambrian and Ordovician rocks throughout most of Indiana are subdivided in ascending order as follows: lower part of the St. Croixan series consisting of the Mt. Simon sandstone and the Eau Claire formation; upper part of the St. Croixan series and the Canadian series consisting of the Knox dolomite; the Chazyan series consisting of the St. Peter sandstone and the Joachim dolomite; the Mohawkian series consisting of the Black River limestone and the Trenton limestone; and the Cincinnatian series consisting of the Eden group (undifferentiated) and the Maysville-Richmond group (undifferentiated).

The Mt. Simon sandstone, the Eau Claire formation, and the lower part of the Knox dolomite may be facies that represent contemporaneous environments, respectively, of beach or littoral deposition, near-shore deposition, and offshore deposition. The St. Peter sandstone was deposited unconformably on the eroded surface of the Knox and was succeeded by carbonate deposition until late Ordovician time. The Cincinnatian series represents shallow-water deposition where the physical and biological environments alternated rapidly between clear water and optimum conditions for life and muddy water and unfavorable conditions for life.

The Mt. Simon sandstone and the Eau Claire formation are virtually untested for oil and gas, although the Mt. Simon has ideal reservoir characteristics of the "blanket-sand" type, and the Eau Claire exhibits rapid local changes in porosity which might serve to localize accumulations of oil or gas. The Knox dolomite contains highly permeable zones, and many shows of gas have been reported, although commercial production is lacking. The St. Peter sandstone has been considered a good prospect for oil or gas, but remarkably few shows of either have been reported. Any oil or gas found in the Black River most likely will be in local dolomitized lenses. Additional Trenton production might be found in northern Indiana, where the formation consists of dolomite, and possibly in southern Indiana, where the formation contains interbedded shale. Only a few shows have been reported from Cincinnatian rocks, and possibilities are not attractive because of the lack of good reservoir rocks.

INTRODUCTION

Cambrian and Ordovician rocks in Indiana were first studied by Logan (1925, 1926, 1931), who assembled information on wells drilled in the State and attempted correlations on the basis of the meager data available to him at that time. Numerous county supplements to Logan's Subsurface strata of Indiana (1931) were published by the Division of Geology of the Indiana Department of Conservation. (See Logan, 1931.) Bieberman and Esarey (1946) discussed the stratigraphy of four deep wells in northeastern Indiana, and Kottlowski and Patton (1953) reported on the basement rocks found in deep tests in Indiana.

The descriptions and correlations presented herein are based upon well records and samples which are on open file at the Indiana Geological Survey and at the Geological Surveys of states adjacent to Indiana. The drilling records on file at the Indiana Geological Survey are essentially complete for the past 15 years, but some test wells drilled earlier may not be represented. The number of test wells drilled to various formations in the Cambrian and Ordovician systems in Indiana based on Geological Survey records is summarized in figure 1. All test wells that penetrated the Black River limestone or deeper formations in the Trenton oil and gas field and all test wells that penetrated the Trenton limestone or deeper formations elsewhere in Indiana are listed by location and shown on plate 1. Counties in Indiana and in adjacent states referred to in this report are shown in figure 2. All test wells referred to in this report are listed by datum-point number in table 1 and are shown on the index map (fig. 3). General stratigraphic and thickness relationships of major stratigraphic units are shown on the cross section (fig. 4).

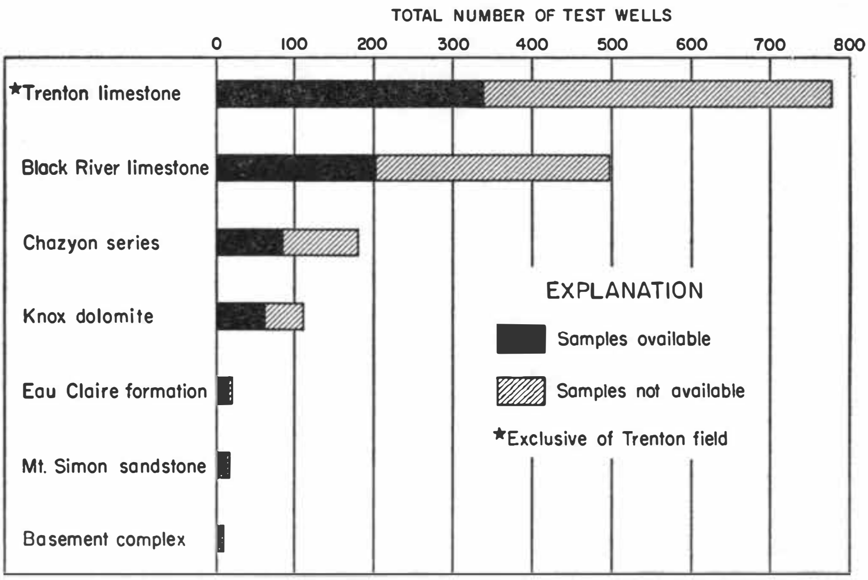

Figure 1.—Graph showing number of test wells in Indiana drilled to Trenton limestone and older rocks.

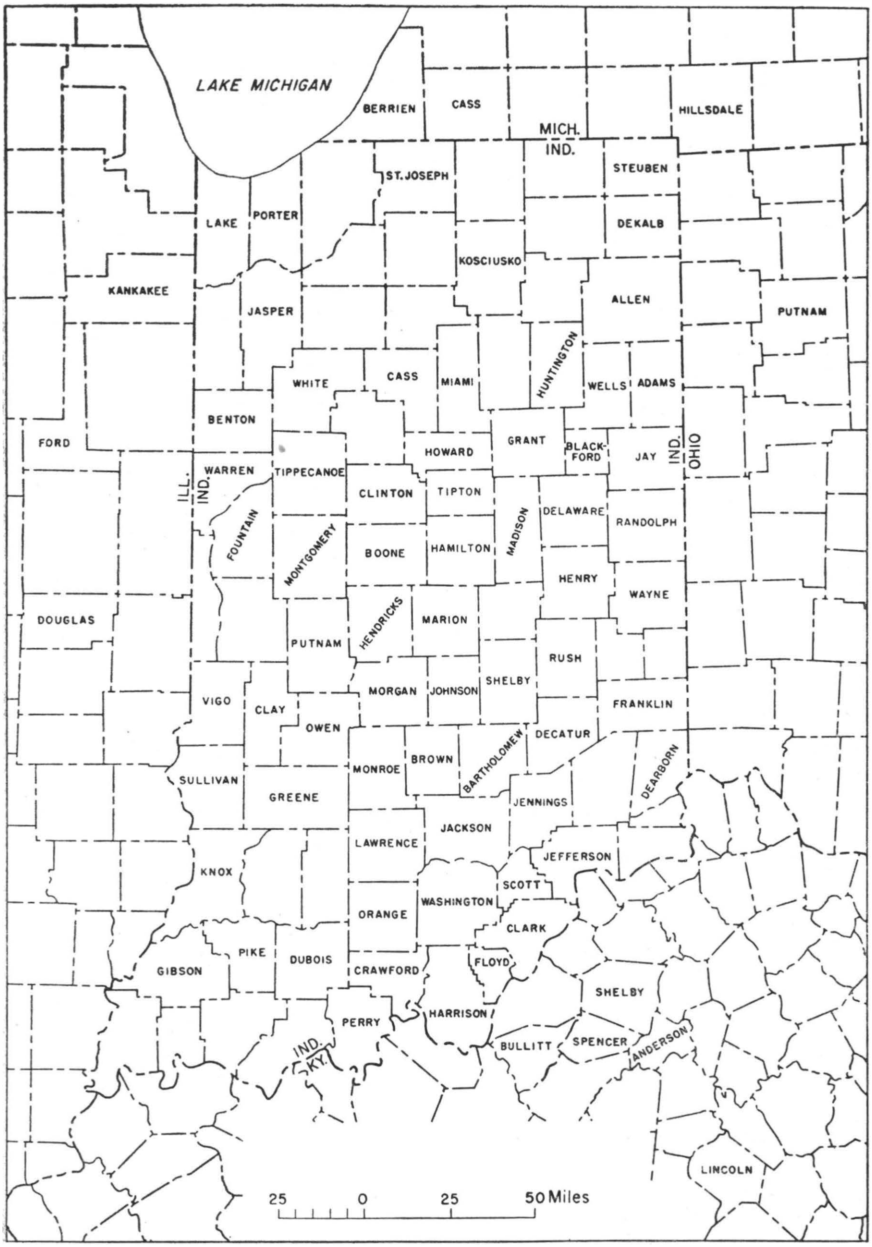

Figure 2.—Map of Indiana and parts of adjacent states showing counties referred to in text.

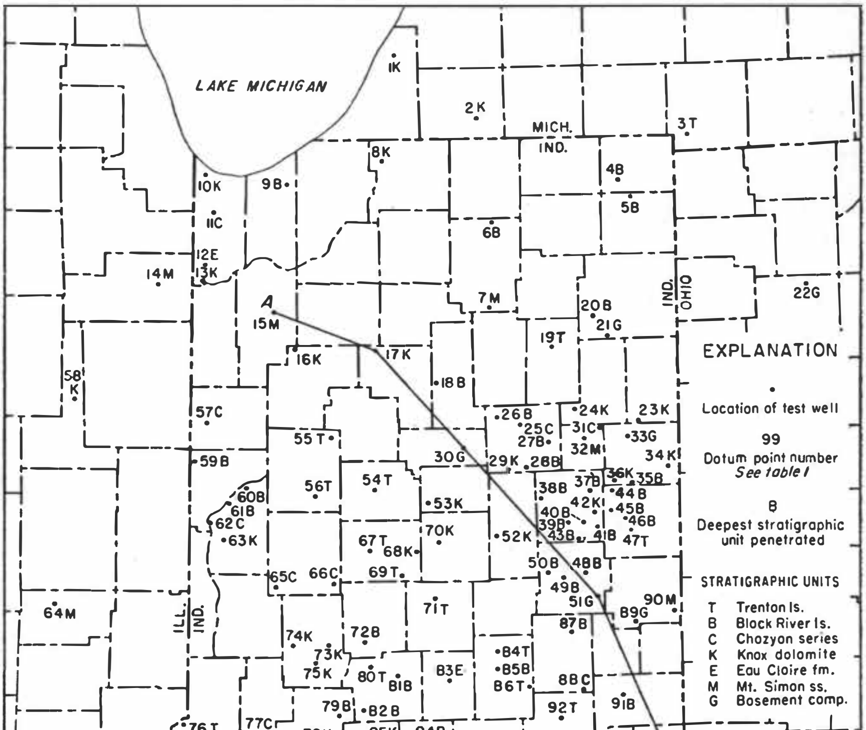

Figure 3.—Index map showing location of test wells referred to in text and illustrations and showing deepest formation penetrated. A-A′ is line of section shown in figure 4.

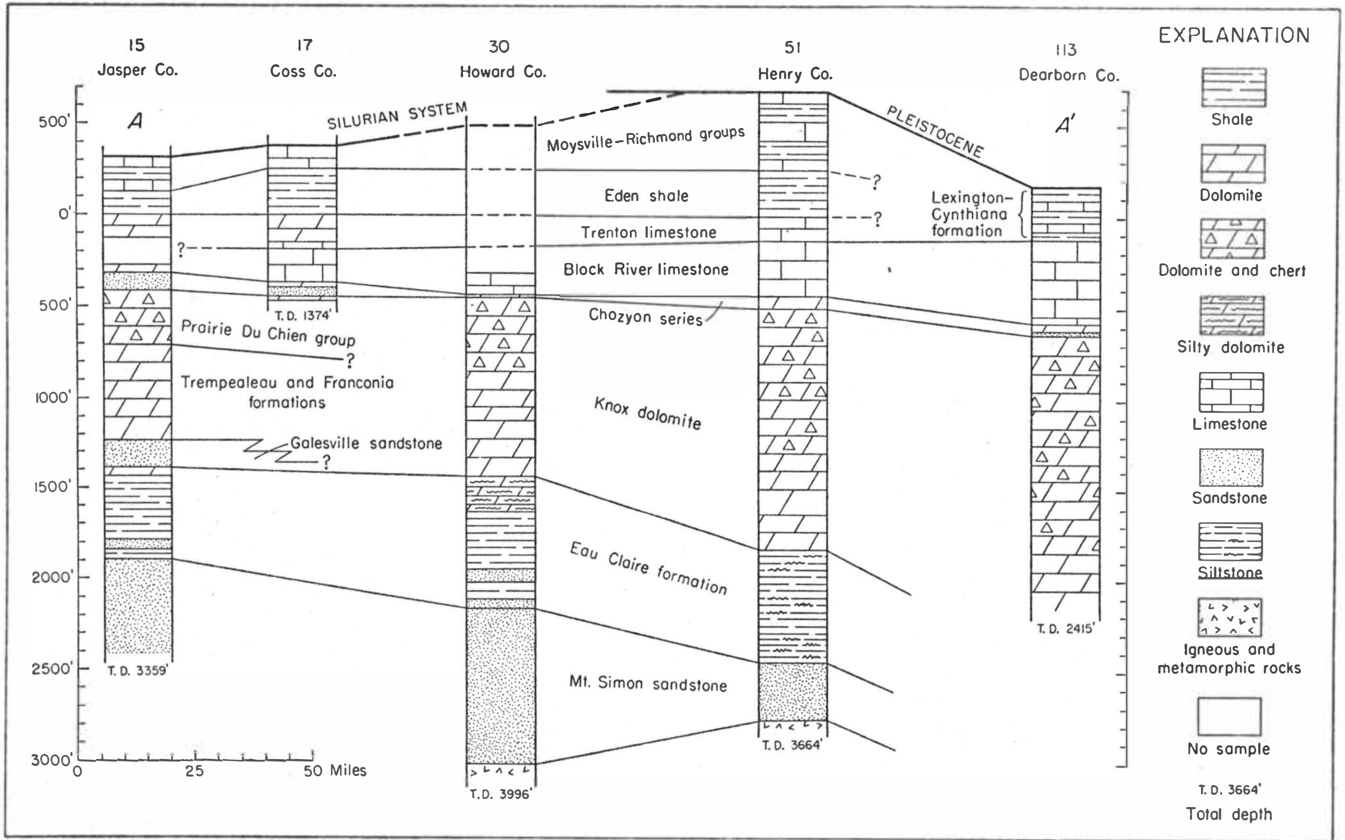

Figure 4.—Cross section along line A-A', figure 3.

Descriptions of Cambrian and Ordovician strata in Indiana included in this report were prepared by the writer and are based upon examination of cuttings with a binocular microscope. Isopach maps and cross sections are based upon the study of cuttings from 148 test wells in Indiana and adjacent states (table 1). Drillers' logs, sample studies by other individuals, and other kinds of information were used as secondary sources but were not used in the compilation of maps and cross sections.

TERMINOLOGY USED IN THIS REPORT

The present report conforms in general to the recommendations of the American Commission on Stratigraphic Nomenclature (1947, 1952, 1956) in the use of the terms *group, formation,* and *member* as rock terms, without time connotation. Complete conformance to the recommendations of the Commission is not possible, as the term *series* (a time-rock term, according to the Commission) has long been applied to some units as both a rock and time-rock term (Cincinnatian series, Mohawkian series). Except where specifically noted, the term series in the present report should also be considered a rock term, without time connotation.

ACKNOWLEDGMENTS

The writer is indebted to the personnel of the Geological Surveys of Illinois, Michigan, Ohio, and Kentucky for assistance in gathering material for this report.

PRECAMBRIAN BASEMENT COMPLEX

Basement rocks in Indiana were described by Kottlowski and Patton (1953). Only six test holes have reached the Precambrian basement complex in Indiana, and all are confined to the north-central and eastern parts of the State (fig. 5).[1] Figure 5 shows estimated contours on the top of the basement complex. This map was prepared by extrapolation of known thickness trends of the overlying Cambrian and Ordovician rocks beyond the basement tests shown.

The contour pattern in figure 5 indicates a broad structural high, apparently centered in southwestern Ohio, that corresponds to the Cincinnati Arch and its extensions, and the contour pattern also indicates a structural basin centered in southeastern Illinois, which is the Illinois Basin. The appearance of these structures on the map does not mean, of course, that they were present at the be-

[1] Two closely spaced test wells in Jay County appear as a single point.

Table 1.—*Test wells referred to in text and illustrations listed by datum-point number*

Datum point no.	State	County	Location			Operator and name of well
			Sec.	T.	R.	
1	Michigan	Berrien	10	4S	18W	Sprenger No. 1 Herwig
2	Michigan	Cass	36	7S	14W	Vanraalte No. 1 Gemberling
3	Michigan	Hillsdale	24	8S	4W	Morriss No. 1 Zeiter
4	Indiana	Steuben	15	36N	12E	Devine No. 1 Weicht
5	Indiana	De Kalb	6	35N	13E	Romer No. 1 Dilley
6	Indiana	Kosciusko	10	34N	6E	Sevens No. 1 Pinkerton
7	Indiana	Kosciusko	12	30N	6E	Eel River No. 1 Blocher
8	Indiana	St. Joseph	8	37N	1E	Nelson No. 1 Kosch
9	Indiana	Porter	9	36N	5W	Egelske No. 3 Egelske
10	Indiana	Lake	29	37N	9W	Superheater No. 1 Superheater
11	Indiana	Lake	24	35N	9W	Sewage Burge
12	Indiana	Lake	5	32N	9W	Fox No. 1 Carsten
13	Indiana	Lake	33	32N	9W	Bonded No. 1 Williams
14	Illinois	Kankakee	24	31N	13E	Hughes No. 1 Parish
15	Indiana	Jasper	14	30N	6W	Kankakee No. 1 Eger
16	Indiana	White	1	28N	5W	Ohio No. 1 Mosley
17	Indiana	Cass	11	28N	1W	Eastman No. 1 Kistler
18	Indiana	Miami	36	27N	3E	Cooper No. 1 Smith
19	Indiana	Huntington	26	28N	9E	MacKenzie No. 1 Huntington County
20	Indiana	Allen	36	30N	11E	Webster No. 1 Harold
21	Indiana	Allen	33	29N	12E	Tecumseh No. 1 Gibson
22	Ohio	Putnam	29	Liberty		Ohio No. 1 Barlage
23	Indiana	Adams	35	25N	13E	McKee No. 1 Glendening
24	Indiana	Wells	11	25N	10E	Fox No. 1 Metz
25	Indiana	Grant	36	25N	7E	Collin No. 1 Marcucelli
26	Indiana	Grant	22	25N	6E	Van Horn No. 1 Woodmausie
27	Indiana	Grant	27	24N	9E	Slagter No. 1 Olynger
28	Indiana	Grant	5	22N	8E	Morris No. 1 Payne
29	Indiana	Grant	6	22N	7E	Gould No. 1 Lee
30	Indiana	Howard	32	24N	5E	Kokomo at Greentown
31	Indiana	Blackford	6	24N	12E	Crescent No. 1 Brown
32	Indiana	Blackford	20	24N	11E	Reed No. 1 Cale
33	Indiana	Jay	29	24N	13E	Petroleum No. 1 Binegar
34	Indiana	Jay	5	22N	15E	Meuhlhausen No. 1 Hilficker
35	Indiana	Jay	35	22N	13E	Ra-Ja No. 1 Ross
36	Indiana	Jay	25	22N	12E	Larapaul No. 1 Landar
37	Indiana	Delaware	17	21N	11E	Johnson No. 1 Wingate
38	Indiana	Delaware	19	21N	9E	K-D No. 1 Keesling
39	Indiana	Delaware	28	20N	10E	Ryan No. 1 Keesling
40	Indiana	Delaware	18	20N	11E	Stone No. 1 Keesling
41	Indiana	Delaware	24	20N	11E	Sinnock No. 1 Watson
42	Indiana	Delaware	13	20N	11E	Weilder No. 2 Leeka
43	Indiana	Delaware	24	19N	10E	Van Buren No. 1 Hoober
44	Indiana	Randolph	5	20N	12E	Tamblyn No. 1 Jones
45	Indiana	Randolph	9	20N	12E	Fitchett No. 2 Racer
46	Indiana	Randolph	30	20N	13E	Dillman No. 1 Mills
47	Indiana	Randolph	9	19N	13E	Unionport No. 1 Johnson
48	Indiana	Henry	6	17N	11E	Sinnock No. 1 Iterman
49	Indiana	Henry	7	17N	10E	Phillips No. 1 Hagerman
50	Indiana	Henry	4	17N	9E	Farmers No. 1 Coble
51	Indiana	Henry	12	16N	11E	Ohio No. 1 May
52	Indiana	Madison	1	19N	6E	Anderson No. 1 Coy
53	Indiana	Tipton	21	21N	3E	Eastman No. 1 Vandeventer
54	Indiana	Clinton	34	22N	1W	Sheets No. 1 Slipher
55	Indiana	Tippecanoe	22	24N	3W	Ritchie No. 1 Dubes

Table 1.—*Test wells referred to in text and illustrations listed by datum-point number*—Continued

Datum point no.	State	County	Location			Operator and name of well
			Sec.	T.	R.	
56	Indiana	Tippecanoe	13	21N	4W	Hassett No. 1 Summers
57	Indiana	Benton	27	25N	9W	Thomas No. 1 Fowler
58	Illinois	Ford	33	26N	9E	Herndon No. 1 Fecht
59	Indiana	Warren	24	23N	10W	Detrick No. 1 Bowman
60	Indiana	Fountain	33	22N	7W	Carter No. 1 Vester
61	Indiana	Fountain	23	21N	8W	Ratcliff No. 1 Young
62	Indiana	Fountain	22	20N	9W	Fountain Oil No. 1 Bilsland
63	Indiana	Fountain	16	19N	8W	Aldridge No. 1 Bodine
64	Illinois	Douglas	36	16N	8E	Ohio No. 1 Shaw
65	Indiana	Montgomery	19	17N	5W	Van Horn No. 1 Foster
66	Indiana	Montgomery	14	17N	3W	Zink No. 1 Kessler
67	Indiana	Boone	28	19N	1W	Zink No. 1 Flaningam
68	Indiana	Boone	34	19N	2E	Smith No. 1 Marshall
69	Indiana	Boone	5	17N	2E	Ottinger No. 1 Ottinger
70	Indiana	Hamilton	13	19N	3E	Hamilton No. 2 Melson
71	Indiana	Marion	15	16N	3E	Borden No. 1 Indianapolis
72	Indiana	Hendricks	5	14N	1W	Dome-Minnick No. 1 Hayworth
73	Indiana	Putnam	17	14N	3W	Hayes No. 1 Nichols
74	Indiana	Putnam	15	14N	5W	Stanolind No. 1 Wells
75	Indiana	Putnam	10	13N	4W	Williams No. 1 Cooper
76	Indiana	Vigo	5	10N	10W	Higginbotham No. 1 Flescher
77	Indiana	Clay	19	10N	6W	Reagan No. 1 Luther
78	Indiana	Owen	23	10N	5W	Sun No. 1 Chambers
79	Indiana	Owen	35	11N	3W	Michel No. 1 Ritter
80	Indiana	Morgan	16	13N	1W	Jefferson No. 1 Brown
81	Indiana	Morgan	35	13N	1E	Weddel No. 1 Barnard
82	Indiana	Morgan	18	11N	1W	Potter No. 1 Hodges
83	Indiana	Johnson	4	12N	4E	Hassett No. 1 Lagrange
84	Indiana	Shelby	35	14N	6E	Snider No. 1 Rice
85	Indiana	Shelby	27	13N	6E	Seevers No. 1 Meloy
86	Indiana	Shelby	9	12N	8E	McDaniel No. 1 McDaniel
87	Indiana	Rush	33	15N	10E	Rich-Lands No. 1 Waggoner
88	Indiana	Rush	25	12N	10E	Rich-Lands No. 1 Spencer
89	Indiana	Wayne	23	15N	13E	Gordon No. 1 Doddridge
90	Indiana	Wayne	22	13N	1W	Wayne County No. 1 Taylor
91	Indiana	Franklin	36	12N	12E	Franklin No. 1 Franklin
92	Indiana	Decatur	8	10N	9E	Nobbe No. 1 Nobbe
93	Indiana	Bartholomew	24	8N	5E	Waterbury No. 1 Lee
94	Indiana	Brown	33	10N	3E	Hiatt No. 1 Hiatt
95	Indiana	Monroe	6	9N	1E	Solomito No. 1 Solomito
96	Indiana	Monroe	29	8N	1E	Pardoe No. 1 Union
97	Indiana	Greene	10	8N	4W	Whitaker No. 1 Starr
98	Indiana	Greene	4	7N	5W	Shicker No. 1 Kiser
99	Indiana	Greene	1	8N	7W	Lyons No. 1 Blanton
100	Indiana	Sullivan	36	8N	9W	Felmont No. 1 Riggs
101	Indiana	Sullivan	19	9N	10W	Myers No. 1 Thomas
102	Indiana	Knox	Loc. 97	3N	10W	Poe No. 1 Guerrettaz
103	Indiana	Lawrence	34	4N	2W	Regional No. 1 Lewis
104	Indiana	Jackson	11	5N	2E	Siosi No. 1 Anderson
105	Indiana	Jackson	6	4N	5E	Aetna No. 1 Turkhorn
106	Indiana	Jennings	30	7N	8E	Ohio Valley No. 1 Phillips
107	Indiana	Jennings	29	6N	7E	Steed No. 1 Maschino
108	Indiana	Jennings	23	5N	7E	Comiskey No. 1 Johnson
109	Indiana	Jennings	12	5N	8E	Smart No. 1 Smart

Table 1.—*Test wells referred to in text and illustrations listed by datum-point number*—Continued

Datum point no.	State	County	Location			Operator and name of well
			Sec.	T.	R.	
110	Indiana	Dearborn	11	6N	2W	Dearborn No. 1 Crobnback
111	Indiana	Dearborn	23	5N	2W	Seevers No. 1 Bruce
112	Indiana	Dearborn	15	5N	1W	Central No. 1 Bobrink
113	Indiana	Dearborn	28	6N	1W	Regional No. 1 Fox
114	Indiana	Jefferson	32	4N	8E	Burton No. 1 Cheatham
115	Indiana	Scott	15	4N	7E	Weston No. 1 Charlton
116	Indiana	Scott	35	4N	7E	Hart No. 1 Hammond
117	Indiana	Clark	18	1N	10E	Russ No. B-2 Stewart
118	Indiana	Clark	7	1N	9E	Stoll No. 1 Waters
119	Indiana	Clark	Grant 195	1N	8E	Clark No. 1 McClellan
120	Indiana	Clark	Grant 165	1S	6E	Smith No. 1 Schubnell
121	Indiana	Clark	Grant 131	1S	7E	Louisville No. 1 Louisville
122	Indiana	Clark	Grant 53	1S	7E	Russ No. 1 Garriott
123	Indiana	Clark	1	1S	5E	Patton No. 1 Martain
124	Indiana	Clark	2	1S	5E	Patton No. 2 Haywood
125	Indiana	Clark	11	1S	5E	Patton No. 1 Haywood
126	Indiana	Washington	10	3N	2E	Tri County No. 1 Owsley
127	Indiana	Washington	8	2N	4E	Washington No. 1 Elrod
128	Indiana	Washington	10	1N	3E	Washington No. 1 Cauble
129	Indiana	Orange	29	3N	2W	Hays No. 1-A Baker
130	Indiana	Orange	17	1N	1E	Cameron No. 1 Barclay
131	Indiana	Dubois	35	3S	5W	Texas No. 1 Luebbehuesen
132	Indiana	Pike	25	1S	9W	Indiana Farm Bureau No. 1 Subar
133	Indiana	Pike	14	3S	8W	Miller No. 1 Nixon
134	Indiana	Gibson	16	1S	11W	Brown No. 1 Bingham
135	Indiana	Gibson	13	3S	14W	Continental No. 1-D Cooper
136	Indiana	Perry	25	4S	3W	Central No. 1 Delaise
137	Indiana	Perry	17	4S	1W	Sun No. 1 Gibson
138	Indiana	Crawford	11	2S	2W	Roggenkamp No. 1 Smith
139	Indiana	Harrison	36	2S	4E	Stoll No. 1 Leonhardt
140	Indiana	Harrison	11	4S	3E	Hayes No. 1 Grove
141	Indiana	Harrison	4	6S	4E	Harrison No. 1 Holliday
142	Indiana	Floyd	28	1S	5E	Chenault No. 1 Scharf
143	Indiana	Floyd	16	3S	6E	Stoll No. 1 Scherzinger
144	Kentucky	Bullitt	6	R	46	Stoll No. 1 Watkins
145	Kentucky	Spencer	13	S	49	Stoll No. 1 Wilkerson
146	Kentucky	Shelby	9	T	54	Stoll No. 1 Whittaker
147	Kentucky	Anderson	17	S	56	Stoll No. 1 Bond
148	Kentucky	Lincoln	13	L	57	California No. 1 Spears

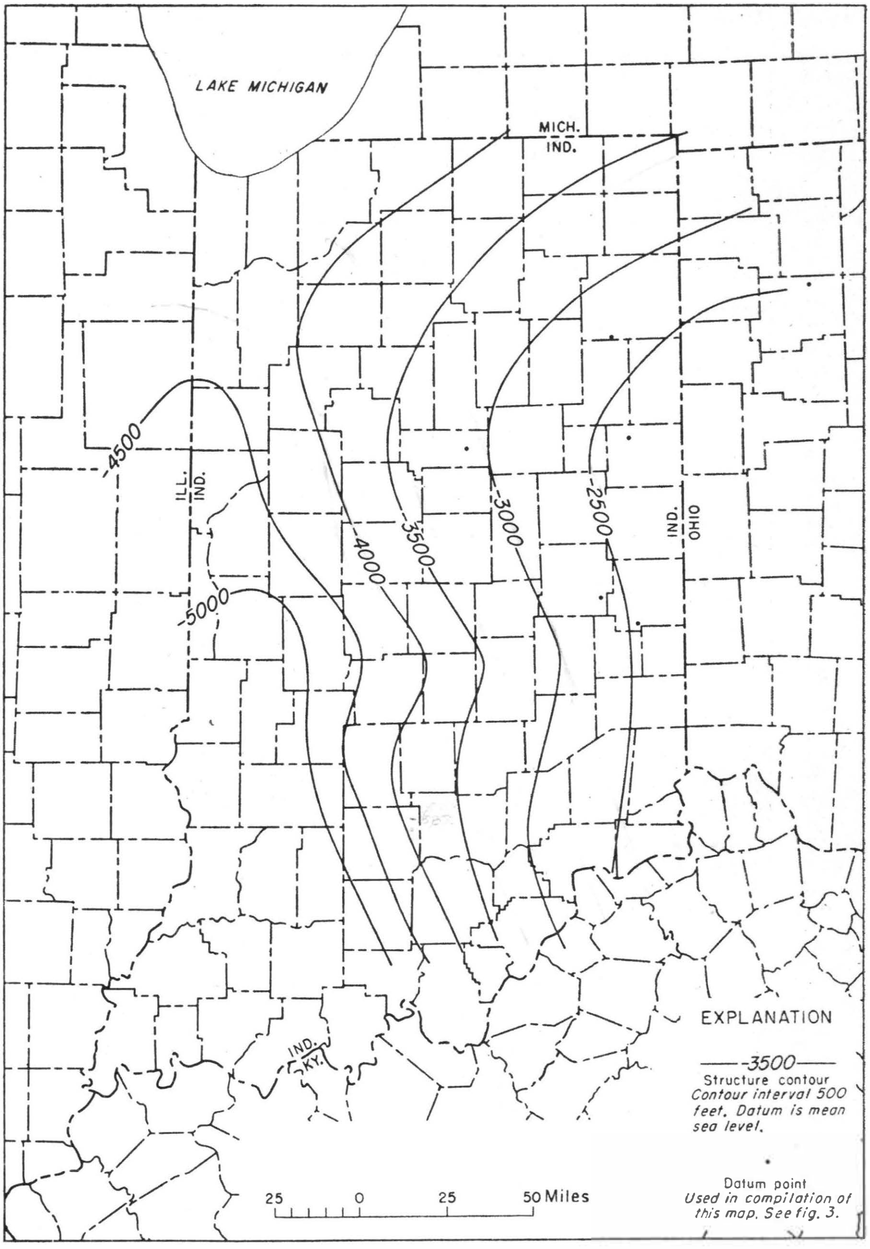

Figure 5.—Map showing inferred structure contours on top of Precambrian basement complex.

ginning of the Paleozoic era. Most evidence indicates that they were not present until at least middle Paleozoic time. Although the top of the basement complex is an erosional surface, the large contour interval used in the map probably minimizes the effect of topography.

ST. CROIXAN SERIES (UPPER CAMBRIAN)

According to Moore (1949, p. 102), the interior of the North American continent was not covered by Early and Middle Cambrian seas. The oldest Paleozoic rocks in Indiana and adjacent states are assumed to be St. Croixan (Late Cambrian) in age.

In this report the St. Croixan series is subdivided into the following formations in descending order: Trempealeau formation, Franconia formation, Galesville sandstone, Eau Claire formation, and Mt. Simon sandstone. Payne (1942, p. 54, footnote 4) also regarded the Galesville, the Eau Claire, and the Mt. Simon as distinct formations. Other usages have been suggested, however (table 2). For example, the United States Geological Survey does not use the name Trempealeau formation but elevates certain units (considered members of the Trempealeau formation by others) to formational rank (Wilmarth, 1938, p. 2178-2179); furthermore, it uses the name Dresbach in place of Galesville (Wilmarth, 1938, p. 631, 657, 1414). Twenhofel and others (1954) regarded the Galesville, the Eau Claire, and the Mt. Simon as members of the Dresbach formation.

The Mt. Simon sandstone and the Eau Claire formation can be identified throughout most of Indiana. The Galesville sandstone and the Franconia and Trempealeau formations, however, can be identified only in northwestern Indiana, and, therefore, equivalent strata elsewhere in Indiana are referred in this report to the lower part of the Knox dolomite. (See table 2.)

RED CLASTICS

Most deep wells drilled in Wisconsin, Michigan, eastern Minnesota, northern Illinois, and northern Indiana encounter a sandstone or sandstone and shale unit that overlies the basement complex and that is overlain by strata of presumed Late Cambrian age. This unit is commonly pink to red and is referred to as the "Red Clastics" or Red Clastics (with or without quotation marks) in the literature. The age of the Red Clastics is not definitely known. Possible equivalents of the Red Clastics in Indiana are included in the basal part of the Mt. Simon sandstone in this report.

Table 2.—*Selected examples of stratigraphic nomenclature of rock units within the lower part of the St. Croixan series as defined in Indiana, modified from various sources referred to in text*

Wisconsin and Minnesota outcrop		Eastern Missouri outcrop	Northern Illinois subsurface	Southern Illinois subsurface	Southern Michigan and eastern Ohio subsurface	Indiana subsurface	
						Northwest	Northeast and south
Dresbach formation	Galesville member	Bonneterre dolomite	Galesville sandstone		Dresbach sandstone	Galesville sandstone	Lower part of Knox dolomite
Dresbach formation	Eau Claire member	Bonneterre dolomite	Eau Claire formation	Bonneterre formation	Eau Claire sandstone	Eau Claire formation	
Dresbach formation	Mt. Simon sandstone member	Lamotte sandstone	Mt. Simon (and Fond du Lac?) sandstone	Lamotte sandstone	Mt. Simon sandstone	Mt. Simon sandstone	

A log of a deep well near Rochester, Minn., given by Stauffer (1927, p. 472-473), indicates that the Red Clastics in that area consist chiefly of red shale, accompanied by some red sandstone and a small amount of green shale. Stauffer recorded a thickness of 2,033 feet.

In the Northern Peninsula of Michigan, the Mt. Simon sandstone is underlain by the red arkosic Jacobsville sandstone. Cohee (1948, p. 1419) stated that the Jacobsville consists of sandstone which is mottled and striped with streaks of red clayey shale and is conglomeratic in its basal part. It may be as much as 1,500 feet thick. This same unit has been encountered in a few wells in the Southern Peninsula, according to Cohee.

Red sandstones underlying the Mt. Simon in subsurface have been reported in Wisconsin (Thwaites, 1923, p. 555; Trowbridge and Atwater, 1934, p. 31-38; Atwater and Clement, 1935, p. 1683-1684) and northern Illinois (Payne, 1942, p. 54; Workman and Bell, 1948, p. 2041-2043; Templeton, 1950). Payne (1942, p. 54) described the basal zone of the Mt. Simon in north-central Illinois as variegated arkosic medium- to coarse-grained sandstone that contains interbedded red and green micaceous shale in the lower half of the zone. He cited a representative thickness of 200 feet for this unit.

The basal part of the Mt. Simon sandstone in northern and central Indiana consists of medium- to coarse-grained generally rounded and frosted loosely consolidated pink sandstone which may be related to the Red Clastics.

Stauffer (1927, p. 474-475) believed that the Red Clastics of Minnesota are Middle Cambrian in age on the basis of fauna. Most writers since Stauffer, however, have believed that these beds are Precambrian in age.

Atwater and Clement (1935, p. 1680-1684) believed that the Red Clastics of the Wisconsin-Minnesota area may be representative of the Hinckley formation of upper Keweenawan (Precambrian) age but suggested continued use of the name "Red Clastics" (their quotation marks) pending further investigation. Payne (1942, p. 54) also suggested the possibility of such a correlation.

Bays and others (1945, p. 1146) and Weller and others (1945) correlated with question the Red Clastics in northern Illinois with the Fond du Lac sandstone (Keweenawan) of northeastern Minnesota. Workman and Bell (1948, p. 2041- 2042) used the combined term Mt. Simon-Fond du Lac? sandstones (their question mark). Raasch (1950) suggested that both the Hinckley and Fond du Lac formations are Cambrian in age. Templeton (1950, p. 151) regarded the Red Clastics in northern Illinois as a local facies of the Mt. Simon sandstone.

Because of the lack of an established correlation and the very slight difference between the basal pink zone of the Mt. Simon and the remainder of the formation in Indiana, the present writer considers this local pink sandstone a part of the Mt. Simon sandstone.

MT. SIMON SANDSTONE

LITHOLOGY AND THICKNESS IN INDIANA

The Mt. Simon sandstone in Indiana is composed of fine to coarse sand which varies in color from clear to pink and is poorly consolidated, even though a small amount of silica cement has been observed. For the most part, the sand is markedly coarser in the Mt. Simon than in any other units of the Cambrian and Ordovician systems in Indiana. The sand grains are generally well rounded and frosted. A small percentage of them contains inclusions of tourmaline, magnetite, hematite, or limonite.[2]

The basal 300 to 400 feet of the Mt. Simon in Indiana commonly has a reddish appearance, but data are still too sparse to determine whether or not this represents an areally persistent lithologic unit. (See discussion of Red Clastics, p. 19-22.)

Variations in thickness of the Mt. Simon sandstone are shown in figure 6. Only six deep test wells in Indiana have penetrated the entire formation. The Mt. Simon probably is more than 2,000 feet thick in northwestern Indiana, as 2,255 feet of sand was encountered in Kankakee County, northeastern Illinois (datum-point no. 14).[3] The formation is probably less than 200 feet thick in southeastern Indiana, as the sand thins in this direction (fig. 6); the sand is only 226 feet thick in Wayne County (datum-point no. 89).

LITHOLOGY AND THICKNESS IN SURROUNDING REGION

Outcrop region.—In outcrop in western Wisconsin, according to Twenhofel, Raasch, and Thwaites (1935, p. 1693-1694), the Mt. Simon sandstone consists of medium- to coarse-grained sandstone and local beds of conglomerate and gray, pink, or red shale. The sand may be yellow, brown, pink, or red. The formation is

[2] Identification by Wayne M. Bundy, formerly on the staff of the Indiana Geological Survey.

[3] All datum-point numbers refer to table 1 and figure 3.

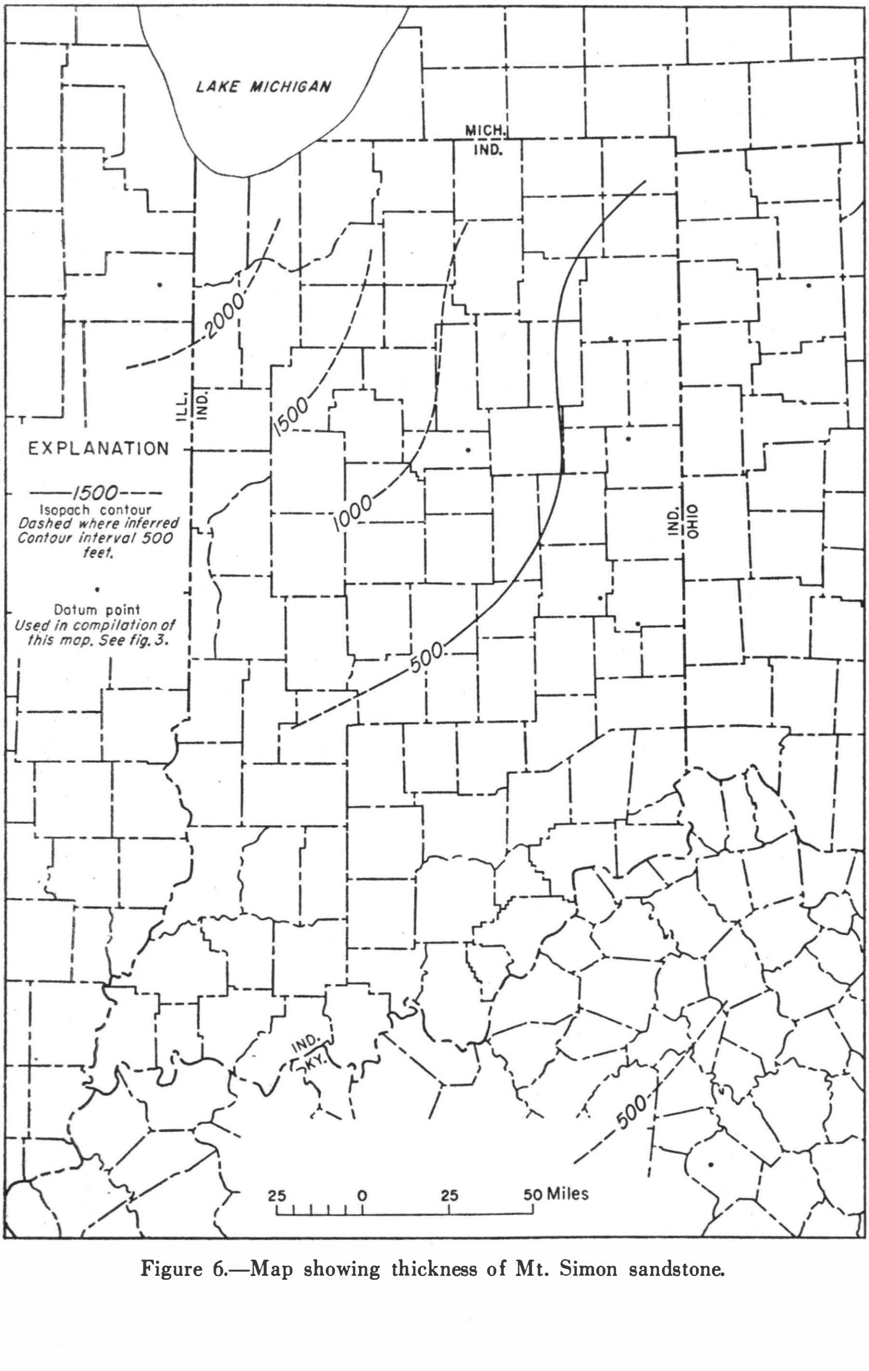

Figure 6.—Map showing thickness of Mt. Simon sandstone.

about 200 feet thick at the type locality (near Eau Claire, Wis.) but thickens in subsurface. The Mt. Simon rests unconformably on Precambrian crystalline rocks or on the Red Clastics. The upper boundary of the Mt. Simon is placed arbitrarily at the base of the first overlying fossiliferous strata (*Cedaria*).

Thwaites (1923, p. 553) described the Mt. Simon in subsurface in central Wisconsin as coarse- to medium-grained gray or yellow sandstone that contains layers of green, blue, and red shale. Less of the formation is coarse grained to the south, and pink layers occur locally. A maximum thickness of 778 feet was recorded in southwestern Wisconsin.

Illinois.—Payne (1942, p. 54) included a representative sample log of the Mt. Simon in north-central Illinois in which the Mt. Simon may be described, in summary, as variegated fine- to coarse-grained sandstone that has some interbedded conglomerate and gray, brown, red, or green shale. Payne cited a representative thickness of 1,690 feet, including a basal 200 feet which may be referred to as Red Clastics.

Templeton (1950, p. 152) cited a maximum known thickness of 2,120 feet for the Mt. Simon in northeastern Illinois. He divided the Mt. Simon into an upper light-colored facies and a lower red facies and made subdivisions on the basis of grain size. Templeton's description of the light-colored facies may be summarized as follows: white, yellow, or pink to light-brown and fine- to very coarse-grained sand; the smaller grains are subangular and the larger are rounded and frosted; the unit is poorly consolidated, but some silica and iron oxide cement are present; an arkosic zone occurs at the base. The red facies is characterized by large amounts of disseminated dark-red hematitic clay and silt and by relatively thick interbeds of dark-red micaceous partly sandy shale and siltstone. Templeton suggested, on the basis of lithologic correlation, that "the Mt. Simon sandstone of Minnesota and the upper part of the Mt. Simon at the type locality belong to the Eau Claire formation" (p. 151).

In cuttings from a test well in Kankakee County, northeastern Illinois (datum-point no. 14), the present writer noted 2,255 feet of the Mt. Simon sandstone, which had been penetrated without reaching the base of the formation. The sand is generally unconsolidated, medium to coarse, and yellowish to colorless. About half of the sand grains are rounded and frosted and half are clear and angular (possibly broken during drilling).

Michigan.—According to Cohee (1948, p. 1419), the Mt. Simon thins eastward from Illinois, is only 300 feet thick in southeastern Michigan, and is absent in southwestern Ontario. Cohee stated that the formation is composed of medium- to coarse-grained subangular to rounded sand and that it has a few thin beds of dolomite and sandy dolomite in the upper part.

None of the test wells in Michigan which are shown on the maps in this report reached the Mt. Simon. A test well in Washtenaw County, southeastern Michigan,[4] penetrated 584 feet of sand which was found by the writer to be generally finer than the sand from the test well in Kankakee County, Ill., described above. The upper 160 feet of sand is very slightly glauconitic and slightly finer grained than the underlying sand; this suggests that the upper sand might be included more properly in the overlying Eau Claire formation.

Ohio.—On the basis of published descriptions, the writer concludes that the Mt. Simon sandstone was penetrated in tests in Clark County, southeastern Ohio (Wasson, 1932), and in Delaware County, central Ohio (Stout and Lamey, 1940), but the formation is not named in these works. In Putnam County, northwestern Ohio (datum-point no. 22), the present writer observed the Mt. Simon sandstone to be 345 feet thick. The upper 160 feet is composed of fine to medium loosely consolidated sand which is generally white, rounded, and frosted, and the lower 185 feet is composed of medium to coarse loosely consolidated sand which also is rounded and frosted but is pink. Fettke (1948, p. 1480) assigned a thickness of 292 feet to the Mt. Simon in this test well.

Kentucky.—Only one test well has penetrated the entire basal sand interval in Kentucky (Lincoln County, south-central Kentucky, datum-point no. 148). In this test well, the basal sand consists of about 600 feet of white unconsolidated to silica-cemented sandstone. The sand is fine to medium grained in the upper 400 feet, medium to coarse grained in the lower 200 feet, and commonly rounded and frosted throughout. Material which has caved from the overlying formations, especially from the immediately superjacent Nolichucky shale, obscures the true lithologic and thickness relationships. Freeman (1953, p. 209) stated that this sand is called the "Spears Sand" by drillers in Kentucky, and she believed (1953, p. 18-19, fig. 1) this sand to be Middle Cambrian in age.

[4] Colvin and others, No. 1 Meinzinger, sec. 12, T. 2 S., R. 7 E., Washtenaw County, Mich.

CORRELATION OF THE MT. SIMON SANDSTONE

Twenhofel, Raasch, and Thwaites (1935, p. 1693-1694) indicated that the upper boundary of the Mt. Simon sandstone in the type area is placed at the base of a faunal zone (*Cedaria*). The identification of this zone is not possible in subsurface work, owing to scarcity of fossils in cuttings. In subsurface, according to these writers (p. 1693), the upper boundary is placed at the top of the highest relatively nonargillaceous medium-grained sandstone.

Workman and Bell (1948, p. 2041-2050) apparently differentiated the Mt. Simon from the overlying Eau Claire in subsurface in Illinois on the basis that the Mt. Simon (Mt. Simon-Fond du Lac(?) in their terminology) consists almost wholly of sand, whereas the Eau Claire in Illinois contains dolomite, limestone, shale, siltstone, and glauconite. They successfully traced the Mt. Simon thus defined throughout Illinois, as available data permitted, and showed its lithologic continuity with the Lamotte sandstone, which is the basal formation of the St. Croixan series in the Ozark region. The same correlation already had been established between the outcrops in the upper Mississippi Valley and in Missouri by Bridge (1937) on the basis of paleontology. It would seem, therefore, that the upper boundary of the Mt. Simon, drawn on faunal grounds in the type area, may be identified on the basis of a change in lithology in subsurface. The present writer used lithologic criteria in identifying the upper boundary of the Mt. Simon sandstone in Indiana. The unit identified as Mt. Simon by Workman and Bell (1948, p. 2041-2043) in Illinois continues to the east into Indiana, as described above. The lower boundary of the Mt. Simon sandstone in Indiana is placed at the contact with igneous or metamorphic rocks below.

Thickness relationships of the Mt. Simon sandstone in Indiana and in adjacent states are shown in figures 4 and 6. The Mt. Simon thins from more than 2,000 feet in northwestern Indiana to 200 feet or less in the southeastern part of the State. These thickness relationships suggest that the source of the sand of the Mt. Simon was to the north, most probably the Canadian shield. The increase in thickness in Kentucky suggests a different source for the basal sand in Kentucky—possibly from the crystalline rocks in the Ozark dome region.

EAU CLAIRE FORMATION

LITHOLOGY AND THICKNESS IN INDIANA

The Eau Claire formation in Indiana contains three characteristic lithologies: (1) very fine to fine dolomitic sandstone or siltstone which is usually pink; some beds contain very abundant glauconite; (2) green, maroon, and black shale, all glauconitic and micaceous; and (3) light-tan silty or sandy dolomite; some beds are glauconitic. Because of the varied lithologies included in the Eau Claire in Indiana, the writer uses the name Eau Claire formation rather than Eau Claire sandstone. The writer has not noted any regular sequence of lithologies within the Eau Claire, but this may be due in part to incorrect evaluation of the amount of caved material. Bieberman and Esarey (1946, p. 6) noted a threefold subdivision of the Eau Claire in eastern Indiana consisting of an upper member of glauconitic dolomite and gray-green and red shale, a middle member of pink glauconitic dolomite and no significant amount of shale, and a lower member of glauconitic sandstone and a few beds of shale. A similar sequence is present in Johnson County, south-central Indiana (datum-point no. 83), as indicated by insoluble residues through the interval, although the entire formation was not penetrated. It is not possible to determine whether such subdivision is applicable throughout the State.

Fragments of an oolitic limestone similar to that described by Workman and Bell (1948, p. 2049) were found in the middle part of the Eau Claire in the deep test well in Johnson County, south-central Indiana (datum-point no. 83). This limestone probably represents the east edge of the oolitic limestone described in Illinois.

The sand in the Eau Claire is cemented with dolomite, in contrast with the poorly consolidated or silica-cemented Mt. Simon below. In addition, the sand in the Eau Claire is much finer than in the underlying Mt. Simon. The sand grains in the Eau Claire approach the silt-size range and are generally angular and clear rather than rounded and frosted as in the Mt. Simon.

Shale is apparently abundant in the Eau Claire. It is difficult, however, to evaluate the true thickness of the interbedded shales from the available cuttings. Electric logs would give an indication of the true picture, but these are not available for the deep test wells.

Glauconite is characteristic of the Eau Claire in Indiana. It generally occurs in the form of nodules and groups of nodules and is bright green. Rare fossil fragments, chiefly *Lingula* sp., are found in cuttings from the Eau Claire.

Variations in thickness of the Eau Claire formation are illustrated in figures 4 and 7. The isopach lines in figure 7 suggest the presence in central Indiana of a broad, elongate lens which trends approximately eastward and westward and in which the maximum thickness of the Eau Claire is between 700 and 800 feet. Available data indicate that the Eau Claire thins from the center of the State to a known thickness of about 450 feet in northern Indiana and about 600 feet in southeastern Indiana.

LITHOLOGY AND THICKNESS IN SURROUNDING REGION

Outcrop region.—According to Twenhofel, Raasch, and Thwaites (1935, p. 1694-1696), the Eau Claire sandstone in western Wisconsin is divided into two faunal zones. The lower (*Cedaria*) zone has its base at the first appearance of the *Cedaria* fauna above the virtually unfossiliferous Mt. Simon sandstone. The overlying *Crepicephalus* zone extends from the lowest occurrence of *Crepicephalus* to the base of the unfossiliferous Galesville sandstone above. The lower zone consists of medium- to fine-grained quartz sand and some silt and clay. Eastward from the outcrop, both the fossils and the shaly layers are absent, and the zone is indistinguishable from the underlying Mt. Simon. The upper zone is similar in lithology to the lower but is somewhat more thickly bedded in outcrop and contains glauconite and red or green siltstone. The maximum thickness of the Eau Claire seems to be about 125 feet.

Illinois.—Thwaites (1923, p. 551-553) studied the Eau Claire in subsurface in southern Wisconsin and northern Illinois and found that the shale content is greater in these regions than in outcrop.

Workman and Bell (1948, p. 2043-2050) described the Eau Claire formation in Illinois as consisting of dolomite, limestone, shale, siltstone, and sandstone. They were able to recognize several facies in various parts of Illinois. They divided the Eau Claire in northeastern Illinois into a lower half, which contains a considerable amount of dolomite and which grades downward and laterally to siltstone and sandstone, and an upper half, which consists chiefly of red and green shale interbedded with sandstone, siltstone, and sandy dolomite. In north-central and northwestern Illinois they found the Eau Claire to consist mainly of sandstone

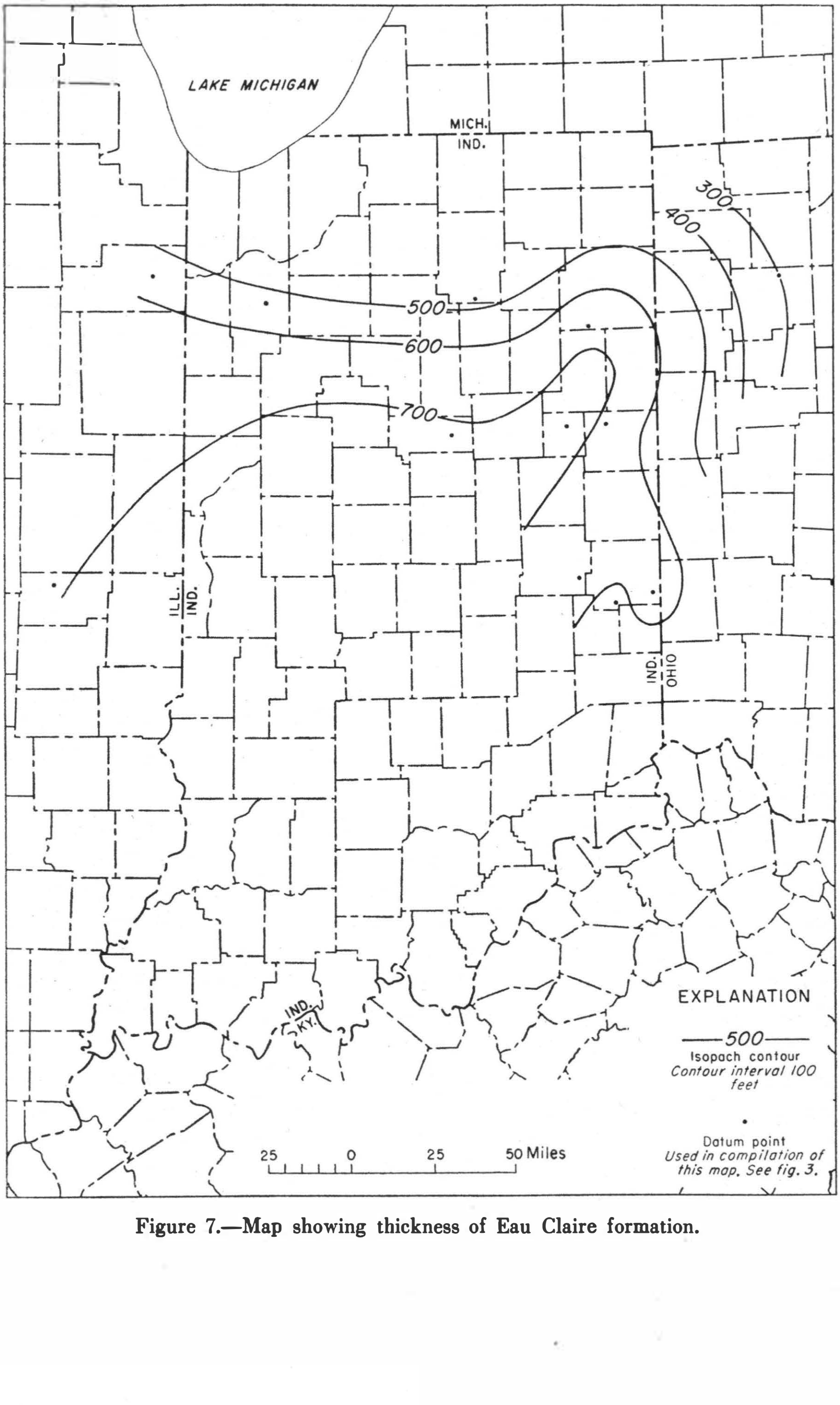

Figure 7.—Map showing thickness of Eau Claire formation.

and some shale and dolomite. Throughout the remainder of Illinois, much of the sandstone is replaced by siltstone, limestone, and dolomite.

Workman and Bell (1948, p. 2049) stated that all Eau Claire rocks except an oolitic limestone unit contain fine-grained glauconite. The oolitic limestone consists of a light grayish-brown matrix and medium to coarse chocolate-brown oolites. A second type of limestone is light gray, green, buff, or white and is very fine grained and contains glauconite and sand. They described the sandstones as very fine grained, dolomitic, gray, green, and brown.

An isopach map of the Eau Claire formation presented by Workman and Bell (1948, fig. 5) indicates a rather uniform rate of thickening eastward across Illinois from less than 300 feet along the Mississippi River to 650 feet or more near the Indiana boundary.

The present writer noted that the Eau Claire is 710 feet thick in a test well in Douglas County, east-central Illinois (datum-point no. 64), and consists mainly of siltstone and shale. The upper 95 feet of the formation consists of argillaceous, silty, and sandy dolomite. An oolitic limestone unit, 140 feet thick, occurs 110 feet below the top of the formation.

In Kankakee County, northeastern Illinois (datum-point no. 14), the Eau Claire is only 580 feet thick; this is attributable to the absence of the oolitic limestone noted in the test well in Douglas County.

Michigan.—Cohee's description (1948, p. 1419) of the Eau Claire in western Michigan suggests that it is similar to the Eau Claire in Illinois in lithology and the presence of glauconite. He stated that the Eau Claire is more sandy in western Michigan than in eastern Michigan and that the formation consists entirely of sandstone in the Northern Peninsula of Michigan. He cited a thickness of 250 feet for the Eau Claire in southeastern Michigan.

Ohio.—The Eau Claire in Putnam County, northwestern Ohio (datum-point no. 22), consists of 100 feet of green and gray shale and silty dolomite, which are underlain by 200 feet of glauconitic silt and very fine to fine sand. Fettke (1948, p. 1480) assigned 350 feet to the Eau Claire in this test well.

Kentucky.—Freeman (1953, p. 19) used the name Bonneterre (dolomite) for the rocks between the basal sand and the overlying Elvins group in Kentucky. (See tables 2 and 3.) According to Howell and others (1944), the Bonneterre of Missouri is the time equivalent of the Eau Claire formation and Galesville sandstone in the upper Mississippi Valley.

In the log of a test well in Lincoln County, south-central Kentucky (datum-point no. 148), Freeman assigned 1,700 feet of strata to the Bonneterre, of which the upper 1,000 feet is essentially dolomite and the lower 700 feet is essentially shale and siltstone. The present writer noted a similarity of the shale and siltstone unit with the lower units in the Douglas County, Ill., test well cited above (datum-point no. 64). Because only the lower part of the dolomite in the Kentucky test well resembles the dolomite portions of the Eau Claire in the Douglas County, Ill., test well, the present writer would assign only the lower 700 feet to the Eau Claire.

CORRELATION OF THE EAU CLAIRE FORMATION

The lower boundary of the Eau Claire formation has been discussed under the heading, Correlation of the Mt. Simon sandstone. The upper limit of the Eau Claire in outcrop also is placed at a faunal boundary, that is, at the disappearance of *Crepicephalus*. There does not seem to be any definite evidence of physical change at this boundary, according to Twenhofel, Raasch, and Thwaites (1935, p. 1696). An arbitrary boundary must be selected in subsurface work, and this generally is the upper limit of the shales and glauconite.

The Eau Claire has been traced from outcrop into subsurface in southern Wisconsin and northern Illinois by Thwaites (1923, p. 551-553), throughout Illinois by Workman and Bell (1948, p. 2043-2050), across Michigan by Cohee (1948, p. 1419), and from Ohio eastward by Fettke (1948, p. 1480, figs. 3 and 5). These authors found that the formation consists of dolomitic sandstone or siltstone and shale and some dolomite or limestone. The presence of glauconite seems to be the most persistent characteristic of the Eau Claire.

The Eau Claire in Indiana shares these characteristics, and its thickness fits the regional trend indicated by the above authors. The Eau Claire of this report is the same as that called Eau Claire in subsurface by other authors. Workman and Bell (1948, p. 2049) correlated the subsurface Eau Claire with the Bonneterre dolomite of Missouri on the basis of physical continuity (table 2). The Bonneterre had already been shown to be the same age as the type Eau Claire by Bridge (1937) on the basis of paleontology.

Thus, subsurface lithologic and outcrop paleontologic correlations seem to be in agreement.

Swann and others (1951, p. 497) noted that beds physically continuous with the type Eau Claire may be separated into three facies: chiefly sandstone (which they called Eau Claire), sandstone, shale, and dolomite (which they called Nolichucky), and dolomite (which they called Bonneterre). Use of the name Nolichucky shale may be advisable, because the type Nolichucky is composed chiefly of shale—which is true at many places in Indiana—whereas the type Eau Claire is composed chiefly of sand—which it never is in Indiana. The present writer chooses to retain the name Eau Claire, however, as physical continuity has been demonstrated between the type Eau Claire and the Eau Claire in Indiana. If such continuity can be established between the Eau Claire in Indiana and the Nolichucky shale in Tennessee, use of the Nolichucky would be justified.

Swann and others (1951, p. 497) stated that the three facies (Eau Claire, Bonneterre, Nolichucky) should interfinger in the Illinois Basin; the present writer believes that they do. Exact correlation of the three facies is uncertain at present.

GALESVILLE SANDSTONE

LITHOLOGY AND THICKNESS IN INDIANA

The Galesville sandstone was identified in two test wells drilled in northwestern Indiana in Lake County (datum-point no. 12) and Jasper County (datum-point no. 15). This sandstone is not present in Kosciusko County to the east (datum-point no. 7) and Howard County to the southeast (datum-point no. 30). (See fig. 8.)

In Lake County (datum-point no. 12), the Galesville is 170 feet thick. The upper 60 feet consists of dolomitic sandstone grading to very sandy dolomite; the sand is medium to coarse grained and rounded and frosted, and the dolomite is light to medium tan and medium crystalline. A small amount of glauconite (or chlorite?) is present in the upper 20 feet. The lower 110 feet is represented in samples by loosely consolidated sand, as described above, without glauconite.

In Jasper County (datum-point no. 15), the Galesville is 155 feet thick. The upper 40 feet includes a much larger proportion of loosely consolidated sand, but the formation is otherwise similar to the Galesville in Lake County. In both places the base of the Galesville is placed at the top of a dark-tan medium-crystalline

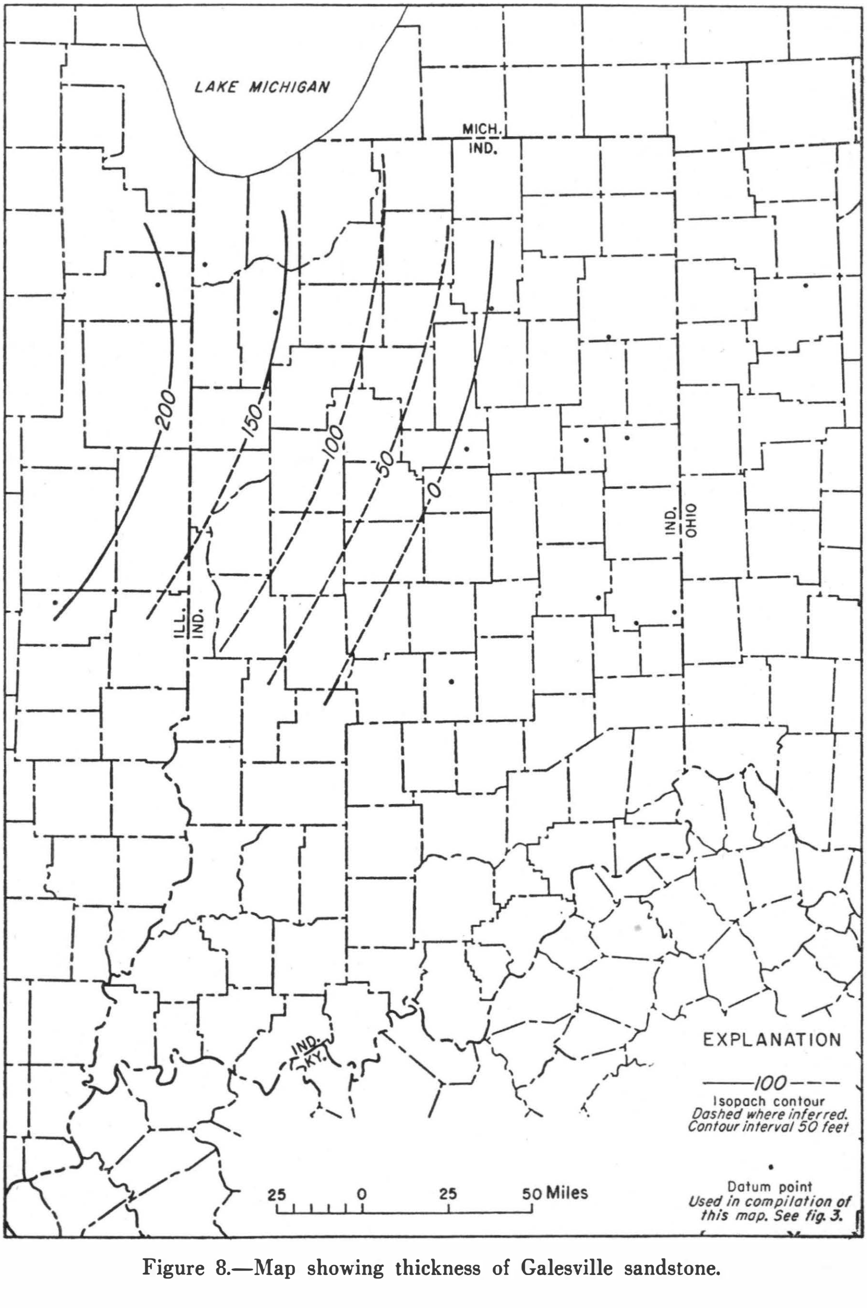

Figure 8.—Map showing thickness of Galesville sandstone.

dolomite, which averages 25 feet in thickness, and which is included within the underlying Eau Claire formation.

LITHOLOGY AND THICKNESS IN SURROUNDING REGION

According to Twenhofel, Raasch, and Thwaites (1935, p. 1697), the Galesville sandstone in outcrop in Wisconsin is medium-grained rather well-sorted sandstone which is white to yellow or, locally, brown to red. They stated that, by definition, it is free from glauconite or fossils and cited a maximum known thickness of 75 feet.

Payne (1942, p. 55) recorded a similar lithology for the Galesville in north-central Illinois, but he gave a thickness of 215 feet for this formation. Workman and Bell (1948, p. 2050-2052) reported the occurrence of "honey-colored" dolomite cement, especially in the upper half of the unit in Illinois. Their isopach map (1948, fig. 6) indicates a thinning of the Galesville from about 200 feet in north-central Illinois to the vanishing point in central Illinois.

Cohee (1948, p. 1425) reported the occurrence of Galesville (Dresbach, in his terminology) in southeastern Michigan and gave a thickness of about 100 feet for this formation. Fettke (1948, p. 1481) assigned 10 feet of glauconite-free dolomitic sandstone in a test well in northwestern Ohio to the Galesville (Dresbach, in his terminology).

CORRELATION OF THE GALESVILLE SANDSTONE

Because of the limited occurrence of the Galesville sandstone in Indiana, the writer has been guided chiefly by correlations made in Illinois.

The upper boundary of the Galesville in Indiana is placed at the contact of this sandstone with the overlying silty dolomite which probably represents the Franconia formation. Cross sections and maps presented by Workman and Bell (1948, figs. 2, 3, and 6) indicate that the Galesville is not present in the southern half of Illinois. In Indiana the unit is confined to the northwestern one-quarter of the State (fig. 8). The reported occurrence (Cohee, 1948, p. 1425) of 100 feet of Galesville sandstone in southeastern Michigan does not appear consistent with the regional trend shown in figure 8.

KNOX DOLOMITE
(UPPER CAMBRIAN AND LOWER ORDOVICIAN)

The Upper Cambrian clastic formations already described are overlain in Indiana by a relatively thick sequence of dolomites and thin, discontinuous sandstones presumed to be transitional from Late Cambrian to Early Ordovician age. Most of the Cambrian and Ordovician formations described in this report can be directly correlated with outcrop equivalents, but this transitional sequence does not appear to be susceptible to subdivision on the basis of present knowledge except in northwestern Indiana (table 3). However, the overall body of rock in Indiana occupies a stratigraphic position similar to that of the Knox dolomite which crops out in eastern Tennessee and has similar lithology. Although continuity with the Knox dolomite of Tennessee has not yet been established, the writer has chosen to refer to the Upper Cambrian to Lower Ordovician dolomite sequence in Indiana as Knox. This designation is commonly used in subsurface studies in Tennessee, Kentucky, and the Illinois Basin. Stratigraphic studies by other workers in the states adjoining Indiana have led to the application of various formational names for the rocks equivalent to the Knox as indicated in table 3.

METHODS OF SUBDIVISION

In order to determine the best method for characterizing various units within the Knox, the following techniques have been investigated: (1) examination of cuttings by means of the binocular microscope; (2) X-ray analysis of clay constituents; (3) quantitative spectrographic analysis of cuttings; and (4) studies of insoluble residues. Of these techniques, studies of insoluble residues showed the best possibility of utilization. Examination of cuttings with the binocular microscope is the simplest method available but is not satisfactory for subdivision, owing to the great overall similarity of the rocks which make up the Knox. It is expected, however, that variations in lithology, as revealed by other methods, will provide criteria for subdivision which then can be applied to microscopic examination.

X-ray analysis of clay constituents of carbonate rocks did not prove successful because the amount of argillaceous material in the Knox is too small for adequate analysis.

Quantitative spectrographic analysis of cuttings shows definite promise as a means for establishing objective rock units which can

Table 3.—*Selected examples of stratigraphic nomenclature of rock units equivalent to the Knox dolomite as defined in Indiana, modified from various sources referred to in text*

	Upper Mississippi Valley outcrop	Ozark region, Missouri outcrop	Northern Illinois subsurface	Southern Illinois subsurface	Central Basin, Tennessee subsurface	Indiana subsurface: Northwest	Indiana subsurface: Northeast and south
		Smithville limestone					
		Powell formation					
Prairie du Chien group	Shakopee (Willow River) dolomite	Cotter dolomite	Shakopee formation	Jefferson City-Cotter formation			
Prairie du Chien group		Jefferson City group					
Prairie du Chien group	New Richmond sandstone	Roubidoux formation	New Richmond sandstone	Roubidoux formation	Knox dolomite	Prairie du Chien group	
Prairie du Chien group	Oneota dolomite	Gasconade dolomite (Van Buren member at base)	Oneota dolomite	Van Buren-Gasconade formation			Knox dolomite
	Madison formation	Eminence dolomite	Gunter-Jordan formation	Gunter-Jordan formation		Gunter formation	

Table 3.—*Selected examples of stratigraphic nomenclature of rock units equivalent to the Knox dolomite as defined in Indiana, modified from various sources referred to in text*—Continued

Trempealeau formation	Jordan member			Trempealeau formation	Eminence dolomite	Knox dolomite	Trempealeau formation	Knox dolomite
	Lodi member	Potosi dolomite			Potosi dolomite			
	St. Lawrence member							
Franconia formation	Bad Axe member	Elvins group	Doe Run dolomite	Franconia formation	Elvins group?		Franconia formation	
	Hudson member		Derby dolomite					
	Goodenough member		Davis formation					
	Ironton member							

be related to observable changes in color and texture within the Knox. Composite samples were taken of 100-foot intervals through the Knox from 3 test wells, 1 each in north-central Indiana (Howard County, datum-point no. 30), in south-central Indiana (Johnson County, datum-point no. 83), and in southeastern Indiana (Dearborn County, datum-point no. 113). (Spot samples also were taken from one additional well for comparison; results were not significantly different.) Contamination of samples by scale and cave was evaluated before zonation. These samples were analyzed for iron, aluminum, calcium, magnesium, manganese, titanium, and silicon.[5] The Knox was successfully subdivided in the 3 test wells on the basis of relative content of iron, aluminum, and silicon into 4 zones (table 4).

Table 4.—*Zonation of Knox dolomite on the basis of chemical content*

Zone	Thickness (feet)	Relative iron content	Relative aluminum content	Relative silicon content
D	250-800	Intermediate	Intermediate	Large
C	150-400	Small	Small	Small
B	ca. 200	Large	Large	Intermediate
A	150 (1 well)	Large	Small	Small

In general, a large iron content in conjunction with a small aluminum content apparently indicated glauconite (zone A); a large iron content and a large aluminum content indicated argillaceous material (zone B); and a large silicon content indicated chert, sand, or silt (zone D).

Complete insoluble-residue studies were made of the same 3 test wells that were used in the spectrographic study and of 2 additional wells, 1 in northwestern Indiana (Jasper County, datum-point no. 15) and 1 in northeastern Indiana (Allen County, datum-point no. 21). This method proved to be the most successful because of the wide variety of composition, colors, and textures of residue. Similar methods have been used in the correlation of equivalent units in Missouri (McQueen, 1931; Grohskopf and McCracken, 1949; McCracken, 1955), Oklahoma (Ireland and Wishart, 1944), Texas (Hendricks, 1952), and Tennessee (Bentall and Collins, 1945). Insoluble residues are described in the next section.

[5] Analyses were made by R. K. Leininger and the staff of the Geochemistry Section, Indiana Geological Survey.

LITHOLOGY AND THICKNESS IN INDIANA

The Knox dolomite in Indiana consists of tan saccharoidal dolomite containing widely ranging percentages of sand or silty dolomite, chert, and sandstone. Thickness variations of the Knox are shown in figures 4 and 9. Only 10 test wells in Indiana, for which samples are available, have penetrated the entire Knox. Because information is scarce, and because the Knox does not lend itself to obvious state-wide subdivision, no subdivision is here recommended. The present writer has felt justified in subdividing the Knox into the Franconia formation, Trempealeau formation, Gunter formation, and Prairie du Chien group in only two test wells (datum-points nos. 12 and 15) in northwestern Indiana; this application is based on the correlations of Workman and Bell (1948) in eastern Illinois (table 3 in the present report). Equivalent rocks in adjacent states have been described by other workers in terms of outcropping formations. This procedure may be justified in Illinois, where these units are actually found in outcrop, but the application of outcrop terminology of the upper Mississippi Valley to these rocks in the states east of Illinois is to be questioned.

In order to illustrate a typical Knox section in Indiana, the writer's log of the Knox for datum-point no. 83 is here included. The possible correlations indicated should not be applied at this time, but they may prove to be useful when additional information becomes available.

Summary log of datum-point no. 83, sec. 4, T. 12 N., R. 4 E., Johnson County, Ind.

	Feet
Knox dolomite	
Dolomite: Light-tan to medium-tan to white, finely saccharoidal to crystalline; contains few floating sand grains. Dolomite 20 to 75 percent of sample; chert 25 to 75 percent of sample. RESIDUE: Chert: Mainly white but some blue; mainly smooth but some finely porous, dense, or quartzose; some blue oolitic, some white with brown oolites, some banded; contains moderate amount of included sand grains in chert. (Possibly Shakopee dolomite, Jefferson City group, and Cotter dolomite?)	154
Sand: Medium- to coarse-grained, rounded and frosted, unconsolidated; 50 to 90 percent of sample. Dolomite: Light-tan to medium-tan to white, very finely to finely saccharoidal; 10 to 50 percent of sample. Chert: 10 to 20 percent of sample. RESIDUE: Sand: Medium- to coarse-grained, rounded and frosted. Chert: Smooth, white, white with brown oolites, brown with white oolites, brown and transluscent; contains abundant included sand grains in chert. (Possibly New Richmond sandstone or Roubidoux formation?)	47

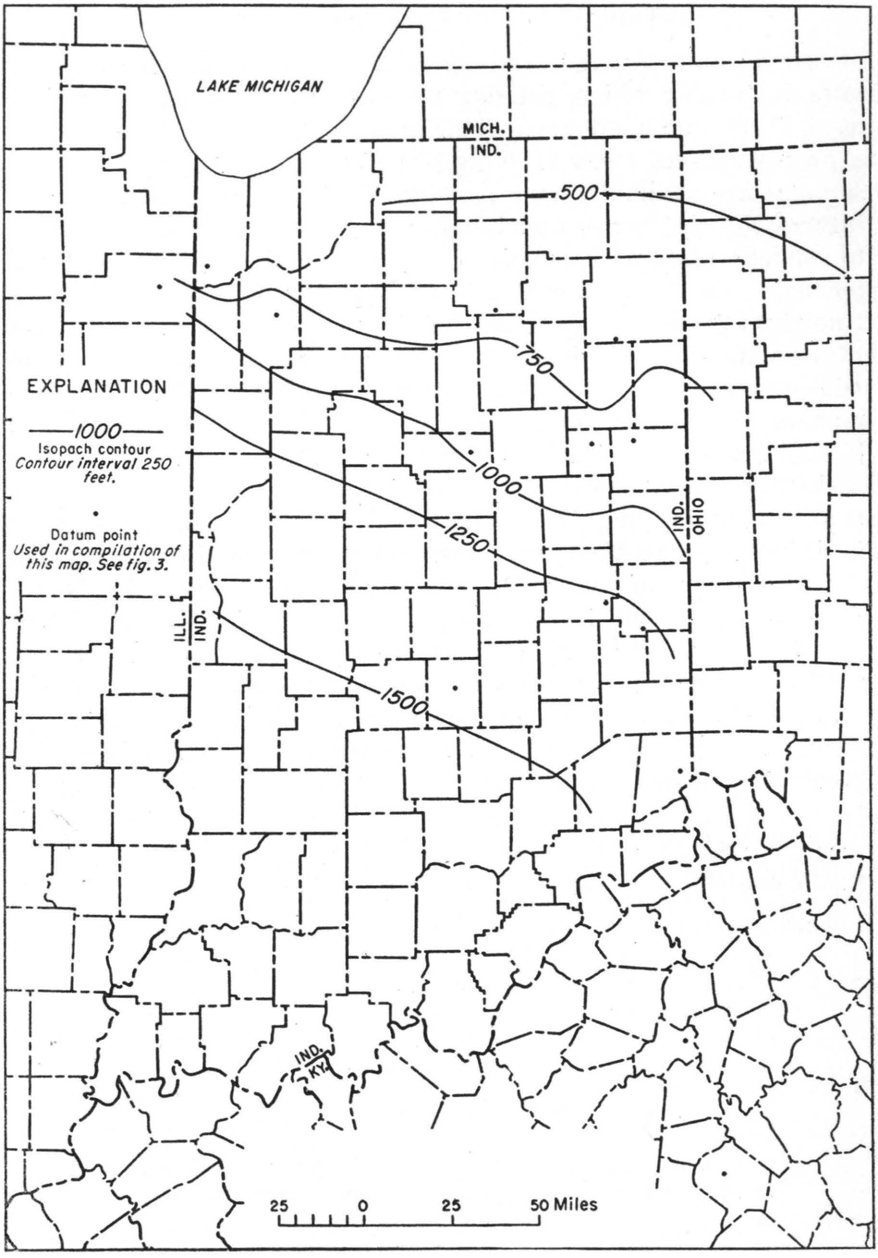

Figure 9.—Map showing thickness of Knox dolomite.

	Feet
Dolomite: Light-tan to light-gray, very finely to medium saccharoidal to crystalline; 20 to 90 percent of sample; sand in lower 30 feet constitutes as much as 30 percent of sample. Chert: 5 to 30 percent of sample. RESIDUE: Sand: Medium-grained, generally angular. Chert: White, dense to finely porous, and gray, smooth. (Possibly Oneota dolomite or Van Buren-Gasconade formation?)..........	91
Dolomite: Light-gray and light-tan to medium-tan, finely to medium saccharoidal; 60 to 95 percent of sample. Chert: 10 to 40 percent of sample. RESIDUE: Chert: Mostly white, dolomoldic; some white, finely porous; some gray, smooth. (Possibly Oneota dolomite or Van Buren-Gasconade formation?)	146
Dolomite: Light-gray and light-tan to medium-tan, finely to medium saccharoidal; generally 50 to 90 percent of sample. Chert: Generally about 50 percent of sample, but ranges from 5 to 100 percent of sample. RESIDUE: Chert: Brown, translucent and gray, translucent, smooth; dolomolds common; some chert mottled blue or mottled or banded brown, especially in lower 20 feet. (Possibly Oneota dolomite or Van Buren-Gasconade formation?)..........	181
Dolomite: Light-gray and light-tan to medium-tan, finely to medium saccharoidal; averages 75 percent of sample. Chert: Averages about 25 percent of sample, but may be as much as 50 percent of sample. RESIDUE: Chert: Generally gray, smooth to dense; some mottled brown. (Possibly Oneota dolomite or Van Buren-Gasconade formation?)	223
Dolomite: Light-tan to medium-tan, finely to very finely crystalline to saccharoidal; 80 to 90 percent of sample. Chert and finely crystalline quartz: About 10 percent of sample. RESIDUE: Chert: Gray, smooth to finely porous to quartzose; lower two-thirds of unit contains well-defined quartz crystals and very fine subhedral quartz crystals. (Possibly Trempealeau formation or Eminence and Potosi dolomites?)	143
Dolomite: Light-tan to medium-tan, finely to very finely crystalline to saccharoidal; 80 to 90 percent of sample. Chert: About 10 percent of sample. RESIDUE: Chert: Brown, quartzose and brown, smooth to gray, quartzose; some white chert with brown oolites. (Possibly Trempealeau formation or Eminence and Potosi dolomites?)	235
Dolomite: Medium-tan to dark-tan, very finely to finely crystalline to saccharoidal; nearly 100 percent of sample; trace of chert and quartz crystals. RESIDUE: Trace of white quartzose to dense chert and fine subhedral quartz crystals. (Possibly Trempealeau formation or Eminence and Potosi dolomites?)	100
Dolomite: Medium-tan to dark-tan, very finely to finely crystalline to saccharoidal; averages 80 percent of sample. Silt: Averages 20 percent of sample. Glauconite or chlorite in rare flakes. RESIDUE: Silt. (Possibly Franconia formation or Elvins group?)....	109
Total thickness	1,429

The following generalizations concerning this log also apply to the Knox elsewhere in Indiana: (1) The upper part of the formation (the upper 842 feet in the above log) consists of (a) tan saccharoidal dolomite that contains a large amount of chert of various colors and textures but that is commonly oolitic and (b) some rounded and frosted sand. (2) The lower part of the formation (the lower 587 feet in the above log) consists of finely crystalline to saccharoidal dolomite that contains 10 percent or less of chert but that includes some glauconite, silt, and shale in the lower part. As shown by the formational names suggested, the upper part of the Knox may be Ordovician in age and the lower part, Cambrian in age. The sequence of formations suggested in the log summary is not apparent throughout the State (perhaps because of the poor quality of some samples), nor is the above two-fold subdivision found to be consistent throughout the State. It is especially inadvisable to attempt to apply these formational names without sufficient evidence, as the presence or absence of these formations would affect interpretations of the marked change in thickness of the Knox as shown in figure 9.

LITHOLOGY AND THICKNESS OF EQUIVALENTS OF THE KNOX DOLOMITE IN SURROUNDING REGION

UPPER MISSISSIPPI VALLEY REGION

Knox dolomite equivalents in the upper Mississippi Valley consist of the following units in ascending order: Franconia formation, Trempealeau formation, and Prairie du Chien group (table 3). Franconia rocks consist of sandstone and some dolomite in outcrop in Wisconsin. The most characteristic feature of the formation is the occurrence of glauconite, which makes up as much as 80 percent of the rock in some thin layers, according to Twenhofel, Raasch, and Thwaites (1935, p. 1697). The Franconia has been subdivided into members in outcrop in the upper Mississippi Valley (table 3), but these members of the Franconia could not be identified in Indiana. Twenhofel, Raasch, and Thwaites reported a maximum thickness of 40 feet for the basal member and a thickness of 120 to 130 feet for the remainder of the formation in Wisconsin.

The Trempealeau formation also has been subdivided into members (table 3), which like those of the Franconia could not be identified in Indiana. The Trempealeau consists of a basal conglomerate overlain by dolomite which is yellow to gray and somewhat glauconitic and which is overlain by gray, buffweathering dolomitic siltstone. The Jordan sandstone was included as the uppermost member of the Trempealeau formation by Twenhofel, Raasch, and Thwaites (1935, p. 1709-1710). It was described as dolomitic thin-bedded gray to brown sandstone. In places the Jordan may be referred to as sandy dolomite.

The Trempealeau formation is overlain by the Prairie du Chien group (Lower Ordovician). The group is divided into the following formations in descending order (Twenhofel and others, 1954): Shakopee dolomite, New Richmond sandstone, and Oneota dolomite.

Powers (1935a, p. 429-433) stated that the Oneota dolomite is subject to gradual lithologic variation along its outcrop belt in Minnesota, Iowa, and Wisconsin. According to his description, the Oneota consists of gray, pink, and buff dolomite in which oolitic chert may be abundant and which may contain various amounts of glauconite, sand, silt, and shale. *Cryptozoon* reef structures are widespread and characteristic. According to Kay (1935), the Oneota ranges from 120 to 170 feet in thickness in the outcrop area of the upper Mississippi Valley.

Kay (1935, p. 283) described the New Richmond sandstone as white or buff medium-textured well-bedded sandstone that has interbedded dolomite and *Cryptozoon* structures. He cited an average thickness of 20 to 25 feet for this formation. Andrews (1955) described a local angular unconformity at the base of the New Richmond in the outcrop area.

The Shakopee dolomite (called Willow River by Kay, 1935, and Powers, 1935a and 1935b) is similar to the Oneota in that the Shakopee is composed of buff dolomite containing oolitic chert, glauconite, shale, siltstone, and *Cryptozoon* reef structures. According to Powers (1935a, p. 434), the Shakopee (Willow River) may be distinguished from the Oneota in that the Shakopee is more thinly bedded and contains less chert. Kay (1935, p. 283) cited a thickness of 50 feet for the type Willow River.

ILLINOIS

Willman and Templeton (1952, p. 109) described the upper part of the Franconia which crops out in northern Illinois as argillaceous silty glauconitic and muscovite-bearing partly dolomitic greenish-gray sandstone. In wells in northern Illinois, according to Payne (1942, p. 55-57), the formation consists of variegated fine-grained dolomitic very glauconitic compact sandstone that is interbedded with greenish, gray, pink, and buff finely crystalline sandy glauconitic dolomites and gray, green, and red sandy glauconitic shales. The formation averages between 150 and 175 feet in thickness.

Workman and Bell (1948, p. 2052-2053) described similar lithologies in subsurface in Illinois. They stated that the Franconia increases in thickness from about 150 feet in northern Illinois to at least 265 feet in east-central Illinois and contains increasing amounts of sandy dolomite in a southerly direction.

The present writer described the Franconia in Kankakee County, northeastern Illinois (datum-point no. 14), as consisting of fine quartz sand, light-tan finely crystalline glauconitic dolomite, some light-gray siltstone, and dark-brown shale. The formation is 150 feet thick. In Douglas County, east-central Illinois (datum-point no. 64), the writer noted that the Franconia contains very little sand and has increased in thickness to 300 feet.

The Trempealeau formation in outcrop in northern Illinois was described by Willman and Templeton (1952, p. 114) as light-buff finely to medium crystalline "reef-type" dolomite which is finely porous to vuggy. The basal beds are glauconitic and silty. These authors stated that many vugs are lined with white to pink crystalline quartz, which serves to differentiate the formation from others in the area.

In subsurface in north-central Illinois, according to Payne (1942, p. 57), the Trempealeau is gray, buff, and pinkish finely crystalline cherty and locally sandy dolomite that has a few lenses of buff medium-grained dolomitic compact sandstone. Payne recorded the occurrence of three irregular glauconitic zones within the formation and the frequent occurrence of fragments of quartz geodes. The average thickness of the Trempealeau in north-central Illinois, according to Payne, is 200 feet.

Workman and Bell (1948, p. 2053) stated that the Trempealeau in subsurface in Illinois consists of dolomites which are correlated with the Potosi and Eminence formations in Missouri. The lower formation (Potosi) is pale-brown, buff, pink, and light-gray very finely to finely crystalline dolomite which contains geode quartz and some glauconite. An isopach map presented by Workman and Bell (1948, fig. 8) indicates that this unit is not present in the extreme part of west-central Illinois and thickens to the north, east, and south. It probably is 200 feet thick in the extreme part of eastern Illinois. The upper dolomite (Eminence), according to these authors (1948, p. 2053-2054), is white to light buff and finely to medium crystalline and contains some very finely dolomoldic white dense chert. It is sandy in some localities, but in other places it is practically free of sand. The isopach map of the Eminence included by Workman and Bell (1948, fig. 9) indicates that the unit is about 100 feet thick in western Illinois and thins to the vanishing point in northeastern Illinois.

The present writer noted that in the Kankakee County test well cited above (datum-point no. 14) the upper 70 feet of the Trempealeau is composed of white to light-gray finely crystalline dolomite and the lower 130 feet of light-tan to pinkish-tan finely crystalline to saccharoidal dolomite. The writer noted a similar subdivision of the Trempealeau in the Douglas County test well cited above (datum-point no. 64) ; in that well the upper part of the Trempealeau was 100 feet thick and the lower part was 160 feet thick.

Workman and Bell (1948, p. 2054-2055) also described a thin sandstone, dolomite, and shale zone which overlies the Trempealeau formation in Illinois. They stated that that zone may include both the Gunter formation of the Lower Ordovician (see below) and the Jordan sandstone of the Upper Cambrian, but, at the time of their work, they were not able to separate the two formations or to determine which formation was involved if only one is present. Consequently, they used the term Gunter-Jordan formations in describing the interval.

Willman and Templeton (1952, p. 116) concluded that exposures in northern Illinois are of the Gunter and that the formation can be traced into Missouri to the south and into Wisconsin to the north. Willman (oral communication) was of the opinion that a sandy zone at the top of the Trempealeau formation in subsurface in Jasper County, northwestern Indiana, is Gunter, not Jordan; thus the name Gunter is used in this report.

Willman and Templeton (1952, p. 116-117) described the Gunter in outcrop in northern Illinois as argillaceous silty finely glauconitic greenish-gray to cream chalky dolomite which contains very fine muscovite flakes and which is slightly sandy in the lower part. The formation contains green clay partings and irregular masses of oolitic chert.

Workman and Bell (1948, p. 2054) described the sandstone portions of the Gunter (Gunter-Jordan, in their terminology) as being very fine to coarse grained and commonly poorly sorted and having some secondary crystallization of previously rounded grains and some loose siliceous oolites. They described the dolomites as being white, light and medium gray, pink, and light brown and containing oolitic chert and some sand. The shales are bluish green and red. The formation ranges from 10 to 40 feet in thickness, according to Workman and Bell (1948, p. 2055).

Willman and Templeton (1952, p. 117-119) described the Oneota dolomite in outcrop in northern Illinois as light-gray to blue-gray uniformly coarsely crystalline dense cherty dolomite. Individual crystals range from 1 millimeter to 2 millimeters in diameter. The basal 9 to 10 feet are composed of lithographic to finely crystalline dolomite. Willman and Templeton (1952, p. 118) stated that: "Gray, white, and light yellow to pink or red chert, most of which is sandy, oolitic, conglomeratic, or strongly banded, occurs throughout the Oneota formation. . . . The lower 12 to 60 feet of the formation ordinarily are finely glauconitic and somewhat sandy; a few sandy streaks are found at higher horizons." *Cryptozoon* is present (commonly in places) in nearly all exposures. These authors cited a thickness of 116 to 180 feet in north-central Illinois, but they stated that the formation thins along the crest of the Ashton Arch in Ogle and Lee Counties, north-central Illinois.

Workman and Bell (1948, p. 2056) described the Oneota dolomite in subsurface in Illinois as being white to light gray, very finely to coarsely crystalline, and somewhat vesicular and containing partly oolitic white to gray granular to dense chert. The formation contains some sand which becomes more abundant toward the base. An isopach map of the Oneota presented by Workman and Bell (1948, fig. 10) indicates a thickening of about 200 feet in northwestern Illinois to more than 400 feet in southeastern Illinois.

Willman and Templeton (1952, p. 119) stated that the New Richmond sandstone resembles the St. Peter sandstone (Middle Ordovician), but that it differs from the St. Peter in being composed of more angular and less frosted grains which are more commonly secondarily enlarged, in being thinner bedded and better cemented, and in containing free siliceous oolites, chert, and a higher proportion of heavy minerals. The formation also contains beds of lithographic dolomite, dolomitic sandstone, and gray, blue, and red shale layers. These authors stated that the New Richmond ranges from 16 to 190 feet in thickness.

The description of the New Richmond sandstone in subsurface in Illinois which is given by Workman and Bell (1948, p. 2057-2058) is similar to that given by Willman and Templeton (1952,

p. 119). The New Richmond is 190 feet thick in La Salle County, north-central Illinois (Payne, 1942, p. 59 and 337), and thins to the north, east, and west. An isopach map of the New Richmond presented by Workman and Bell (1948, fig. 11) indicates an elongate lens of New Richmond with an axis extending from north-central Illinois to southwestern Illinois in which the formation is 100 to more than 175 feet thick.

The Shakopee formation was described by Willman and Templeton (1952, p. 120) as dolomite which varies greatly in purity, color, and crystal size but which is mostly "yellow-buff" and finely crystalline to dense. The formation also includes shale, siltstone, sandstone, chert, and glauconite. In north-central Illinois, the Shakopee formation ranges from the vanishing point to about 165 feet in thickness, according to these authors.

The Shakopee dolomite was described by Workman and Bell (1948, p. 2058-2060) as consisting of light- to medium-gray very fine- to fine-grained dolomite; this dolomite contains chert that is dull to dense and partly oolitic and that is similar to the chert of the Oneota. They noted the occurrence of local sandstone lenses and thin red, gray, and green shale beds. An isopach map of the Shakopee formation presented by Workman and Bell (1948, fig. 12) indicates that the formation is approximately 200 feet thick in northern Illinois and is 600 feet or more thick in south-central Illinois.

Descriptions of the Prairie du Chien group in Illinois indicate that it is nearly identical to the Prairie du Chien group of the type section and that the Oneota and Shakopee dolomites thicken to the south. Cross sections presented by Workman and Bell (1948, figs. 2 and 3) show a truncation of the Prairie du Chien group by the St. Peter sandstone to the north. This truncation is similar to the truncation of the Knox in Indiana.

MICHIGAN

Cohee (1948, p. 1425) described the Franconia in Michigan as fine angular glauconitic quartz sandstone that has some interbeds of sandy dolomite. According to Cohee, the Franconia is 10 to 20 feet thick in southeastern Michigan. The Trempealeau, he stated, is 500 feet thick in southeastern Michigan, and this formation can be subdivided in ascending order into the same three members as in the upper Mississippi Valley region: the St. Lawrence, the Lodi, and the Jordan. According to Cohee (1948, p. 1425), the basal part of the St. Lawrence member consists of gray sandy very glauconitic dolomite overlain by dark-gray to black dolomitic shale and dolomite. The Lodi member is generally white to buff dolomite that is slightly sandy. Pink dolomite occurs locally in this member in southeastern Michigan. The Jordan sandstone is present in northern Michigan, where it consists of 5 to 30 feet of well-rounded, frosted, and pitted quartz grains.

The present writer studied samples taken through the Franconia-Trempealeau interval from a test well in southeastern Michigan[6] and found these formations generally similar in lithology and thickness to the Franconia and the Trempealeau in the test well (datum-point no. 14) in Kankakee County, Ill., although formational boundaries were less distinct in the Michigan test well. The writer believes that it is inadvisable at this time to attempt a detailed subdivision of these rocks on the basis of terminology of the upper Mississippi Valley because of the limited amount of available information.

Cohee's description of the Oneota dolomite (1945b; 1948, p. 1426) indicates that in southwestern Michigan the Oneota is lithologically much the same as in Illinois and is about 300 feet thick. However, he stated (1945b) that in northern Ottawa County, southwestern Michigan, ". . . the Oneota dolomite is primarily sandstone with subordinate chert and dolomite."

Cohee (1945b; 1948, p. 1426) recognized 5 to 10 feet of New Richmond sandstone in southwestern Michigan. In addition, he stated (1945b; 1948, p. 1426) that the Shakopee formation is found in wells in part of southwestern Michigan and consists of buff, brown, and gray dolomite and thin beds of shale and a small amount of chert. Cohee cited thicknesses of 100 and 120 feet for the Shakopee in southwestern Michigan. In Ottawa County, he stated, the Shakopee consists of sandstone, gray and dark shaly dolomite, and dolomitic shales.

As he stated above in discussing the Franconia and the Trempealeau, the present writer deems it inadvisable to apply nomenclature of the upper Mississippi Valley in southern Michigan—especially as the Oneota and the Shakopee, as described by Cohee, differ so greatly in places from the type Oneota and Shakopee.

OHIO

Fettke (1948, p. 1480-1481) followed Cohee's correlations (1945a, 1945b) of Upper Cambrian formations in northwestern Ohio. Fettke based his description of the Franconia and the

[6] Colvin & Associates and Rotary Electric Steel No. 1 Viola Meinzinger, sec. 12, T. 2 S., R. 7 E., Washtenaw County, Mich.

Trempealeau formations in northern Ohio mainly on information from a test well in Putnam County, northwestern Ohio (datum-point no. 22 of the present report).

According to Fettke, the Franconia formation in the test wells in Putnam County is 25 feet thick and consists of fine- to medium-grained brownish-gray dolomitic sandstone containing a little glauconite. Fettke stated that the unit could not be recognized in other test wells in central Ohio.

The Trempealeau formation in the test well in Putnam County, he said, consists of relatively finely crystalline pure dolomite and a minor amount of interbedded dolomitic siltstone and shale. The dolomite is sandy and glauconitic in its lower part. The formation contains more silt and sand in central Ohio.

Fettke (1948) did not report the occurrence of the Gunter or the Jordan formations in Ohio, and these were not observed by the present writer in cuttings from test wells in Ohio which were studied by him. Fettke (1948, p. 1482-1483) assigned, with question, 33 feet of light brownish-gray very finely crystalline dolomite and light greenish-gray dolomitic shale and siltstone to the Oneota formation in Putnam County, northwestern Ohio (datum-point no. 22 of the present report). Fettke stated that lower Ordovician strata were not recognized in central Ohio in his study.

The present writer has examined drill cuttings from deep test wells in Ohio in Putnam County (datum-point no. 22), Wyandot County,[7] and Logan County.[8] He does not believe that the limited information available justifies the application of outcrop terminology of the uper Mississippi Valley to deep test wells in western Ohio.

MISSOURI

As the Knox dolomite in Indiana is similar to the equivalent Cambrian and Ordovician strata in Missouri, the following summaries of descriptions by Grohskopf and McCracken (1949, p. 31-32) of insoluble residues of the Missouri units are included. These names have also been used by Freeman (1953) in subsurface in Kentucky and by Workman and Bell (1948) in southern Illinois.

[7] (Operator unknown) No. 1 Nora Heck, sec. 18, Crawford Township.
[8] Ohio Oil Co. No. 1 Virgil Johns et al., McArthur Township.

Descriptions of insoluble residues

Lower Ordovician:

Eminence dolomite:

Low residue content. The dominant residue is finely granular or quartzose chert. White quartzose oolitic chert and thin sand lenses are found in the upper part of the formation, and druse may occur in the lower part.[9]

Potosi dolomite:

Near the type area the residue may represent as much as 80 percent by volume of the original sample. Banded quartz druse is the outstanding feature. The Potosi may be zoned on the basis of sequences of white and brown quartzose dolomolds, brown free quartzose oolites, and crystalline quartz. Brown finely granular silica is found throughout.

Elvins group:

Derby-Doe Run formations: The residue of the upper part is similar to Potosi and in addition has traces of green shale and "clay minerals." Glauconitic sand and brown and green shale, together with sponge spicules and echinoderm fragments, are found in a lower part.

Davis formation:

The residue of the upper part is at least 65 percent fine sand and fine glauconite and shows lamination. Shales with less sand content are usually found in the lower part. Coarse sand and large pellet glauconite are characteristic residues of the basal part of the formation.

Upper Cambrian:

Cotter dolomite:

The upper shaly zone contains small quantities of tiny quartz masses, and the middle cherty oolitic unit contains large free pitted oolites, spicules, and echinoderm fragments; the lower unit is relatively noncherty.

Jefferson City group:

Smooth oolitic chert is the major residue. Free brown oolites are found at the top, siliceous spicules in the middle part, and quartz masses at the base.

Roubidoux formation:

Residue consists of brown quartzose oolitic chert at the top and dark smooth oolitic chert, white oolitic smooth chert and sandstone, or pure sandstone below. Sandy chert is prevalent.

Gasconade and Van Buren dolomites:

The Gasconade-Van Buren contact may be vague. Upper Gasconade: Residue constitutes 10 percent or less of sample and consists of brown and green quartzose chert. Lower Gasconade: Represented by 50 to 60 percent of white smooth and quartzose oolitic chert which grades downward into gray-white smooth oolitic or dark shades of gray or blue chert. Van Buren: Characterized by brown oolites in smooth chert. Quartz druse and large dolomolds in chert are reliable markers in the Van Buren. Both Gasconade and Van Buren are free of sand.

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[9] For descriptive terminology of residues, see Ireland and others (1947).

KENTUCKY

Freeman (1953, p. 19-20) used descriptions similar to those of Grohskopf and McCracken (1949, p. 31-32) for Knox equivalents in Kentucky. In Anderson County, west-central Kentucky (datum-point no. 147 in this report), Freeman (1953, p. 55-56) assigned 200 feet of gray crystalline dolomite containing gray smooth to quartzose chert to the Eminence dolomite, 247 feet of brown dolomite and brown to tan quartzose to granular chert to the Potosi dolomite, and 396 feet (base not reached in test well) of medium to coarsely crystalline brown and white dolomite containing white and tan chert, granular silica, pyrite, green shale, and glauconite to the Elvins group. In Lincoln County, south-central Kentucky (datum-point no. 148), Freeman (1953, p. 208-209) assigned 140 feet to the Eminence, 300 feet to the Potosi, and 400 feet to the Elvins. Presumably the test well in Anderson County very nearly reached the base of the Elvins.

Freeman (1953, p. 20) described the Eminence in Kentucky as pale-gray finely to coarsely crystalline dolomite that contained only traces of gray quartzitic chert. The Van Buren-Gasconade section was described by Freeman as light-colored medium crystalline dolomite which contains considerably more chert than the underlying Eminence. The Van Buren-Gasconade section is generally dense white to translucent and contains "thick-walled dolomolds" and irregularly shaped oolites.

Freeman (1953, p. 21) stated that the dolomites above the Roubidoux formation are more finely crystalline than the dolomites in the older formations and that they include more clastic material, such as fine silt, floating sand grains, and, rarely, green shale. The cherts of the post-Roubidoux dolomites are more oolitic and dolomoldic than the underlying units. Freeman believed that these Missouri formations can be identified in subsurface in Kentucky.

By examining drill cuttings from the test well in Anderson County, west-central Kentucky, cited above (datum-point no. 147), Freeman (1953, p. 54-55) recognized the following formations in the upper Knox: Jefferson City-Cotter (405 feet), Roubidoux (138 feet), and Van Buren-Gasconade (627 feet). The upper 145 feet of Freeman's Jefferson City-Cotter section was observed by the present writer to be lithologically identical to the Shakopee dolomite in the test well in Douglas County, east-central Illinois (datum-point no. 64). The general lithologic aspect of the rocks throughout the interval is similar in the two test wells.

Freeman (1953, p. 207-208) recorded the following formations and thicknesses for the test well in Lincoln County, south-central Kentucky, cited above (datum-point no. 148): Jefferson City-Cotter (680 feet), Roubidoux (190 feet), and Van Buren-Gasconade (460 feet). The upper 500 feet of Freeman's Jefferson City-Cotter section in this test well bears a marked resemblance to the Shakopee dolomite, as it appears in Illinois.

PROBLEMS OF KNOX STRATIGRAPHY

Preliminary studies have indicated that the Indiana Knox is closely related to the equivalent sections in both Illinois and Kentucky. As the terminology used in eastern Illinois is derived from the type area of the upper Mississippi Valley, and as the terminology used in Kentucky is derived from the type area in Missouri, a decision must be reached with respect to the most satisfactory system of nomenclature in Indiana. This decision must be based upon detailed stratigraphic studies, particularly studies of insoluble residues.

Detailed stratigraphic studies also will aid in understanding the nature of the thinning of the Knox in a northerly direction. An unconformity at the top of the Canadian series is well known in outcrop and marks one of the most important breaks in the Paleozoic stratigraphy of the craton. The thinning of the Knox in Indiana, however, apparently is not entirely due to truncation, as upper Knox equivalents have been identified in northern Indiana and southwestern Michigan. On the other hand, only lower Knox equivalents are present in southeastern Michigan and northwestern Ohio. A better understanding of the Knox stratigraphy in Indiana will aid in the interpretation of historical geology in surrounding states.

CHAZYAN SERIES

The stratigraphy of the Chazyan series is not yet well understood. In the upper Mississippi Valley area, the Chazyan series is thought to be principally represented by the St. Peter sandstone, but carbonate rocks above and below the St. Peter are included within the Chazyan by many writers (cf. Twenhofel and others, 1954). It is generally assumed that the St. Peter sandstone and associated beds are not the same age throughout their extent and that they were deposited upon rocks which may range from Early

Ordovician to Late Cambrian in age.[10] (See table 5 for examples of nomenclature of Chazyan series.)

LITHOLOGY AND THICKNESS IN INDIANA

Thickness variations and total thickness of sandstone in the Chazyan series are presented in figure 10. In Lake and Jasper Counties in the extreme northwestern part of Indiana, the Chazyan series is almost wholly represented by the St. Peter sandstone. The sand is loosely consolidated, fine to medium grained, and rounded and frosted. Approximately 5 feet of soft green fissile shale is included in the Chazyan below the St. Peter in Jasper County (datum-point no. 15). This green shale is similar in lithology to shale of the Glenwood formation described in other states (table 5), but the name Glenwood is not applied in Indiana because of the irregular areal and stratigraphic distribution of the shale. The thickness of the St. Peter in these counties ranges from 95 to more than 135 feet.

The St. Peter sandstone is thinner south and east of Lake and Jasper Counties, and the sand is associated with dolomite. Between central Jasper County (datum-point no. 15) and northwestern White County (datum-point no. 16) to the southeast, a distance of about 20 miles, the Chazyan series changes from sandstone (St. Peter) about 95 feet thick to interbedded dolomite and sandstone about 80 feet thick in which only 40 feet of the interval is composed of sand. The dolomite is light tan and very finely saccharoidal; the sand is very fine to medium grained and rounded and frosted and is included within the dolomite as well as in discrete beds. In Cass County to the east (datum-point no. 17), the Chazyan is about 60 feet thick and contains about 25 feet of sandstone. The sand is interbedded with limestone and dark-gray argillaceous dolomite in addition to light-tan very finely saccharoidal dolomite. In St. Joseph County (datum-point no. 8) and Kosciusko County (datum-point no. 7), the Chazy section is similar to the equivalent section in Ohio and southeastern Michigan in that it is marked by a thin green dolomitic shale. The shale is associated with light-tan finely saccharoidal dolomite which resembles the underlying Knox. In Allen County, northeastern Indiana (datum-point no. 21), no evidence of the Chazyan series was found, and there the Black River limestone rests directly on the Knox. This seems to prevail only locally, however.

[10] For regional studies of the St. Peter sandstone and associated strata, see Dake (1921), Thiel (1935), Edson (1935), and Dapples (1955).

Table 5.—*Selected examples of stratigraphic nomenclature of rock units within the Chazyan series as defined in Indiana, modified from various sources referred to in text*

<table>
<tr><th>Upper Mississippi Valley outcrop</th><th>Southeastern Missouri outcrop; southern Illinois subsurface</th><th>Northern Illinois outcrop and subsurface</th><th>Northwestern Indiana subsurface</th><th>Northeastern and southern Indiana subsurface</th></tr>
<tr><td rowspan="4">St. Peter sandstone</td><td>Joachim limestone</td><td>Glenwood formation</td><td rowspan="4">St. Peter sandstone</td><td rowspan="2">Joachim dolomite</td></tr>
<tr><td>Dutchtown limestone</td><td rowspan="3">St. Peter sandstone</td></tr>
<tr><td>St. Peter sandstone</td><td rowspan="2">St. Peter sandstone</td></tr>
<tr><td>Everton formation</td></tr>
</table>

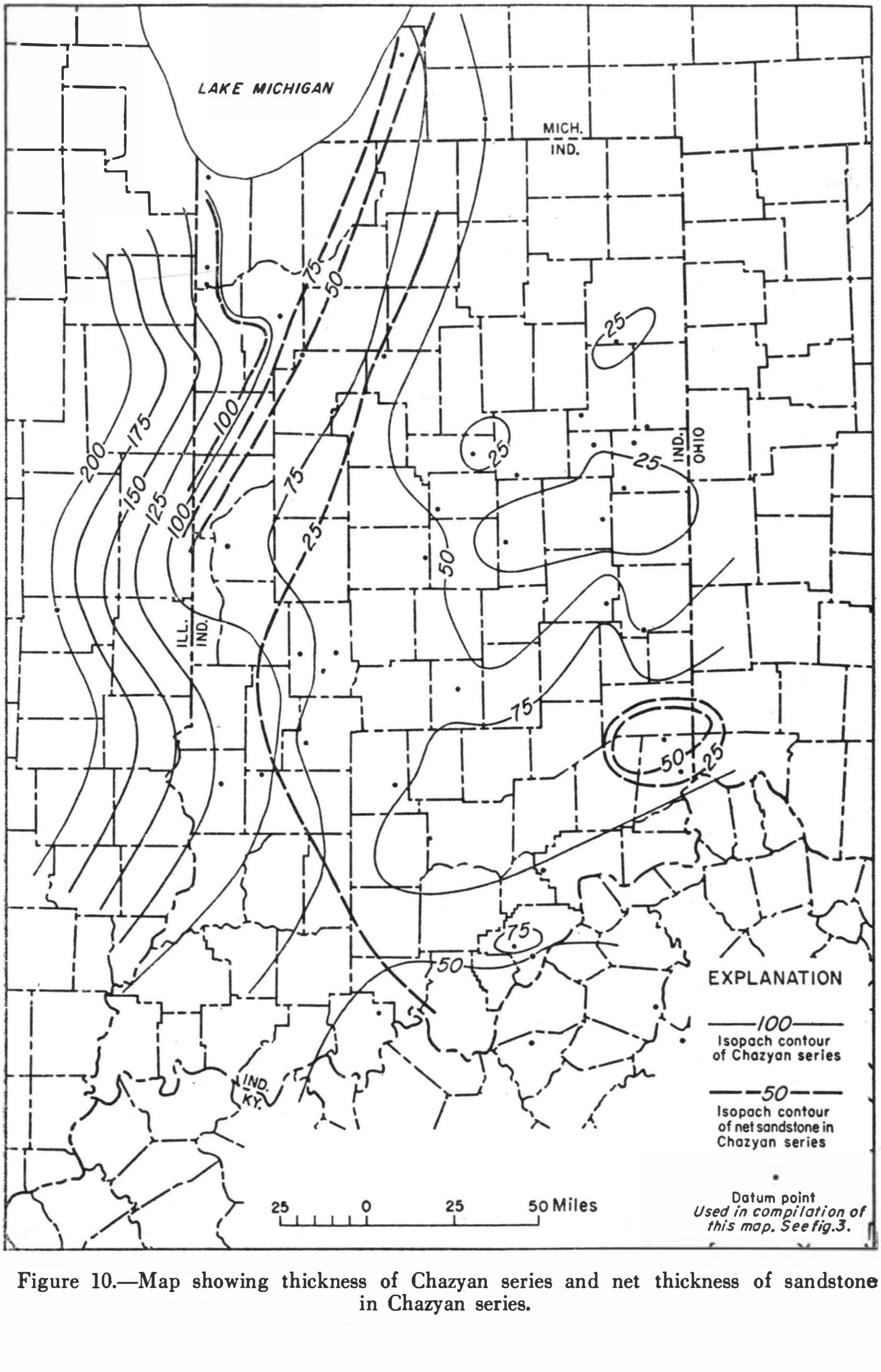

Figure 10.—Map showing thickness of Chazyan series and net thickness of sandstone in Chazyan series.

In the counties in west-central Indiana, to the south of the region where the Chazyan series is represented by a thick accumulation of homogeneous St. Peter sandstone, there is a definite sand unit that is associated with beds which can be assigned to the Joachim dolomite. For example, in Greene County (datum-point no. 99), the Joachim dolomite consists of 70 feet of light-tan very finely saccharoidal dolomite and interbedded dark-gray dolomitic shale. The Joachim beds are underlain by 30 feet of fine to coarse rounded and frosted loosely consolidated dolomitic St. Peter sandstone. This sequence and thickness are apparently characteristic of both west-central and southwestern Indiana.

Along the Kentucky boundary, in southeastern Indiana, the section is much the same as in west-central Kentucky. (See p. 59-60.) The Joachim dolomite is light greenish gray and very finely saccharoidal and contains included sand grains and green argillaceous dolomite. In test wells in Indiana, the Joachim appears to be transitional with the fissile green shale of Illinois and Michigan described below. The Joachim dolomite in southern Indiana is underlain in places by 10 feet or less of sandstone of the St. Peter type; this sandstone is generally finer grained, however, than the sandstone in the northern part of the State.

Some test wells in counties in southeastern Indiana near the Ohio boundary have revealed definite sandstone units at the base of the Joachim, some of which are 50 feet or more in thickness. The sand is similar in stratigraphic position and lithology to the St. Peter sandstone in the northern part of the State.

LITHOLOGY AND THICKNESS IN SURROUNDING REGION

ILLINOIS

The Everton formation which, according to Du Bois (1945, fig. 4), underlies the St. Peter sandstone in southern Illinois has not been identified in Indiana.

The St. Peter sandstone crops out in northern Illinois and locally in Calhoun County, western Illinois (Lamar, 1928, pl. 1). Detailed descriptions of the St. Peter sandstone in outcrop in Illinois were given by Willman (1942, p. 71-80) and Lamar (1928, p. 14-29).

In general, the formation consists of friable white fine- to medium-grained quartz sandstone of high purity in which the grains are rounded and frosted. The formation locally reaches a recorded thickness of 578 feet in subsurface in northern Illinois, but thicknesses of 200 to 300 feet are more common (Payne, 1942,

p. 61 and pl. 21). Payne (1942) and Workman and Bell (1948, p. 2060) reported the occurrence of variegated dolomitic and sandy shales containing chert pebbles in the basal few feet of the St. Peter sandstone.

The Glenwood formation, according to Payne (1942, p. 62), unconformably overlies the St. Peter sandstone in most of the area of northern Illinois which he studied. (See also Bevan, 1926.) The formation, Payne stated, consists of sandstone, shale, and dolomite. The sandstone is white, buff, gray, partly dolomitic, and fine and coarse grained and contains lenses of shale and dolomite. Shale that is brown, green, and gray and sandy and dolomitic overlies the sandstone. Dolomite that is gray, brown, buff, and green and finely crystalline overlies the shale. Payne (1942, p. 63) stated that in northern Illinois the Glenwood is about 15 feet thick in most places but that it may be as much as 100 feet thick.

Workman and Bell (1948, p. 2060) used the term Glenwood-St. Peter in surface work in Illinois, as the formations are difficult to separate. They cited a range in thickness of 100 to 300 feet and an average thickness of 180 feet for the Glenwood-St. Peter section in the southern two-thirds of Illinois.

The Glenwood-St. Peter section is overlain in southern Illinois by the Dutchtown formation, according to Du Bois (1945, fig. 4), who described (1945, p. 27) the formation as dark-gray or black argillaceous dolomite that contains interbedded light-brown or buff dolomite and thin beds of dark-brown, gray, or green dolomitic shale and sandstone. The formation is 100 feet thick throughout most of the Illinois Basin but thickens abruptly to more than 600 feet in the southern part of Illinois. The Dutchtown has not been identified in Indiana.

The Joachim formation underlies the Plattin formation in central and southern Illinois and overlies the Dutchtown in places where it occurs. According to Du Bois (1945, p. 25-26), the Joachim consists chiefly of dolomite which is buff, brown, or gray and very finely granular or crystalline ("earthy"). Banding in the dolomite is common, and thin beds of gray or brown dolomitic shale may occur in the lower parts of the formation. Du Bois stated that much gypsum or anhydrite is interbedded with, and grades into, the dolomites and shales.

MICHIGAN

Cohee (1948, p. 1426-1427) stated that the St. Peter sandstone is present in western Michigan but is absent in most places in eastern Michigan. According to him, the Glenwood formation in southwestern Michigan consists principally of fine-grained sandstone and shaly dolomite and ranges from 10 to more than 100 feet in thickness. In southeastern Michigan, a shale which is 5 to 30 feet thick and which is green, brown, or gray and in places pyritic and sandy has been found at the base of the Black River. Cohee stated that this shale may not be the exact time equivalent of the Glenwood farther west.

Cohee (1945b, fig. 1) indicated that Black River limestone directly overlies the Trempealeau formation in most of southeastern Michigan. A cross section through southern Michigan presented by Cohee (1945b, fig. 2) shows local occurrences of St. Peter sandstone and Glenwood shale resting upon Oneota dolomite and Shakopee dolomite.

In samples from a test well in Berrien County, southwestern Michigan (datum-point no. 1), the present writer observed 86 feet of interbedded sandstone, shale, and dolomite lying between the Black River formation and the Knox dolomite. The sandstone, which is fine to medium grained, loose, and, in part, rounded and frosted, was estimated to make up 75 percent of the cuttings. The interbedded shales that are green and fissile represent about 20 percent of the cuttings. The medium-tan finely crystalline dolomite represents about 5 percent of the cuttings. A little white oolitic chert is present, probably associated with the dolomite. This interval probably should be referred to as Glenwood-St. Peter, as in Illinois.[11]

In a sample from Washtenaw County, southeastern Michigan,[12] the present writer noted that the Black River limestone rests directly upon the lower part of the Knox. A few fragments of green shale were observed in the samples below the contact.

In a sample from a test well in Bullitt County, west-central Kentucky (datum-point no. 144), the present writer noted at least 45 feet of light greenish-gray very finely saccharoidal dolomite with included sand grains, which he refers to the Joachim dolomite. The base of the unit was not reached in this test well. In Shelby County, central Kentucky (datum-point no. 146), the same unit is at least 15 feet thick and contains green argillaceous dolomite like that found in Wyandot County, northwestern Ohio, and Logan County, west-central Ohio. This is not, however, the green fissile shale associated with the Glenwood-St. Peter interval in

[11] This test is also included by Cohee (1945b, fig. 2).

[12] Colvin & Associates and Rotary Electric Steel No. 1 Viola Meinzinger, sec. 12, T. 2 S., R. 7 E., Washtenaw County, Mich.

Illinois and Michigan. Freeman's log (1953, p. 280) includes this unit as part of the Wells Creek limestone. In Anderson County, north-central Kentucky (datum-point no. 147), the Joachim, like that found in Shelby County, Ky., is 20 feet thick and is underlain by a 5-foot unit of very fine-grained to fine-grained sandstone. The present writer assigns the underlying dolomite to the Knox, although the upper 100 feet contains sand units and fragments of green fissile shale.

OHIO

A distinct break occurs between the Black River limestone and the underlying Knox in Ohio. Stout and Lamey (1940, p. 684-686) stated that this break is marked in many places by bluish-green shale. These authors suggested that the shales are residues from the solution of underlying carbonate rocks and reported the occurrence of 5 feet of such shale in Delaware County, central Ohio.

In studying cuttings from a well in Wood County, northwestern Ohio,[13] the present writer noted 10 feet of greenish-gray argillaceous finely to medium saccharoidal dolomite between the Black River limestone and the Knox dolomite. In Wyandot County, northwestern Ohio,[14] an interval of about 13 feet between the Black River limestone and the Knox dolomite is occupied by green argillaceous dolomite, possibly interbedded with light-tan lithographic limestone. Apparently this same unit occurs in Logan County, west-central Ohio,[15] but in the latter test well it appears to be as much as 25 feet thick.

KENTUCKY

For detailed discussions of the Chazyan series and equivalents in Kentucky, see Jillson (1938), Edson (1935 and 1939), and Freeman (1939; 1950, p. 17-19; and 1953, p. 22-26).

Freeman (1950, p. 17-19) assigned the strata between the Mohawkian limestones and the Knox in the Jackson Purchase region in western Kentucky to the Big Buffalo series, which included the Joachim dolomite, the St. Peter sandstone, and the Everton formation. According to Freeman (1950, p. 18), the Big Buffalo series in the Jackson Purchase region consists of interbedded fine-grained pale-gray to white dolomite which may enclose fine to medium sand grains and white to pale-gray limestone. Also included are green shales, sandstones, red argillaceous dolo-

[13] Sun Oil Co. No. 1 H. E. Cross, sec. 13, Plain Township, Wood County, Ohio.
[14] (Operator unknown) No. 1 Nora Heck, sec. 18, Crawford Township, Wyandot County, Ohio.
[15] Ohio Oil Co. No. 1 Virgil Johns et al., McArthur Township, Logan County, Ohio.

mite, and green sandy dolomite. In Marshall County, western Kentucky, the Big Buffalo has been drilled to a depth of 780 feet without reaching the base of the unit, according to Freeman.

Freeman (1953) related limestones of the Chazyan series in central Kentucky to the overlying Black River limestones and combined the two units in most logs. She mapped (1953, pl. 6) the thickness of the St. Peter sandstone in eastern Kentucky, but the logs presented by her for datum points in some mapped areas indicate the inclusion of much interbedded limestone. The St. Peter, as mapped, may actually represent sandy zones within the Knox described by Born (1940).

CORRELATION OF THE CHAZYAN SERIES

Correlation of the Chazyan series in this report is based on the lithologic similarity of stratigraphic units in Indiana to equivalent stratigraphic units in Illinois and Kentucky.

The St. Peter sandstone in northwestern Indiana is a continuation of the St. Peter in northern Illinois. Apparently most of Indiana was beyond the limit of thick sand deposition, as the Chazyan series contains a large percentage of dolomite throughout most of the State. This dolomite, unlike the dolomite phase of the overlying Black River or the underlying Knox, generally is very finely saccharoidal. The dolomite is identical, at least in central and southern Indiana, to the Joachim dolomite in Illinois. The same unit can be traced into west-central Kentucky. The Joachim of this report probably is the Stones River of other workers.

Both Joachim and St. Peter are absent in northeastern Indiana, and the Chazyan series generally is marked by a thin green shale or argillaceous dolomite, as it is in southeastern Michigan and northwestern Ohio.

A relatively thick sand unit, underlying the Joachim and overlying the Knox, is present in southeastern Indiana. This sand possibly represents the weathered and sorted residue of sand within the upper part of the Knox. It seems likely, however, that the sand would contain chert fragments, owing to the amount of chert in the upper Knox. For only one test well (Johnson County, south-central Indiana, datum-point no. 83) can a convincing argument be made, on the basis of included chert, for a weathered-Knox origin of the sand.

The relationship of the sand in southeastern Indiana to the St. Peter mapped by Freeman (1953, pl. 6) is unknown. Freeman's map indicates that the sand in east-central Kentucky is not continuous with the St. Peter in Illinois nor with the sand in southeastern Indiana. Possibly the occurrences in both Indiana and Kentucky represent local accumulations derived from some source other than that of the St. Peter sandstone of outcrops in the upper Mississippi Valley.

MOHAWKIAN SERIES

In the type area in central New York, upper Middle Ordovician rocks are assigned to the Black River limestone and the Trenton limestone, both of group rank (table 6). The names Black River limestone and Trenton limestone also are used in Ohio, Michigan, and Indiana and frequently in subsurface work in the Illinois Basin. In these states and in the Illinois Basin, Black River limestone and Trenton limestone refer to specific rock units which are

Table 6.—*Selected examples of stratigraphic nomenclature of rock units within the Mohawkian series as defined in Indiana, modified from various sources referred to in text*

<table>
<tr><th colspan="2" rowspan="2">Northwestern New York outcrop</th><th rowspan="2">Upper Mississippi Valley outcrop</th><th rowspan="2">Southeastern Missouri outcrop</th><th colspan="2" rowspan="2">Central Kentucky outcrop</th><th colspan="2">Indiana subsurface</th></tr>
<tr><th>North</th><th>Southeast</th></tr>
<tr><td colspan="2">Utica shale</td><td></td><td></td><td colspan="2">lower part of Cynthiana limestone</td><td>?</td><td rowspan="5">Lower part of Lexington-Cynthiana formation</td></tr>
<tr><td rowspan="4">Trenton limestone (group)</td><td>Coburg limestone</td><td rowspan="3"></td><td rowspan="3"></td><td colspan="2" rowspan="4"></td><td rowspan="4">Trenton limestone</td></tr>
<tr><td>Shevman Falls limestone</td></tr>
<tr><td>Kirkfield limestone</td></tr>
<tr><td>Rockland limestone</td><td>Decorah formation</td><td>Decorah formation</td></tr>
<tr><td rowspan="3">Black River limestone (group)</td><td>Chaumont formation</td><td rowspan="2">Platteville dolomite
?</td><td rowspan="3">Plattin limestone</td><td rowspan="3">High Bridge limestone</td><td>Tyrone limestone</td><td colspan="2" rowspan="3">Black River limestone</td></tr>
<tr><td>Lowville limestone</td><td>Oregon limestone</td></tr>
<tr><td>Pamelia limestone</td><td>Glenwood shale</td><td>Camp Nelson limestone</td></tr>
</table>

described in the following sections. Exact correlation of these units in subsurface with the type area has not been definitely established.

In Indiana both the Black River and the Trenton limestones are assigned to the Mohawkian series and are considered formations, which at present are not further subdivided in subsurface work.

It should be noted that *Trenton* is used in the restricted sense in this report. In the past, the name "Trenton" has been applied erroneously in oilfield terminology to all rocks between the St. Peter sandstone and the base of the Cincinnatian series.

LITHOLOGY AND THICKNESS IN INDIANA

BLACK RIVER LIMESTONE

The Black River limestone, as defined in Indiana, is in most places light tan to dark tan, is mostly lithographic but somewhat very finely crystalline, and is in part argillaceous and dolomitic. The formation thickens regularly in a southerly direction from about 200 feet in north-central Indiana to more than 500 feet in the southern part of the State (fig. 11). The lower 100 to 200 feet are commonly dark and very argillaceous. Soft green shales occur within the upper 50 feet throughout most of the State and probably represent the "pencil cave" or the "mud cave" or both of the Tyrone limestone of Kentucky. The most distinctive characteristics of the Black River limestone in Indiana are lithographic limestone, which no other formation in the Cambrian and Ordovician in Indiana contains, and bentonitic shales. These two features together distinguish the Black River limestone from the underlying Chazyan series and Knox dolomite and the overlying Trenton limestone throughout most of Indiana.

In the extreme northwestern part of Indiana the Black River consists entirely of dolomite, and the distinguishing features described above are not present. This formation in northwestern Indiana is an extension of the Plattin (Platteville of some authors) dolomite of Illinois and is separated from the overlying Trenton (Galena of some authors) on the basis of the finer texture of the Black River.

TRENTON LIMESTONE

Throughout most of Indiana the Trenton limestone consists of light- to medium-tan fossiliferous dolomitic limestone. The formation contains some dolomite throughout northern Indiana and

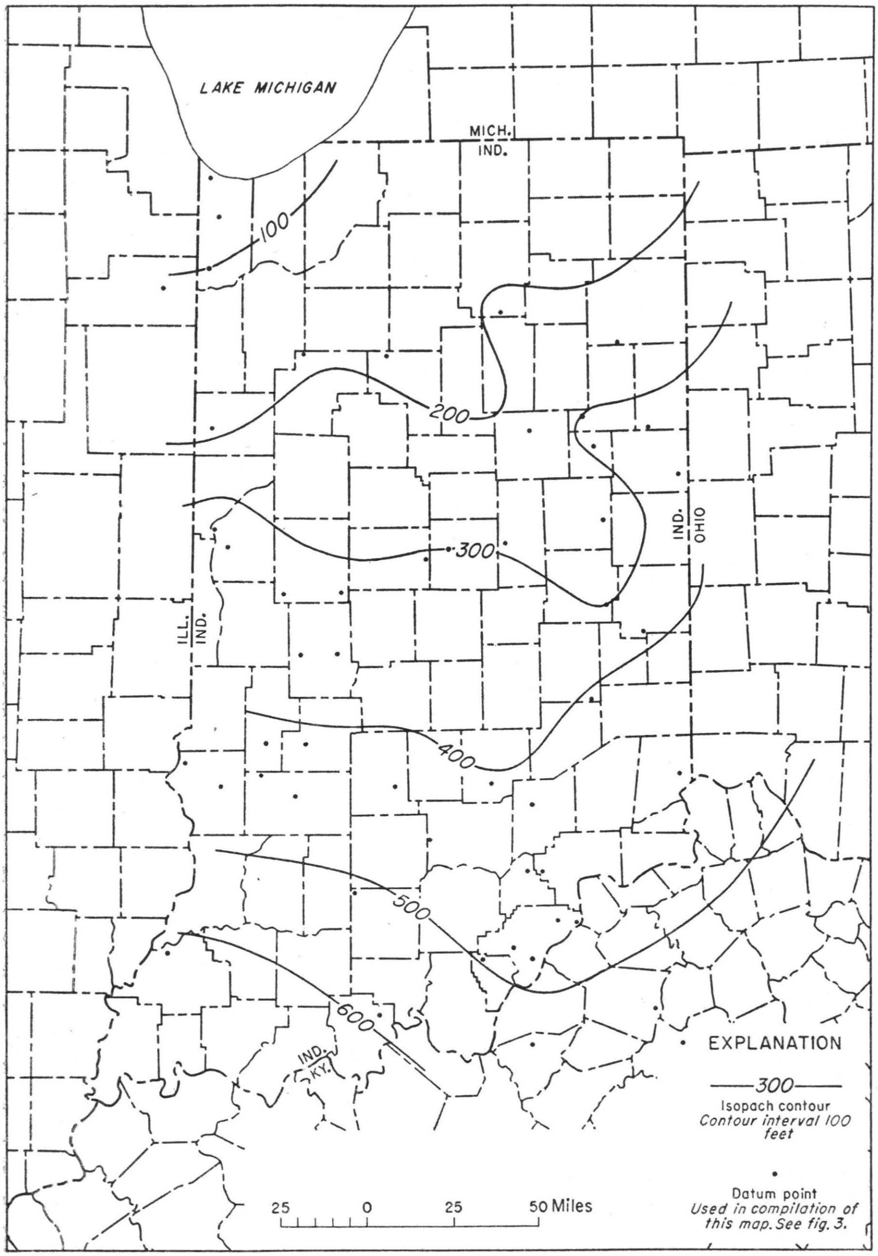

Figure 11.—Map showing thickness of Black River limestone.

consists entirely of dolomite in the northwestern part of the State. In southeastern Indiana the section normally occupied by the Trenton limestone consists of interbedded limestone which is lithologically similar to the Trenton limestone and shale which is lithologically similar to the Eden shale.

In northwestern Indiana the Trenton is about 200 feet thick (fig. 12). It is the continuation of the Galena dolomite of Illinois and consists entirely of dolomite. This dolomite facies thins in a southeasterly direction and is confined to the uppermost part of the Trenton (fig. 13). The pinching out of this porous dolomite zone toward the crest of the Cincinnati Arch has formed the stratigraphic trap of the "Trenton" oil and gas field in northeastern Indiana and northwestern Ohio.

Figure 12 indicates variations in thickness of the Trenton limestone, as defined in Indiana. The Trenton is 225 feet or more thick in northeastern Indiana and decreases in thickness fairly uniformly to about 25 feet in southern Indiana. Information, although sparse, is sufficient to indicate that the Trenton limestone is not present locally in southeastern Indiana and that the Eden shale rests upon the Black River limestone.

The upper boundary of the Trenton limestone southeast of the dashed line indicated in figure 12 cannot be determined because of gradation between the Trenton limestone and the overlying Eden shale. This interval, as stated above, is composed of interbedded limestone and shale and probably corresponds to all or part of the Lexington limestone and the Cynthiana formation, which crop out in central Kentucky, and which are herein referred to as the Lexington-Cynthiana formation.[16] The dashed line in figure 12 may be considered an arbitrary cutoff (as defined by Wheeler and Mallory, 1953) which separates the Trenton limestone, as it occurs throughout most of Indiana, and the transitional Lexington-Cynthiana formation.

The base of the Lexington-Cynthiana is well marked by the underlying Black River limestone (fig. 14). Exact placement of the upper contact is more difficult. In general, the writer placed the upper limit of the Lexington-Cynthiana at the top of the first limestone above the Black River and below the Maysville group.

The shale in the Lexington-Cynthiana appears, on examination with the binocular microscope, to be the same as the Eden shale.

[16] Freeman (1953, fig. 5) indicated a similar boundary in the Lexington limestone separating "Utica shale on thin limestone" on the north from "interbedded limestone and shale" on the south. Freeman placed the boundary on the Kentucky side of the Ohio River, however.

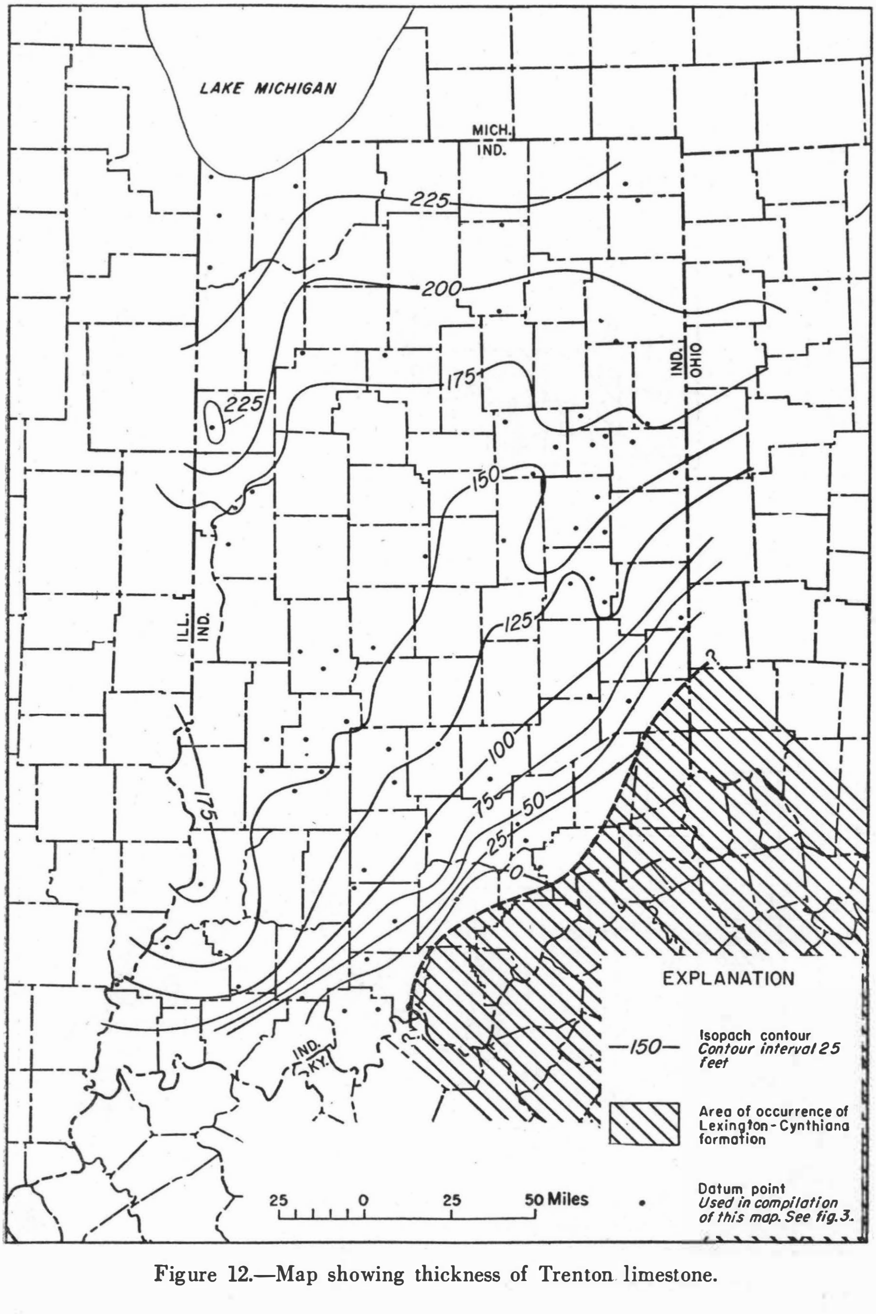

Figure 12.—Map showing thickness of Trenton limestone.

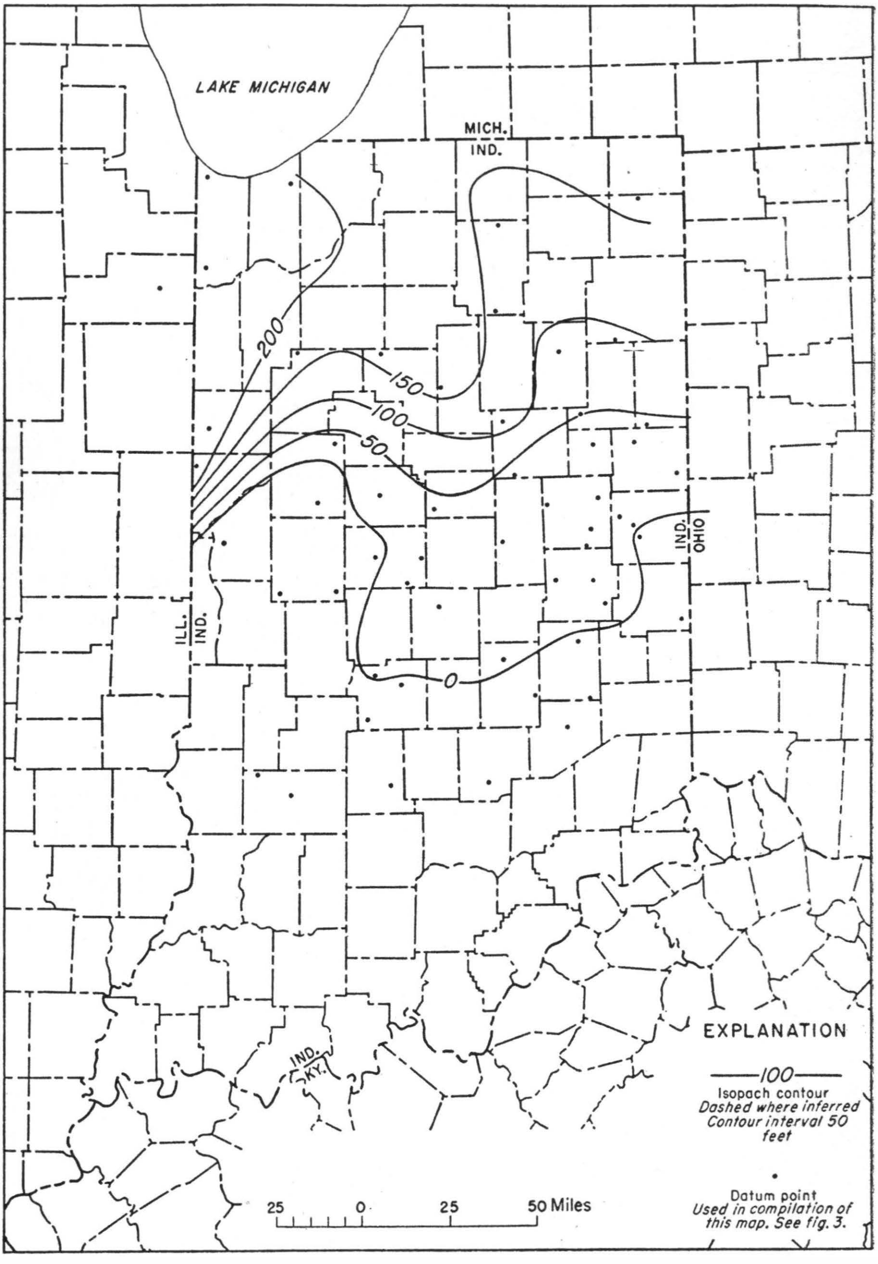

Figure 13.—Map showing thickness of dolomite facies of Trenton limestone.

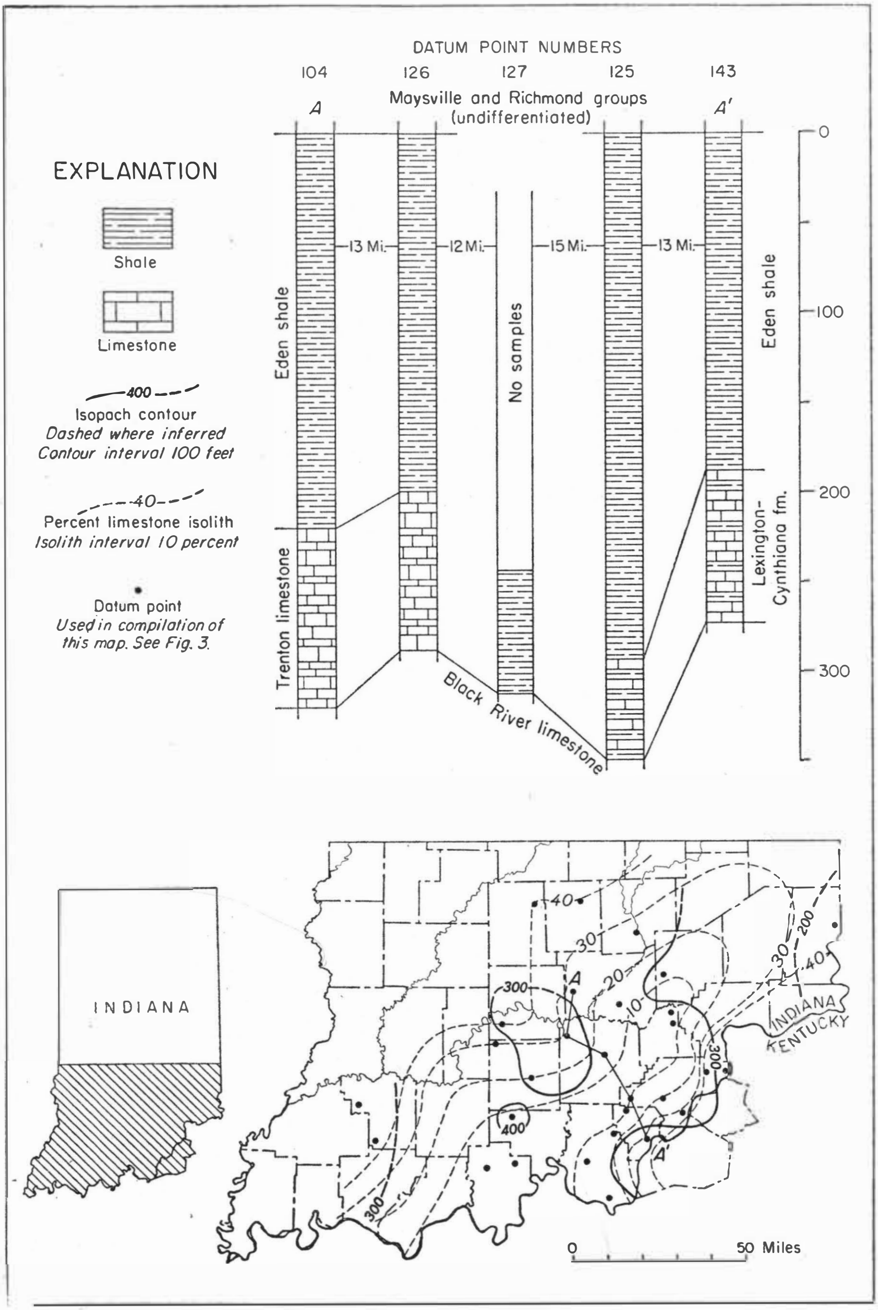

Figure 14.—Isopach and limestone percentage map of Eden shale and Lexington-Cynthiana formation and cross section from Jackson County, Ind., to Floyd County, Ind. (line A-A′), showing relation of Eden shale, Trenton limestone, and Lexington-Cynthiana formation.

Insoluble residues of the shale in the Lexington-Cynthiana are browner than residues of the Eden shale. Limestone in the formation is generally more dolomitic, is much less fossiliferous, and is more brownish than limestones in the Maysville group.

Thickness and lithologic relationships of the Eden shale and the Lexington-Cynthiana formation are shown in figure 14. The limestone percentage pattern in figure 14 indicates that the interval from the top of the Eden shale to the top of the Black River limestone contains less than 10 percent limestone in Harrison and Crawford Counties and southern Washington County and that the relative amount of limestone increases both to the northwest and to the southeast. A diagrammatic cross section (fig. 14) from western Jackson County to southern Floyd County illustrates the relationships of the lithologic units involved.

LITHOLOGY AND THICKNESS IN SURROUNDING REGION

ILLINOIS

The Plattin (Platteville)[17] formation in northern Illinois was described by Du Bois (1945, p. 23) as consisting mostly of brown, buff, or gray dolomite and limestone and some chert. The dolomite is finely to medium crystalline and the limestone is finely crystalline to lithographic. Members have been described in outcrop but usually cannot be identified in subsurface. In general, the distribution of the dolomite facies is related to structure rather than to stratigraphic zones (Payne, 1942, p. 64). In southern and central Illinois, according to Du Bois (1945, p. 23-24), the Plattin formation consists of generally brown and buff finely crystalline to lithographic argillaceous limestone, some chert, thin beds of granular dolomite, and calcareous shale. The formation ranges in thickness from more than 700 feet in southernmost Illinois to less than 100 feet in parts of northern and western Illinois. Twenhofel and others (1954) considered the Plattin (Platteville) formation to be Black River in age.

The Plattin formation is overlain by the Decorah formation, which is included in the Trentonian Stage (Twenhofel and others, 1954). The base of the Decorah is difficult to determine in subsurface, according to Du Bois (1945, p. 21), and subsurface "Decorah" may include some upper Plattin.

Payne (1942, p. 65) described the Decorah formation in northern Illinois as brown, gray, buff, and purplish cherty usually argillaceous dolomite or limestone that has thin partings of gray,

[17] Names in parentheses are of local usage, according to Du Bois (1945, p. 17).

brown, and purplish brittle fossiliferous calcareous shale. In well cuttings, according to Payne, distinctive features are: (1) speckled limestone and dolomite, (2) scolecodonts and conodonts, (3) shaly surfaces and pits in cuttings, and (4) speckled and partly sandy translucent chert.

According to Du Bois (1945, p. 22), the Decorah consists at most places of interbedded limestones, dolomites, and shales and interbedded "metabentonite?," which occurs at random. Du Bois cited an average thickness of 35 to 40 feet for the Decorah in most of central and southern Illinois.

The Galena formation, which overlies the Decorah, was included in the Trentonian Stage by Twenhofel and others (1954). The Galena in outcrop in northern Illinois consists mostly of crystalline dolomites that have thin shale partings. In subsurface in northern Illinois, according to Du Bois (1945, p. 17-19), the Galena consists of either gray to buff or brown finely to medium crystalline dolomite or, rarely, limestone which is more or less vesicular. At many places the lower part contains light-gray or white porcellanous chert. The Galena has been divided into members in outcrop, but in subsurface these are commonly not differentiated. In subsurface in central and southern Illinois, according to Du Bois, the Galena (Kimmswick) consists of medium to coarsely crystalline buff, brown, or white limestone which may be tinged with pink. Chert is present but rarely is abundant. The formation may be divided into a lower fossiliferous zone and an upper nonfossiliferous zone. An isopach map presented by Du Bois (1945, fig. 5) indicates a maximum thickness of 250 feet in northwestern Illinois and a minimum thickness of 75 to 100 feet in southwestern Illinois. The thickness along the Illinois-Indiana boundary ranges between 175 and 200 feet.

MICHIGAN

The Black River and the Trenton limestones crop out in the Northern Peninsula of Michigan and have been described by Hussey (1936 and 1952). According to Cohee (1948, p. 1432), the Black River limestone at places in the Southern Peninsula of Michigan is 150 to 517 feet thick and consists of light-brown and gray fossiliferous dense to crystalline limestone and dolomite. The uppermost beds included in the Black River of Michigan are believed to be Trenton in age, according to Cohee. He stated that the basal part of the Black River limestone may consist of either fine-grained dark-gray to black argillaceous limestone or limestone and shale. Chert fragments have been found at the top of the Black River in local areas.

Cohee (1945b) described the Trenton limestone in the Southern Peninsula as 203 to 479 feet thick and as consisting of light-brown to brown and gray fossiliferous fine-grained to crystalline limestone and dolomite, except in the central part of the Michigan Basin, where it appears to be composed entirely of limestone. The basal part of the Trenton is a zone 20 to 40 feet thick that consists of dark-gray to black somewhat argillaceous fine-grained limestone in some places and of limestone and shale in others. This zone serves as a good stratigraphic marker, according to Cohee, except in Berrien County, southwestern Michigan, where both the Black River and the Trenton consist of dolomite. (See isopach map of Middle Ordovician rocks, Cohee, 1948, fig. 6.)

OHIO

Fettke (1948, p. 1484-1486) has described the Black River and the Trenton limestones in Ohio. He discussed only those rocks below the top of the Trenton limestone, but noted (p. 1463) that this horizon is not necessarily the top of the Middle Ordovician in terms of time-rock correlation. Fettke reviewed the problem of the placement of the top of the Middle Ordovician in northwestern New York and concluded that unanimous agreement had not been reached as to whether the upper part of the Utica shale (which overlies the Trenton in that area) is Middle or Late Ordovician in age. The problem is further complicated by the fact that the Utica is overlain by another shale (Lorraine), which makes placing the boundary on the basis of lithology difficult.

Stout and Lamey (1940, p. 683) identified the Utica shale in Ohio and stated that it is well developed in the northern and eastern parts of the State but is thinner in outcrop, along the Ohio Valley, where it is known as Fulton. Twenhofel and others (1954), however, indicated that the Fulton is definitely younger than the Utica.

Because of current unsolved problems in correlation, Fettke (1948, p. 1484-1486) did not separate the Black River and the Trenton limestones and referred to the combined formations as Mohawkian limestones. He described the "Mohawkian limestones" as ranging in composition from argillaceous to almost pure limestone and from very fine crystalline to lithographic. Dolomites and dolomitic limestones are practically absent, he stated, and minor amounts of chert are present at certain horizons. Bentonites occur as thin layers in the Black River and the Trenton in the northern part of the Appalachian Basin, according to Fettke. An isopach map, Middle Ordovician limestones, presented by Fettke (1948, fig. 6), indicates a thickness of 600 feet in most of northwestern Ohio.

Of particular interest is the locally dolomitized upper part of the Trenton limestone in northwestern Ohio; this is the reservoir rock of the Trenton (Lima-Indiana) oil and gas field. This zone, according to Landes (1946, p. 317), consists of 10 to 30 feet or more of porous dolomite which has been altered from limestone. Various figures, mostly ranging from 20 to 25 percent, have been cited in the literature as the minimum magnesium-carbonate content of the Trenton limestone in areas that have produced oil and gas. A map prepared by Panyity (1921, fig. 2) indicates that the oil and gas fields of northwestern Ohio are confined within the 25 percent minimum magnesium-carbonate isolith.[18]

The present writer has examined the Black River and the Trenton limestones from test wells in northwestern Ohio and found them identical to most samples in Indiana. In general, the Trenton limestone consists of light-tan to medium-tan crystalline limestone and in northwestern Ohio ranges from about 50 to 200 feet in thickness. The Black River limestone consists of light-tan to dark-tan lithographic argillaceous limestone and in northwestern Ohio ranges from about 300 to 500 feet in thickness.

KENTUCKY

Outcrop.—According to McFarlan and White (1948, p. 1627-1646) the High Bridge limestone, which is the oldest rock unit exposed in central Kentucky, is divided into the following three formations in descending order:

Tyrone limestone:
Dense gray, dove, or cream-colored limestone with small facets of coarsely crystalline calcite; contains a persistent bed of bentonite 15 to 25 feet below the top.

Oregon magnesian limestone:
Gray to cream and buff-colored granular magnesian limestone.

Camp Nelson limestone:
Dense limestone of the Tyrone type with irregular patches of granular limestone of the Oregon type.

[18] For other references to the producing zone of the Trenton in northwestern Ohio, see Ley (1935), Carman and Stout (1934), Phinney (1891), and Orton (1888).

Huffman (1945, p. 173) and Twenhofel and others (1954) suggested that the Tyrone and the Oregon limestones are included in the Trentonian Stage, but that the Camp Nelson limestone is part of the Black River Stage. The present author believes that the High Bridge group, regardless of exact age, forms a distinctive and useful rock unit that is characterized by lithographic ("dense") limestones and that is a continuation in Kentucky of the Black River limestone of Indiana.

The High Bridge limestone group is overlain by the Lexington limestone group, which has been subdivided on the basis of lithology and fauna. McFarlan and White (1948, p. 1634) described the general lithology of the Lexington limestone as fossiliferous thin- to medium-bedded gray crystalline limestone and some shale. The Lexington limestone is included in the Trentonian Stage, according to Twenhofel and others (1954), and is overlain by the Cynthiana formation, which differs lithologically from the Lexington in containing a larger percentage of shale. The Cynthiana is transitional between the Trentonian and Cincinnatian Stages.

McFarlan and others have reviewed the rather complex stratigraphy of the Lexington limestone and the Cynthiana formation in Kentucky (McFarlan and Freeman, 1935; McFarlan, 1938 and 1943; McFarlan and White, 1948). Work continued by McFarlan and his associates has resulted in a revision of concepts regarding the relationships of the Lexington and the Cynthiana. A complete summary of these revisions, as described by McFarlan and White (1948), is beyond the scope of this report, but a brief description is pertinent because of a similar problem involving the equivalent beds in Indiana.

An unconformity was long assumed to exist at the top of the Lexington limestone in central Kentucky. This assumption was due to the misidentification of upper Lexington beds (Devils Hollow) as middle Lexington (Perryville). The resulting "unconformity" was observed in areas where the Lexington apparently thinned and the overlying Cynthiana apparently thickened. When the beds erroneously referred to middle Lexington (Perryville) were seen to be representative of the upper Lexington, it became apparent that the relationship is one of facies change rather than one of unconformity.

McFarlan and White (1948, p. 1645) stated:

> It is hardly a coincidence that the downward thickening of the Cynthiana in the southern, southwestern, eastern, and northern Bluegrass [central Kentucky] is in the areas of a thinning upper Lexington interval. This may be

interpreted as a Cynthiana invasion of a region of low relief but there is no physical evidence of unconformity. Before the realignment of the Perryville, an unconformity had to be recognized irrespective of the physical evidence. With the removal of this one brick in the stratigraphic structure, the collapse of others followed. The contemporaneity of the lower "Cynthiana" in these several marginal areas with the late Lexington seems to be reasonably certain.

Subsurface.—Freeman included a map (pl. 7) of the combined Chazy and Black River intervals in a report published in 1953. The map indicates a thickness ranging from 400 to 850 feet along the Indiana-Kentucky boundary and thicknesses of 1,450 feet in western Kentucky and 1,500 feet in eastern Kentucky. The strata mapped as Chazy-Black River by Freeman include the Joachim dolomite and the Black River limestone of the present report and the St. Peter? sandstone in eastern Kentucky. The Black River limestone of Freeman is a continuation of the High Bridge limestone of outcrop.

Freeman identified several of the overlying outcrop formations in subsurface. Three wells logged by both Freeman and the present writer are compared in the section on Correlation of the Mohawkian series.

CORRELATION OF THE MOHAWKIAN SERIES

The lithologic correlation of the Black River limestone with the equivalent units in adjacent states is fairly certain. Thus the Black River limestone of Indiana can be traced into Illinois, where it is known as the Plattin (Platteville) formation, and into Kentucky, where it is known as the High Bridge limestone. The Black River limestone, as defined in the present report, is also identifiable in Ohio and Michigan.

Similarly, the Trenton limestone of Indiana can be shown to be a continuation of the Galena and the Kimmswick formations of Illinois. Relationships of the Trenton of Indiana to the Lexington limestone and the Cynthiana formation of Kentucky are not as clear. No further information about the time-rock correlation of the Mohawkian series is available from present investigations. If the upper part of the High Bridge limestone of Kentucky is part of the Trentonian Stage, as suggested by Huffman (1945) and Twenhofel and others (1954), then the upper part of the Black River of Indiana is also probably Trentonian. Whether or not this age relationship is definitely established, the Black River limestone, as defined in Indiana, and the High Bridge limestone of Kentucky form a continuous and valuable lithologic unit in subsurface work.

CINCINNATIAN SERIES

The Cincinnatian series (Upper Ordovician) has its type locality in the Cincinnati Arch region of southeastern Indiana, southwestern Ohio, and northern Kentucky. The name Cincinnatian series also is used in subsurface work in Indiana, Michigan, Ohio, and most of Kentucky.

In its type area the Cincinnatian series has been subdivided into three groups which are in descending order: Richmond group, Maysville group, and Eden shale group. These groups have been subdivided (table 7) into many formations which are based in part upon lithology but to a larger extent upon the occurrence of characteristic megascopic fossils. Many of the "formations" are more properly referred to as *biostratigraphic zones.* Identification of these biostratigraphic zones in subsurface has not been successful because of the difficulty in identifying fossils that have been broken by drilling. Consequently, the present description of the outcrop character of the Cincinnatian is general, and other works, especially those of Cumings (1908 and 1922), Cumings and Galloway (1913), and McFarlan (1943), should be consulted for details of outcrop stratigraphy.

The Maquoketa shale, which crops out in northwestern Illinois, eastern Iowa, and southwestern Wisconsin, has been considered to be Richmond in age by most workers. The name Maquoketa has been used in subsurface work in Illinois and western Kentucky for the Ordovician strata which overlie the Galena (Kimmswick) formation.

CINCINNATIAN SERIES IN OUTCROP

The Eden shale in outcrop in Indiana was described by Cumings (1922, p. 424) as soft blue to greenish marly shales which weather readily to marly clays of a yellowish to greenish color and which are interstratified with occasional thin layers of fossiliferous limestone or of sandstone.

In Ohio and northern Kentucky the Eden is much the same, although basal Eden is referred to as Fulton shale. The Fulton shale is not present in outcrop in Indiana (Cumings, 1922, p. 423).

In central Kentucky the lower Cincinnatian is generally the same as in Indiana and Ohio. The upper part is represented by the Garrard siltstone, which is transitional with lower Maysville strata (Twenhofel and others, 1954).

The Maysville and Richmond groups in outcrop in Indiana, Ohio, and Kentucky can be generally described as interbedded

Table 7.—*Selected examples of stratigraphic nomenclature of rock units within the Cincinnatian series as defined in Indiana, modified from various sources referred to in text*

<table>
<tr><th colspan="2" rowspan="2">Cincinnati Arch outcrop</th><th rowspan="2">Illinois outcrop and subsurface</th><th rowspan="2">Western Indiana subsurface</th><th colspan="2">Eastern Indiana subsurface</th></tr>
<tr><th>North</th><th>Southeast</th></tr>
<tr><td rowspan="5">Richmond group</td><td>Elkhorn limestone</td><td rowspan="15">Maquoketa shale</td><td rowspan="15">Maquoketa shale</td><td colspan="2" rowspan="9">Maysville-Richmond group (undifferentiated)</td></tr>
<tr><td>Whitewater and Saluda formations</td></tr>
<tr><td>Liberty formation</td></tr>
<tr><td>Waynesville formation</td></tr>
<tr><td>Arnheim formation</td></tr>
<tr><td rowspan="5">Maysville group</td><td>Mt. Auburn formation</td></tr>
<tr><td>Corryville formation</td></tr>
<tr><td>Bellvue formation</td></tr>
<tr><td>Fairmount formation</td></tr>
<tr><td>Mt. Hope formation</td><td colspan="2" rowspan="4">Eden shale group (undifferentiated)</td></tr>
<tr><td rowspan="4">Eden shale group</td><td>McMicken shale</td></tr>
<tr><td>Southgate shale</td></tr>
<tr><td>Economy shale</td></tr>
<tr><td>Fulton shale</td><td rowspan="2"></td><td rowspan="2">Upper part of Lexington-Cynthiana formation</td></tr>
<tr><td colspan="2">Upper part of Cynthiana limestone</td></tr>
</table>

fossiliferous limestone and calcareous shale, the percentage of limestone being markedly greater in these two groups than in the Eden shale.

CINCINNATIAN SERIES IN SUBSURFACE IN INDIANA

Thickness variations of the Cincinnatian series are presented in figure 15. Near the region of Cincinnatian outcrop the subsurface continuation of the type Cincinnatian series is similar in lithology and thickness to that of outcrop. The Maysville and Richmond groups cannot be separated in subsurface, however, and the writer has chosen to use the term Maysville-Richmond group for the combined units.[19]

As indicated in figure 15, the isopachs of the Cincinnatian series in Indiana trend slightly east of north, and the total section in northern Indiana is somewhat thinner than in the south. This thinning appears to be at the expense of the Maysville-Richmond group, inasmuch as the Eden shale maintains its thickness and in some places actually increases in thickness. In addition, the Maysville-Richmond group contains a larger percentage of shale toward the north; this fact makes separation of the Maysville-Richmond and the Eden more difficult. The trend of increasing shale content in upper Cincinnatian rocks continues northeastward across Ohio, and farther east the Cincinnatian series consists entirely of shale (Lorraine and Queenston of New York, for example). The Cincinnatian series also thickens considerably in this direction (Fettke, 1948, fig. 7).

The Cincinnatian series in southwestern Indiana is similar in lithology to that of the outcrop in southeastern Indiana, but it differs markedly in thickness. The Maysville-Richmond group appears to thin more rapidly toward the west than the Eden shale does.

In west-central and northwestern Indiana the Cincinnatian series consists of upper and lower shale units separated by interbedded shale and limestone or dolomite units. The dolomite facies of the Cincinnatian series, like that of the Trenton limestone, is typical of northwestern Indiana. This same threefold subdivision is typical of the Maquoketa shale in Illinois, both in sequence and lithology, and thus the name Maquoketa shale is properly used for Upper Ordovician strata in west-central and northwestern Indiana. For example, in Warren County, west-central Indiana (datum-point no. 59), the writer noted the following subdivisions:

[19] Bieberman and Esarey (1946, p. 5) also were unable to make this separation.

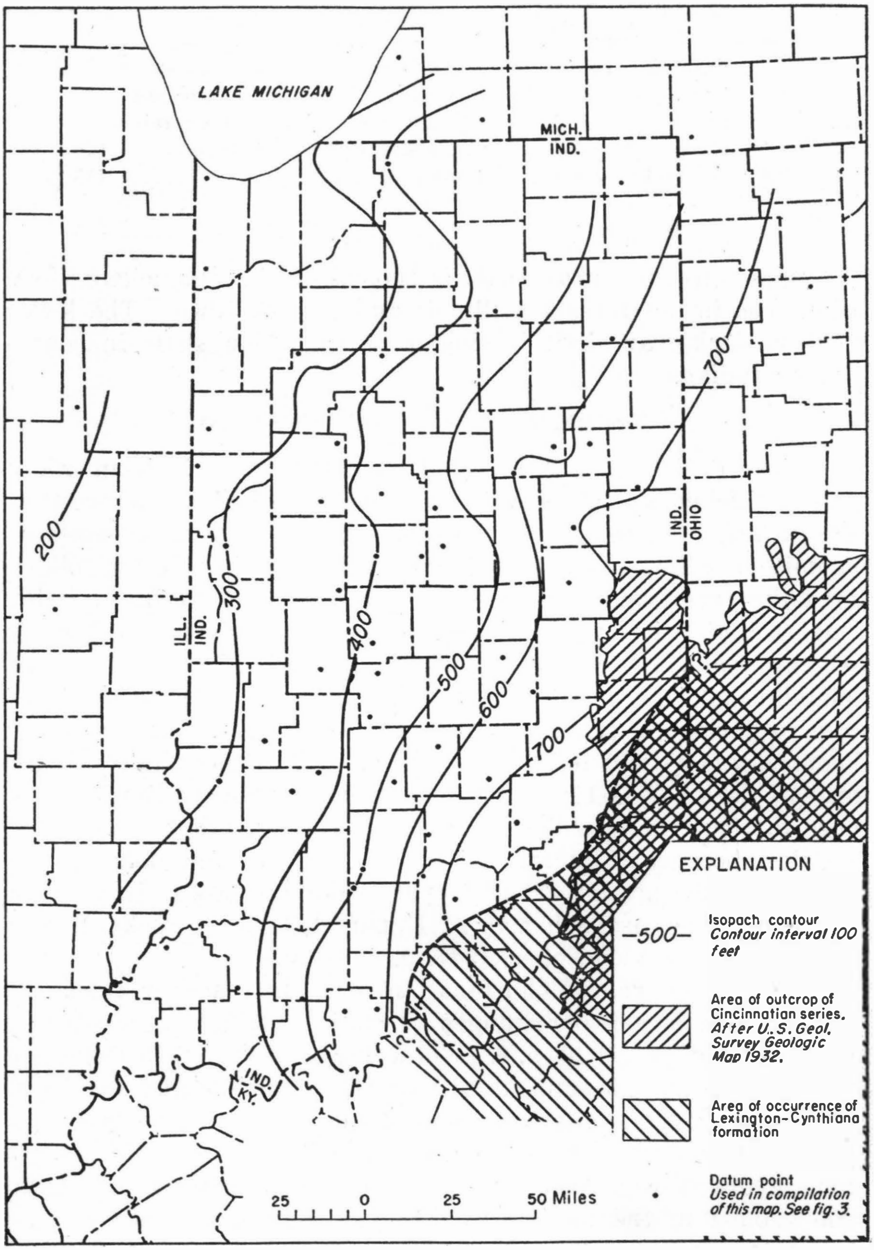

Figure 15.—Map showing thickness and outcrop of Cincinnatian series.

Maquoketa shale:	Feet
Shale: Greenish-gray, massive, soft	40
Interbedded dolomite (75 percent) and shale (25 percent): Dolomite varies from light gray to yellowish gray and finely saccharoidal to finely crystalline and contains fossil fragments; shale is medium gray, calcareous	120
Shale: Medium dark-gray, hard	115
Total thickness	275

The upper greenish-gray shale is typical of the Maquoketa shale in outcrop in northwestern Illinois and eastern Iowa. The lower medium dark-gray shale is similar to the Eden shale in southeastern Indiana.

SUBSURFACE IN MICHIGAN AND OHIO

Cohee (1948, p. 1438) stated that Upper Ordovician rocks reach a thickness of 900 feet in southeastern Michigan, where they consist largely of gray and dark-gray shale and small amounts of dolomite and limestone. Cohee divided these rocks into the following units from youngest to oldest: Queenston (shale), Lorraine (shale), and Utica (shale). The Queenston consists of light-gray to gray shale and some red shale and interbedded limestone or dolomite and is 110 to 200 feet thick. The Lorraine consists of gray to dark-gray calcareous shale and thin beds of limestone or dolomite and is 290 to 390 feet thick. The Utica shale is dark gray to black and is 150 to 200 feet thick. These subdivisions are more difficult to establish westward across Michigan, according to Cohee, because of lateral variation. Limestone and dolomite are common in the upper part of Upper Ordovician rocks in western Michigan. (See isopach map of Upper Ordovician rocks, Cohee, 1948, fig. 7, and also Cohee, 1947, p. 299-300.)

As stated above, the Cincinnatian series increases in thickness and contains larger percentages of shale eastward across Ohio. Stout and Lamey (1940, p. 681) described a test well in Delaware County, central Ohio, and noted that the Maysville and the Richmond groups are similar and consist of dark-bluish to greenish-gray calcareous shale and thin interbedded limestone. The limestone layers average about 35 percent of the Richmond and Maysville groups in the test well. The Eden shale is similar, they stated, except that it contains less limestone, which is distributed as widely spaced thin nodular layers. Stout and Lamey (1940, p. 675) cited a combined thickness of 870 feet for these 3 units. These authors assigned the underlying 150 feet of brown shale and dark carbonaceous limestone to the Utica shale. The Utica shale of Stout and Lamey may represent the Lexington-Cynthiana formation of this report.

SUBSURFACE IN KENTUCKY

Freeman (1953, p. 31-35) has described the Cincinnatian series in Kentucky, and, except as noted, her comments are summarized below. Because of the difficulty in identifying the Fulton shale (basal Cincinnatian), Freeman included the Cynthiana formation and the Fulton and the Million shales in a combined unit referred to as Cynthiana-Million. The upper Eden and lower Maysville equivalent is the Garrard, which Freeman described as sandy to silty and argillaceous dark-gray limestone. She considered the Garrard as time-transgressive but a widespread and useful stratigraphic marker nevertheless.

The Fairmount, which Freeman considered the lowermost member of the Maysville group, is about 120 feet thick and is described as a series of fossiliferous and phosphatic limestones interbedded with calcareous shale which is similar to the underlying Cynthiana-Million except for faunal content. According to Freeman, the Garrard facies "rises in the section northward at the expense of the Fairmount." The Fairmount is overlain by the Tate, a green dolomitic siltstone which becomes increasingly calcareous and argillaceous to the north. The Tate is overlain by the Gilbert limestone, which Freeman considered the top of the Maysville group. The Gilbert is described as thin heavy-bedded almost black fine-grained and dense limestone. It is rarely more than 8 to 10 feet thick.

Freeman (1953, pl. 9) included in her report an isopach map of the Richmond group, which indicates that the Richmond group is not present west of a line extending through west-central Kentucky and Harrison, Lawrence, and Vigo Counties, Ind. The present writer does not agree with this interpretation. According to Freeman (1953, p. 34):

> Near the southern part of the Lexington dome . . . the Richmond is mainly green, argillaceous, silty dolomite. Northeastward it becomes first more calcareous, then less green and silty, until just south of the Ohio River it is lithologically similar to the underlying Maysville, that is, fossiliferous gray limestone interbedded with calcareous shale, the shale increasing northward. In a small area west of the dome the Richmond is dolomitic, locally having clean, but thin, dolomites which have contained a little oil. On the southeast, the Richmond becomes increasingly silty, with the green color changing to red, first as red silty shales, then red silts, and finally the red sandstones of the Medina.

SUBSURFACE IN ILLINOIS

Du Bois (1945, p. 7-16) has studied the subsurface Maquoketa shale in Illinois.[20] Du Bois' subdivisions of the Maquoketa shale can be summarized as follows: (1) upper green shale which commonly contains thin lenses of limestone or dolomite; (2) middle carbonate rock zone which is dominantly limestone or dolomite, but which may contain thin green or brown shale layers; and (3) lower brown shale which may contain interbedded argillaceous limestone or dolomite and lenses of green shale. Du Bois suggested that a twofold subdivision is more suitable in the southwestern part of Illinois (p. 7): (1) an upper green interbedded silty shale or sandstone; and (2) a lower generally brown calcareous shale that has local siltstone or sandstone lenses.

An isopach map presented by Du Bois (1945, fig. 1) indicates that the Maquoketa shale ranges from the vanishing point in west-central Illinois and northern Illinois to 200 to 300 feet in thickness along the Illinois-Indiana boundary.

CORRELATION OF THE CINCINNATIAN SERIES

Correlation of the Cincinnatian series in subsurface is, in general, fairly certain. Two problems, as yet, remain unresolved. These are: (1) the correlation of the Lexington-Cynthiana formation change in southern Indiana and (2) the age relationship of the Cincinnatian series and the Maquoketa shale. The first problem already has been discussed in the section on the Mohawkian series (p. 64 and 68).

The Cincinnatian series and Maquoketa shale are continuous in subsurface, although they differ in thickness and to some extent in lithology. The Maquoketa shale in outcrop along the Mississippi River is considered to be Richmond (late Cincinnatian) in age by most workers because of paleontologic evidence. Thus, if the Maquoketa shale is of Richmond age, strata of Eden and Maysville age must disappear somewhere between the outcrop of the Cincinnatian series in the type area in the Cincinnati Arch region and the outcrop of the Maquoketa shale along the Mississippi River. Such a relationship, if it exists, requires either (1) a basal unconformity in the area of occurrence of the Maquoketa shale (which removed strata of Eden and Maysville age before deposition of the Maquoketa) or (2) that the Cincinnatian series be a time-transgressive unit which was deposited by a sea encroaching

[20] See Payne (1942, p. 66-67) for a description of the subsurface Maquoketa in north-central Illinois.

from the east upon a Trenton surface and which did not reach Iowa, for instance, until Richmond time.

Physical evidence is lacking, at present, to support either of these hypotheses, and correlation by tracing of beds in subsurface leads to the conclusion that deposition was continuous in both areas throughout Cincinnatian time.[21] Further work, both in subsurface and on outcrop, is necessary before the history of deposition of the Cincinnatian series and the Maquoketa shale can be fully understood.

HISTORICAL GEOLOGY AND ENVIRONMENTAL RECONSTRUCTION

Any discussion of geologic history should be based upon studies of time-stratigraphic units rather than the rock units which are described in this report. In the absence of time-stratigraphic studies, this reconstruction of the geologic history of Indiana during lower Paleozoic deposition, which is based upon available information, should be considered tentative. Suggested time-rock correlations of Cambrian and Ordovician units in subsurface in Indiana are shown in figure 16.

Indiana was not covered by Early or Middle Cambrian seas. Deposition began in Late Cambrian time with sands (basal Mt. Simon) derived from the Canadian shield. The belief that the sands were derived from the shield is based upon their marked thickening in that direction—a character common to most lower Paleozoic sands in Indiana and the adjacent states. Although Paleozoic deposition began with sand throughout Indiana, and sand deposition continued to the end of Mt. Simon time in the northern part of the State, the following evidence suggests that other kinds of sediments were being deposited concurrently in the remainder of the State.

The Mt. Simon sandstone is overlain by the Eau Claire formation, which is composed of fine sandstone, shale, and dolomite. The Eau Claire reaches its maximum thickness somewhat to the south and parallel to the maximum-thickness trend of the Mt. Simon. The Mt. Simon thins markedly in the area of thickening of the Eau Claire; this fact suggests that they complement each other and are partly contemporaneous. The Knox dolomite overlies the Eau Claire and reaches its maximum recorded thickness in Indiana south of the area of maximum thickness of the Eau Claire. It has

[21] Evidence exists for an unconformity between Middle and Upper Ordovician beds in outcrop along the Mississippi River, however (Willman, oral communication).

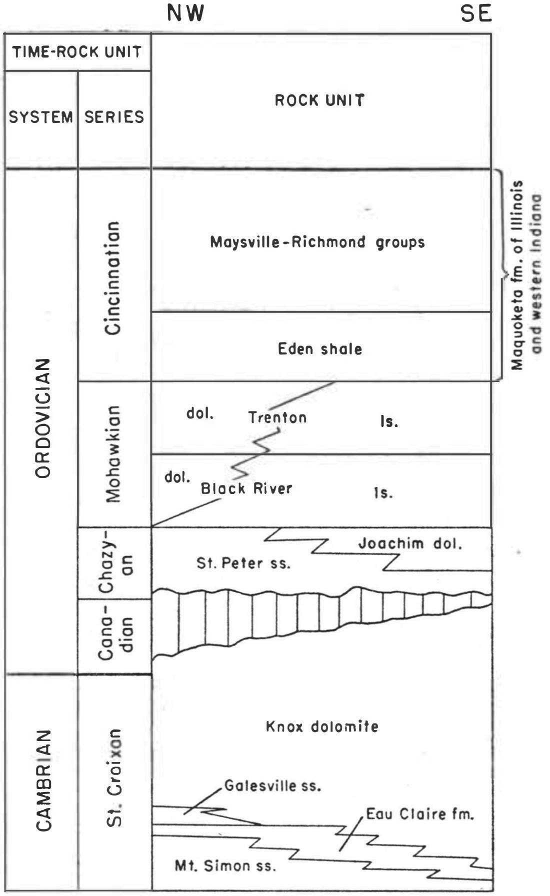

Figure 16.—Generalized columnar section showing suggested time-rock correlations of Cambrian and Ordovician units in subsurface in Indiana.

been pointed out above that the northward thinning of the Knox is due mostly to truncation. Thickness and lithologic relationships, however, strongly suggest that the Mt. Simon, Eau Claire, and lower Knox may have been generally contemporaneous facies in which the Mt. Simon represents a beach deposit composed of coarse sand derived from the Canadian shield, the Eau Claire represents a strand-line deposit of interbedded sandstone, shale, and carbonate rocks, and the lower Knox represents seaward deposition, predominantly of carbonate rocks. The superposition of Knox overlying Eau Claire and Eau Claire overlying Mt. Simon may be explained on the basis of northward transgression of those formations.

Late Knox deposition consisted primarily of carbonates, and except in northwestern Indiana (toward the shield) sands were local and insignificant. Some of the upper Knox was removed by erosion at the end of early Ordovician time.

In northwestern and west-central Indiana the St. Peter sandstone was deposited on the post-Knox unconformity. The St. Peter is thickest in northwestern Indiana, thins markedly to the east and south, and is not present in northeastern and southern Indiana. The Joachim dolomite, however, thickens to the south; this fact suggests that the St. Peter and Joachim may also have been partly contemporaneous.

The Black River limestone was deposited throughout the State after rocks of the Chazyan series had been deposited. In northwestern Indiana the Black River overlies the St. Peter sandstone, in southwestern and central Indiana it rests upon Joachim dolomite, and in places in northeastern Indiana it rests upon Knox. The time of its deposition appears to have been one of relatively great tectonic stability in Indiana, as the formation is remarkably uniform throughout the State. It thickens in a southerly direction; this fact suggests a somewhat more negative structural tendency in that direction, as there is no evidence of postdepositional erosion. The Black River consists of limestone except in northwestern Indiana, where it is composed entirely of dolomite. Because this and other Middle Ordovician dolomites of the upper Mississippi Valley seem to be related to minor structures, the present writer believes that they were originally deposited as limestones and later altered to dolomite. The date of such an alteration is not known.

Deposition of limestone continued with deposition of the Trenton throughout most of Indiana. The Trenton, with two notable exceptions, is fairly uniform in lithology and thickness throughout most of the State. It consists entirely of dolomite in northwestern Indiana. This dolomite facies thins to the south and east but maintains its position at the top of the formation. The writer believes that this dolomite facies, like the dolomite of the Black River, is a postdepositional feature.

The end of Trenton deposition was marked throughout most of the State by an abrupt change to shale (Eden) and rare beds of limestone. In the southernmost part of Indiana, however, shale deposition began before the end of Trenton-limestone deposition to the north. In this southern area some limestone was deposited along with the earliest shale of Eden type; this limestone may represent local reef or biostromal accumulations which were intermittently covered with mud. The linear trend of the boundary of this type of deposition (figs. 12 and 15) is unexplained at present. Possibly it is related to some ancient oceanographic feature, but a reconstruction of the paleogeography on the basis of present knowledge would be very questionable.

Deposition of Eden shale in eastern Indiana was succeeded by deposition of large quantities of limestone (Maysville and Richmond) which were formed from biostromal accumulations of the remains of carbonate-secreting animals—bryozoa, crinoids, pelecypods, and brachiopods. Animal life was extremely abundant during Maysville and Richmond time, but mud was washed intermittently over the biostromal accumulations as is evidenced by the interbedded thin shale layers. Shale deposition was more or less continuous in western Indiana during the Late Ordovician, as the Maquoketa shale contains much less limestone than the Maysville and Richmond.

OIL AND GAS POSSIBILITIES IN CAMBRIAN AND ORDOVICIAN ROCKS

OIL AND GAS POSSIBILITIES IN SURROUNDING STATES

ILLINOIS

Bays (1945, p. 35) suggested that petroleum possibilities in the Maquoketa shale (equivalent of Cincinnatian series; see table 7) in Illinois are limited to porous zones in the middle carbonate unit and to local sandstone lenses[22] in southwestern Illinois. Porous zones are formed in the middle carbonate unit in northern Illinois, but only where the upper green shale has been removed and the middle carbonate is overlain by Silurian rocks. Such porous zones are not known to have been formed in central and southern Illinois, according to Bays.

Cohee (1941, p. 3) maintained that production from Mohawkian rocks in Illinois has been limited to the Kimmswick (Galena) limestone (table 6). Oil was produced noncommercially from this limestone in Kankakee County, northeastern Illinois, in 1900.

Oil from the Kimmswick (Galena) has been produced commercially from 13 wells in the Westfield pool, Clark County, southeastern Illinois, according to Cohee (1941, p. 4). This field

[22] This facies is not present in Indiana.

is on a dome on the axis of the La Salle anticline. Main production is from Mississippian strata. The Kimmswick (Galena) pay zone, Cohee stated (1941, p. 4), consists of coarse dolomitic limestone which is fossiliferous and contains clear calcite crystals. At most places the zone is 90 to 100 feet below the top of the Kimmswick (Galena). Initial production from the zone averaged 100 barrels per well in the first 24 hours. Within 2 or 3 months production was reduced to 10 or 12 barrels. Similar results were obtained in two wells in the Martinsville pool, Clark County, Ill.

Oil from the Kimmswick (Galena) has been produced commercially in small amounts in the Centralia and Salem pools in south-central Illinois and in the Waterloo and Dupo pools in southwestern Illinois (Cohee, 1941, p. 5-11). In all these pools the producing rock is dolomitic limestone.

Bays (1945, p. 37) suggested that the most favorable area for further Galena (Kimmswick) exploration is along the Ozark dome in southwestern Illinois, where considerable pre-Maquoketa erosion of the Galena may have produced sufficient permeability.

According to Bays (1945, p. 37), the Decorah, Plattin, and Joachim formations (see tables 5 and 6) have not produced commercial oil and show little prospect of doing so because of a lack of effective permeability. The Dutchtown formation (see table 5)[23] contains sandstones that may serve as reservoirs.

The St. Peter has been tested on various structures in northern Illinois without success. Workman and Bell (1948, p. 2062) did not consider the northern third of Illinois favorable for production from the St. Peter sandstone (see table 5) and lower formations. The St. Peter and the underlying formations are largely untested throughout the remainder of the State. Workman and Bell (1948, p. 2062) listed the following porous zones that lie below the St. Peter (see tables 3 and 4) : (1) crevices and cavities in the Shakopee dolomite, (2) porous New Richmond sandstone in its area of extensive thickness in central Illinois, (3) crevices and cavities in the Trempealeau dolomite, (4) Galesville sandstone, (5) lenticular parts of the Eau Claire formation, and (6) Mt. Simon sandstone. Authenticated shows of oil or gas have not been reported from any of these zones, however.[24]

MICHIGAN

Cohee (1948, p. 1446) reported that Trenton production in Michigan is confined to the southeastern part of the Southern

[23] This formation is not known to be present in Indiana.
[24] For additional discussion, see Swann and others (1951, p. 353-357).

Peninsula, in Monroe and Wayne Counties. He also listed (1948, table 2) six showings below Middle Ordovician in test wells. He stated that showings of gas in the Trenton had been reported in Washtenaw County, southeastern Michigan, and a showing of oil had been reported in Barry County, southeastern Michigan.

Cohee believed that further oil discoveries in the Trenton and the Black River rocks depended upon locating porous zones associated with fracturing and dolomitization on top or on the flanks of domes and anticlines. He recommended drilling the entire Black River-Trenton section. With regard to the lower formations, Cohee believed that stratigraphic and structural traps may be associated with the unconformity at the top of the Lower Ordovician along the major folds in and bordering the Michigan Basin.

OHIO

Production from the Trenton limestone in the Trenton (Lima-Indiana) oil and gas field has already been discussed as being from a dolomitized zone in the upper part of the formation. According to Fettke (1948, p. 1490), extensive drilling to the top of the Trenton in central Ohio has not resulted in the discovery of local areas of dolomitization. He reported that a small amount of oil has been obtained at four localities from sandy zones in what is believed to be Trempealeau. These localities, as listed by him, are widely spaced, but most of them are in central Ohio. Fettke stated (1948, p. 1491) that:

> Of 67 available records of wells that penetrated strata below the Black River in central Ohio, 27 reported showings of oil and gas, some accompanied by salt water, a short distance below the unconformity, less than 40 feet. Of those that were drilled appreciable distances below the unconformity, very few reported any additional showings of oil or gas. Salt water, on the other hand, has been encountered, commonly in considerable volumes, even as deep as the Mt. Simon sandstone.

The showings in Ohio listed by Cohee (1948, table 2) also should be consulted.

Fettke (1948, p. 1491-1492) pointed out that these showings are associated with the unconformity at the top of the Lower Ordovician and that they suggest migration and entrapment of oil beneath the unconformity. Commercial accumulation may be found in places where porous and permeable layers are of sufficient thickness and areal extent.

Freeman (1953, p. 35-42) discussed the depositional and structural history of Cambrian and Ordovician rocks with reference to possible future production in Kentucky. According to her, the extension of the thin Trenton limestone below black shale in southern Indiana and northern Kentucky (see fig. 14 of the present report) suggests a possible source and reservoir along the flank of the Ozark dome in western Kentucky. Other possibilities include areas of facies change such as the present production in southern Kentucky from a coquina ("Granville") which is included in the Eden group.

Freeman (1953) discussed at length production from the Ellenberger and the Arbuckle formations of Oklahoma and Texas because of similarity in their age and lithology to equivalent formations in Kentucky. Freeman concluded (p. 37) that the following requisites are necessary for Ellenberger-Arbuckle-Knox production:

(1) Dolomite, principally because some interstitial porosity is generally found in the coarser dolomites, and because dolomite either fractures more easily than limestone or heals less readily. (2) Sharp folds (a) to initiate the necessary fracturing, (b) to facilitate more rapid erosion of overlying beds so that the older formations can be overlapped by younger organic strata, and (c) to cause the stresses necessary to distill this organic material into oil.

According to Freeman (1953, p. 38), the only indications of oil in the Knox of Kentucky have been found in the areas of the sharpest known structures in the State. These areas are in southwestern Kentucky, where test wells showed small amounts of oil in fractures, and in central Kentucky, where gas has been found in both the St. Peter sandstone and the Knox. Structures of sufficient magnitude to produce conditions similar to those found in the Arbuckle and the Ellenberger producing areas are not known in Kentucky, according to Freeman. Further, the Knox of Kentucky is nowhere unconformably overlain by beds of sufficiently high organic content to serve as possible sources of petroleum.

Freeman concluded (1958, p. 38) that deeper production in Kentucky is most likely to come from lower Paleozoic sands, if they can be found in contact with source beds, possibly along so-called crypto-volcanic structures or the crests of old structures which are reflected in the isopachs of younger systems.

Two areas were recommended for further exploration by Freeman (1953, pl. 10). These are (1) in southern Illinois and western Kentucky for Trenton production and (2) along the Ohio River in north-central Kentucky and southern Indiana for Knox production.

OIL AND GAS POSSIBILITIES IN INDIANA

MT. SIMON SANDSTONE

Commercial oil or gas has not been produced from the Mt. Simon sandstone (basal Upper Cambrian) in Indiana. Shows of tar, heavy oil, and oil stain or "rainbow" were reported in the Mt. Simon in 3 of the 12 test wells which penetrated the Mt. Simon sandstone. None of these shows were examined by the present writer. Reported shows of oil and gas below the Trenton and the Black River limestones in Indiana are listed in table 8.

The Mt. Simon sandstone is an ideal reservoir for petroleum from the standpoint of lithologic character and stratigraphic relationships. As it is a "blanket-sand," any entrapment would have to be structural, however. It consists of highly porous and permeable coarse rounded quartz sand. It is friable and could be drilled easily. The Mt. Simon thins rapidly from north to south in Indiana and probably interfingers with the Eau Claire formation. In some places the Mt. Simon is overlain by shales of the Eau Claire which might serve as a cap rock. In other places it is overlain by dolomite or fine dolomite-cemented sandstone of the Eau Claire which may be somewhat porous and cannot serve as a cap rock.

The Mt. Simon sandstone appears to be an attractive prospect for exploration on the basis of lithology and stratigraphic relationships, but the formation is virtually untested in Indiana. Oil has not been found in commercial quantities in the many water wells which have been drilled to the Mt. Simon in northern Illinois and southern Wisconsin. Workman and Bell (1948, p. 2062) pointed out that less oil might be present in older strata such as the Mt. Simon sandstone. However, this formation cannot be condemned without further testing throughout most of Indiana.

EAU CLAIRE FORMATION

Commercial oil or gas has not been produced from the Eau Claire formation in Indiana. Shows of gas, oil, tar, heavy oil, dead oil, and oil stain were reported in the Eau Claire in 7 of the 17 test wells which penetrated the Eau Claire formation in Indiana (table 8). None of the shows were examined in the well cuttings by the present writer.

The Eau Claire consists of interbedded dolomite, fine-grained standstone, and shale. In general, shale is more common in the Eau Claire in the southern part of the State than in the northern part. Although details are not known, there is no doubt that the Eau Claire exhibits marked changes in porosity and in ability to

Table 8.—*Reported shows of oil and gas below the Trenton and Black River limestones in Indiana listed by counties*[1]

County	Location			Operator and name of well	Depth (feet)	Description	Formation	Source
	Sec.	T.	R.					
Adams	35	25N	13E	McKee No. 1 Glendening	1,626	sso	Knox	Scout
					1,799-1,804	so		
					1,803-08	o sat		
					1,800-15	sdo		
					2,024-29	sso		
					2,260-61	so		
Adams	35	25N	13E	Seip No. 1 Glendening	1,720-25	o disc	Knox	Sample study (not author's)
					1,725-30	sl o disc		
					1,742-65	sl o disc		
					1,770-85	sl o st		
					1,795-1,800	o disc		
					1,830-40	sl o st		
					1,875-85	sl o st		
					1,885-1,915	"few black paraffin pellets"		
					1,950-60	sl o st		
					1,985-2,010	"some paraffin pellets"		
					2,010-20	sl st		
					2,021-25	sl st		
					2,065-80	sl st		
					2,150-70	v sl o st		
					2,185-2,205	sl disc		
					2,205-15	"cons paraffin pellets"		
					2,215-25	"buff oil disc"		
					2,245-65	v sl disc		
Allen	33	29N	12E	Tecumseh No. 1 Gibson	2,127-47	tar	Knox	Sample study (not author's)
					2,147-75	"specks of tar"		
					2,188-2,204	tr tar		
					2,259-68	tr tar		
					2,268-74	sl tr tar		
					2,345-51	tr tar		

Table 8.—*Reported shows of oil and gas below the Trenton and Black River limestones in Indiana listed by counties*—Continued

County	Location			Operator and name of well	Depth (feet)	Description	Formation	Source
	Sec.	T.	R.					
					2,725-48	tar	Eau Claire	Sample study (not author's)
					2,826-74	l o st		
					2,933-52	l o st		
Benton	27	25N	9W	Thomas No. 1 Fowler	1,710-15	o and tar specks	St. Peter	Sample study (not author's)
Blackford	15	24N	11E	Jones No. 1 Simonton	1,632	"green sand, approx. 14 feet showing below the green sand"	Knox	Driller's log
Blackford	20	24N	11E	Reed No. 1 Cale	1,518-27	o st	Knox	Sample study (not author's)
					1,568-74	tr o disc		
					1,583-91	tr o disc		
					1,643-80	tr o disc		
					1,771-75	tr o disc		
					1,827-52	"gas bubbles"		
					1,843-52	tr o disc		
					1,859-65	v o disc		
					2,315	gas	Eau Claire	Scout
Cass	11	28N	1W	Eastman No. 1 Kistler	1,294-97	"show of live oil"	Joachim-St. Peter	Driller's log
					1.354-58	sl o disc		Sample study
					1,369-71	show	Knox	Scout
Clark	Grant 195	1N	8E	Clark No. 1 McClellan	1,547	"paraffin and black, dead, and very heavy oil"	Knox	Driller's log
Dearborn	15	5N	1W	Central No. 1 Bobrink	775-815	so	Joachim	Driller's log
					500-867	"gas would burn in bailer"		
Dearborn	28	6N	1W	Regional No. 1 Fox	1.335-40	"top carrying a little crude"	Knox	Driller's log
Dearborn	27	7N	2W	Dearborn No. 1 Shoemaker	1.900-20	"showed oil"	Knox	Driller's log

Table 8.—*Reported shows of oil and gas below the Trenton and Black River limestones in Indiana listed by counties*—Continued

County	Location			Operator and name of well	Depth (feet)	Description	Formation	Source
	Sec.	T.	R.					
Decatur	7	9N	10E	Decatur at Greensburg	2,626	"rainbow showings"	Knox	Correspondence in Geological Survey files
					2,890	"good showing of oil; small particles on top of the bailing water, but it was black oil"		
					2,850	"showed good rainbows"		
Delaware	13	20N	11E	Weilder No. 2 Leeka	1,617-50	so	Knox	Driller's log
Floyd	28	1S	5E	Chenault No. 1 Scharf	2,220	sdo	Knox	Scout
Howard	32	24N	5E	Kokomo at Greentown	1,650-65	" 'oily' stain"	Knox	Sample study (not author's)
					1,850-80	sl o st		
					1,890-1,925	sl o disc "(?)"		
					2,060-85	sl o disc		
Huntington	19	28N	10E	Lantz No. 1 Ream	2,723-65	so	Knox	Driller's log
					2,823	so		
Jasper	14	30N	6W	Kankakee No. 1 Eger	1,635-50	tr tar	Knox	Sample study (not author's)
					1,665-75	tr tar		
					1,875-1,920	tr tar		
					2,050-77	tr tar		
					2,085-96	"small chunk of tar"		
					2,150	show		Scout
					2,215-26	"trace tarry residue in lower part"	Galesville	Sample study (not author's)
					2,557-73	"sho heavy oil"	Eau Claire	Scout
					2,688-2,709	some tar		Sample study (not author's)
					3,308-3,311	some tar	Mt. Simon	Scout
					3,359-73	"sho heavy oil"		Sample study (not author's)

Table 8.—*Reported shows of oil and gas below the Trenton and Black River limestones in Indiana listed by counties*—Continued

County	Location			Operator and name of well	Depth (feet)	Description	Formation	Source
	Sec.	T.	R.					
Jay	24	22N	12E	Wesner No. 2 Current	1,378-90	"good oil sand"	St. Peter?	Driller's log
Jay	25	22N	12E	Larapaul No. 1 Lander	1,372-90	so	St. Peter?	Scout
Jay	21	22N	13E	Steed	1,406	so	St. Peter?	Scout
Jay	25	24N	13E	Seip No. 2 Carson	2,045-70	sso	Knox	Scout
Jay	29	24N	13E	Petroleum No. 1 Binegar	1,800-10	so	Knox	Scout
					1,819-26	vsso		Sample study (not author's)
					1,881-85	tr tar		
					1,897-1,905	tr tar		
					1,998	sg		Scout
					2,086-2.175	tr tar		Sample study (not author's)
					2,086-88	"cons paraffin"		
					2,146-51	"few pellets of paraffin"		
					2,214-30	so		
					2,214-19	"slightly oily or paraffinic"		
					2,275-85	v sl o disc		
					2,348-59	ssdo	Eau Claire	
					2,380-2,405	sl sdo		
					2,380-2,412	"oil film residue on acid bath"		
					2,732-45	"slight oil show, much tar"		
					3,305	"rainbow"	Mt. Simon	Scout
					3,317-21	"slight oil staining?"		Sample study (not author's)
					3,367-71	so v l disc	basement	
					3,374-79	so		
Jay	29	24N	13E	Farm Bureau No. 1 Binegar	1,817-22	so	Knox	Driller's log
					1,998	sg		Scout
					1,826-56	sso		
					2,214-22	so		

Table 8.—*Reported shows of oil and gas below the Trenton and Black River limestones in Indiana listed by counties*—Continued

County	Location			Operator and name of well	Depth (feet)	Description	Formation	Source
	Sec.	T.	R.					
					2,392-96 2,404-12	"rainbow" "rainbow"	Eau Claire	
Jay	7	24N	14E	Sub-Trenton near Bryant	2,130 2,340	so so	Eau Claire?	Driller's log
					2,800 3,269	"coal tar" do	Mt. Simon?	Analysis Driller's log
Jennings	30	7N	8E	Ohio Valley No. 1 Phillips	1,484-1,507	so	Joachim	Scout
Johnson	5	12N	4E	Universal No. 1 McQuiston	1,832-57 1,857-59 1,859-63	"oil sand" "paraffin" "oil sand"	Knox	Driller's log
Johnson	5	12N	4E	Universal No. 2 McQuiston	1,838-93 2,010-2,275 2,302-67	"oil sand" sg so	Knox	Driller's log
Madison	8	18N	8E	Munson No. 1 Munson	1,446-47	"Show black asphalt. Stuck on bit and bailer. Would not flow into well."	St. Peter?	Driller's log
					1,558-1,602	"several streaks of saturation. Made good show of light oil in 1,000 feet of water. Carried enough gas to light in bailer and burn for minute or two."	Knox	
Madison	1	19N	6E	Anderson No. 1 Coy	1,431	"Show gas, enough to light"	Knox	Scout
Monroe	29	8N	1E	Pardoe No. 1 Union	2,373-2,478 2,478 92	"Asphalt" reported in many samples "Asphalt" also reported	Knox	

Table 8.—*Reported shows of oil and gas below the Trenton and Black River limestones in Indiana listed by counties*—Continued

County	Location			Operator and name of well	Depth (feet)	Description	Formation	Source
	Sec.	T.	R.					
Monroe	6	9N	1E	Solomito No. 2 Solomito	2,359	sg	St. Peter?	Driller's log
					2,375-85	sog	Knox	
Scott	26	2N	6E	Pigeon Roost No. 2 Grubbs		"so in Sub-Trenton"	?	Scout?
Wayne	22	13N	1W	Wayne County No. 1 Taylor	1,962-68	"light show of gas"	Knox	Sample study
					2,005	"light show of gas"		(not author's)
					2,187-2,210	"asphalt"		Scout
					2,187-2,206	"asphaltic material"		Sample study
					2,215-26	"traces asphaltic material"		(not author's)
					2,285-90	"hard lustrous hydrocarbon"		
					2,301-09	traces of asphalt		
					2,366-71	traces of asphalt		
					2,482-90	traces of asphalt		
					2,805-10	"some asphalt present"	Eau Claire	
					2,823-28	"some asphalt present"		
					2,911-20	"tar residue"		
					2,961-71	"tar residue"		
					2,996-3,006	"tar residue"		
					3,064-68	"tar residue"		
Wayne	23	15N	13E	No. 1 Doddridge	2,590	tr o	Knox	Scout
Wells	11	25N	10E	Fox No. 1 Metz	2,248-52	"sho live oil"	Knox	Scout

[1] Information was obtained from the files of the Indiana Geological Survey, Bloomington, except for formational designations which were made by the present writer. Special acknowledgment is due to Mr. H. J. Bourne, of Portland, Ind., who supplied the Geological Survey with information concerning shows of oil and gas. Descriptions have been abbreviated as follows:

cons	considerable	l	light or little	sdo	show of dead oil	sso	slight show of oil
disc	discoloration	o	oil or oily	sg	show of gas	st	stain
do	dead oil	s	show	sl	slight	tr	trace
g	gas	sat	saturated or saturation	so	show of oil	v	very

trap and retain hydrocarbons. The shape of the formation as a whole in Indiana is lenticular and probably is due to interfingering with the Mt. Simon sandstone to the north and the Knox dolomite to the south. What effect this interfingering would have on the reservoir characteristics of the Eau Claire is not known. Like the Mt. Simon, this formation is virtually untested.

KNOX DOLOMITE

Commercial oil or gas has not been produced from the Knox dolomite in Indiana. About 120 tests have been drilled to the Knox in Indiana, and all varieties of shows of oil, gas, and tar have been reported in 26 tests (table 8). None of the shows were examined in the well cuttings by the present writer.

The Knox dolomite consists of cherty dolomite and some sand lenses. It thins markedly in a northerly direction owing mainly to an erosional unconformity at the top. The Knox is permeable, but irregularly so. Water is reported in the Knox in most places in amounts which have made cable-tool drilling difficult. Controlling the flow of water is a serious consideration because the Knox may be 1,500 feet or more thick. Gas is commonly reported in the Knox in shows large enough to burn in the bailer. That there is gas in the Knox is not doubted, but the writer does not know of any accurate test that has been made to determine how much gas is present or in what part of the formation it occurs.

The upper surface of the Knox throughout Indiana is an erosional unconformity. In most places the overlying formations of the Chazyan series appear to be as porous as the Knox itself. In northeastern Indiana, however, the Chazyan series is thin or absent, and the overlying Black River limestone generally has a very low porosity. In this region some gas is evidently trapped along the unconformity by the Black River limestone, and further exploration may reveal commercial quantities of gas.

CHAZYAN SERIES

Commercial oil or gas has not been produced from the Chazyan series in Indiana. About 200 test wells have penetrated the Chazyan series in Indiana, and shows of oil or gas have been reported in the St. Peter sandstone in 7 and in the Joachim dolomite in 3 of these test wells. None of the shows were examined in well cuttings by the present writer.

The St. Peter sandstone has been thought by many to be the most logical deep formation for oil and gas exploration. In some respects this is a well-founded assumption. The St. Peter consists of medium-grained rounded sand which is porous and permeable. In addition, the St. Peter thins rapidly from northern Illinois and northwestern Indiana and is not present in northeastern Indiana. This pinchout of a permeable sand beneath an impermeable limestone (Black River) should provide ideal conditions for the entrapment of oil or gas. But the fact that only 7 shows have been reported from 200 test wells in Indiana suggests that the St. Peter is a less attractive prospect than some other deep formations. The apparent scarcity of oil and gas may be due to flushing, as the St. Peter is full of fresh water everywhere in northern Indiana. In southern Indiana the formation contains salt water; this may or may not indicate flushing. It may be that no suitable source of hydrocarbons was available to what might have been an excellent reservoir.

Little is known of the possibilities of the Joachim dolomite, but it, too, appears to contain little or no oil or gas. It is less porous than the St. Peter but generally contains abundant water, and it probably cannot serve to trap oil or gas in the St. Peter.

BLACK RIVER LIMESTONE

Approximately 500 test wells have been drilled into the Black River limestone in Indiana, and many shows have been reported. Small quantities of commercial oil have been found in northeastern Indiana, but the amounts are small compared to the production from the overlying Trenton.

The Black River limestone consists of very finely crystalline or lithographic limestone except in northwestern Indiana, where it is composed of saccharoidal dolomite. The formation is too impermeable throughout most of Indiana to serve as a reservoir except in the northwestern part of the State, where the formation is composed entirely of dolomite, and in other local areas of dolomitization. The Black River is overlain by the Trenton limestone throughout most of Indiana and by the dolomite facies of the Trenton in northwestern Indiana (fig. 13). In general, the Trenton is more permeable than the Black River and cannot serve to trap oil or gas in the Black River. A notable exception is in southern Indiana, where the Black River is directly overlain by black shale (fig. 12). If local dolomitized areas offer increased permeability, the top of the Black River may contain oil or gas where it is overlain by black shale.

TRENTON LIMESTONE

Production of oil and gas from the old Trenton field has been negligible for the past 40 years, and it seems unlikely that much more commercial oil will be found there. Although an exact duplication of the conditions which resulted in this great field will not be found, some guidance in future Trenton exploration can be obtained from a study of the old field.

Entrapment of oil in the Trenton field seems to be a function of changing permeability and structural control. Oil is found only in the upper dolomitized parts of the Trenton (fig. 17C) ; oil seldom is found in the Trenton in areas where the dolomite facies is not present. On the other hand, gas is found over a much larger area in which much of the reservoir is limestone with low permeability (fig. 17B) ; this fact suggests that the gas was better able to migrate into less permeable parts of the formation than the oil was. Throughout the field the Trenton is overlain by shale. Accumulation also seems to be controlled by structural relief on the Cincinnati Arch (fig. 17A), although structural relief is low and dips in the field are only 10 to 20 feet per mile.

It would seem logical for further Trenton exploration to seek conditions elsewhere in the State that are similar to those in the old Trenton field. The dolomite facies of the Trenton limestone thickens to the north and west in Indiana (fig. 17C) and retains the lithologic character found in the old field. The dolomite is overlain by shale as in the old field. The overlying shale seems to contain less carbonaceous matter to the west of the field, but the effect of this difference is not known. The second condition described in the old field—that is, the structural effect of the Cincinnati Arch—is not duplicated, although an extension of the Arch seems to continue to the northwest in Indiana (fig. 17A). Because of the dolomite facies and positive structure northwestern Indiana appears to be the most favorable part of the State for further Trenton exploration. Some Trenton oil has been found in south-central Indiana (Bartlettsville pool, Monroe and Lawrence Counties), but this oil seems to be in local fracture zones associated with faulting. The present writer believes that, with the possible exception in the region of occurrence of the Lexington-Cynthiana formation described in the next paragraph, Trenton exploration would be more justifiable in the northern half of Indiana, where dolomite facies of the Trenton is present, than in the central and southern parts of the State, where the Trenton is composed entirely of limestone.

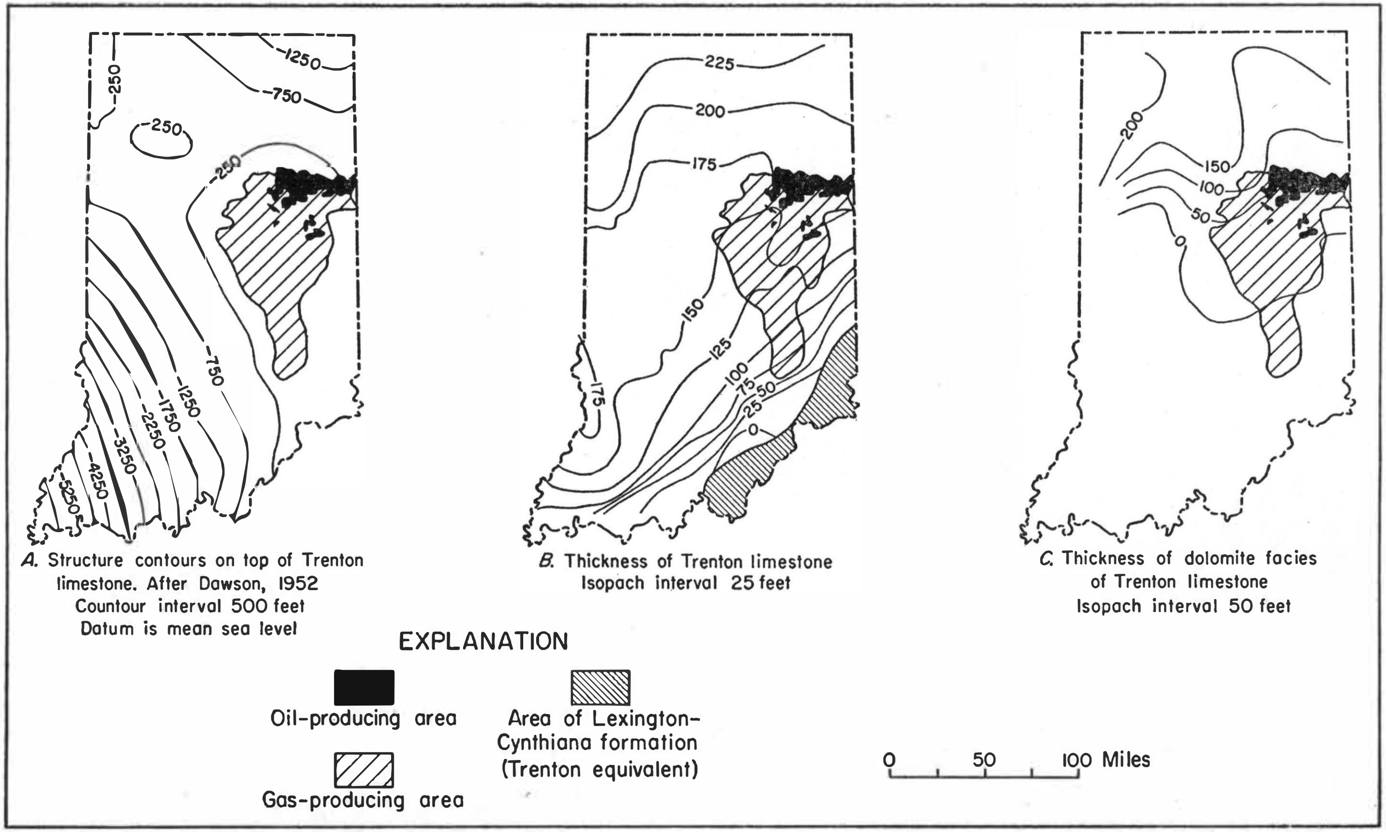

Figure 17.—Maps showing relationship of structure, thickness, and lit hology of Trenton limestone to accumulation of oil and gas in Trenton field. Extent of Trenton field after Dawson and Lowrance, 1952.

A second area worthy of consideration is in the southern part of the State where Trenton limestone and black shale of the Eden type are interbedded in what has been termed the Lexington-Cynthiana formation in this report. This zone has had little testing in the past, and stratigraphic relationships are not clear. It is apparent, however, that the section consists of local lenses of limestone isolated in a body of black shale. Limestone of the Trenton type is not present locally, and the black shale rests directly on the Black River limestone. These conditions are evidence of rapid changes in permeability which, if sufficiently great, would localize any oil or gas that may be present.

CINCINNATIAN SERIES

Neither the Cincinnatian series nor the Maquoketa shale has produced commercial oil or gas in Indiana, but a small amount of gas from the upper Cincinnatian is used locally in western Jefferson County. The large number of test wells that passed through the Cincinnatian in testing the Trenton in northeastern Indiana and the lack of suitable permeability make it doubtful that commercial oil or gas will be found in the Cincinnatian in that area. Maquoketa shale has been tested in many places in eastern Illinois without encouraging shows; this fact suggests that the Maquoketa of western Indiana also may be a poor prospect.

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GEOLOGICAL SURVEY
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DEPARTMENT OF CONSERVATION
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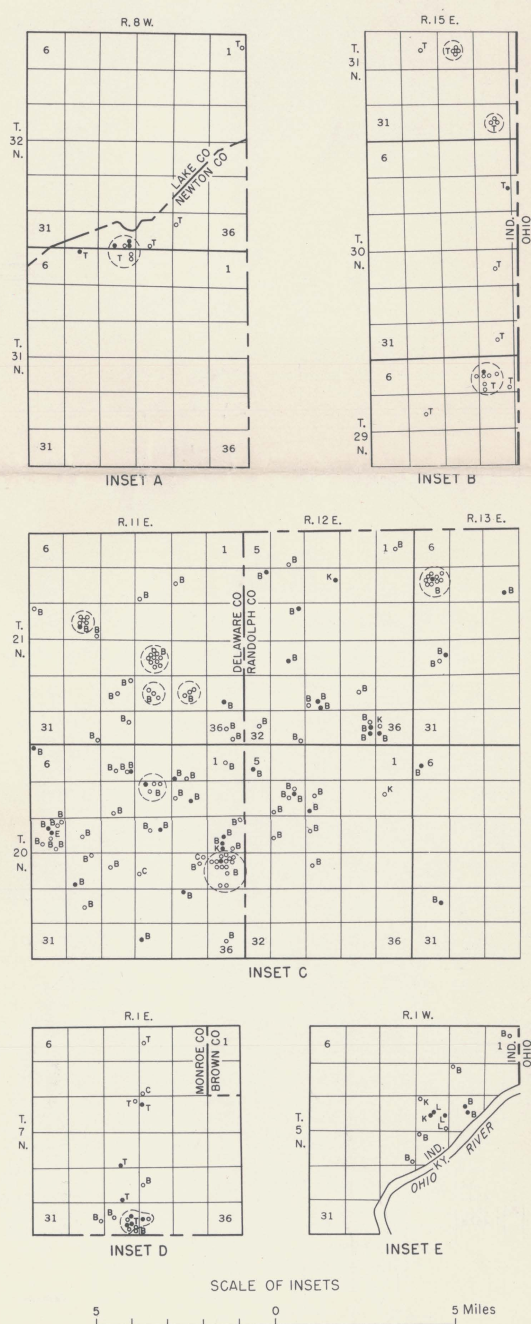
BULLETIN 14 PLATE 1

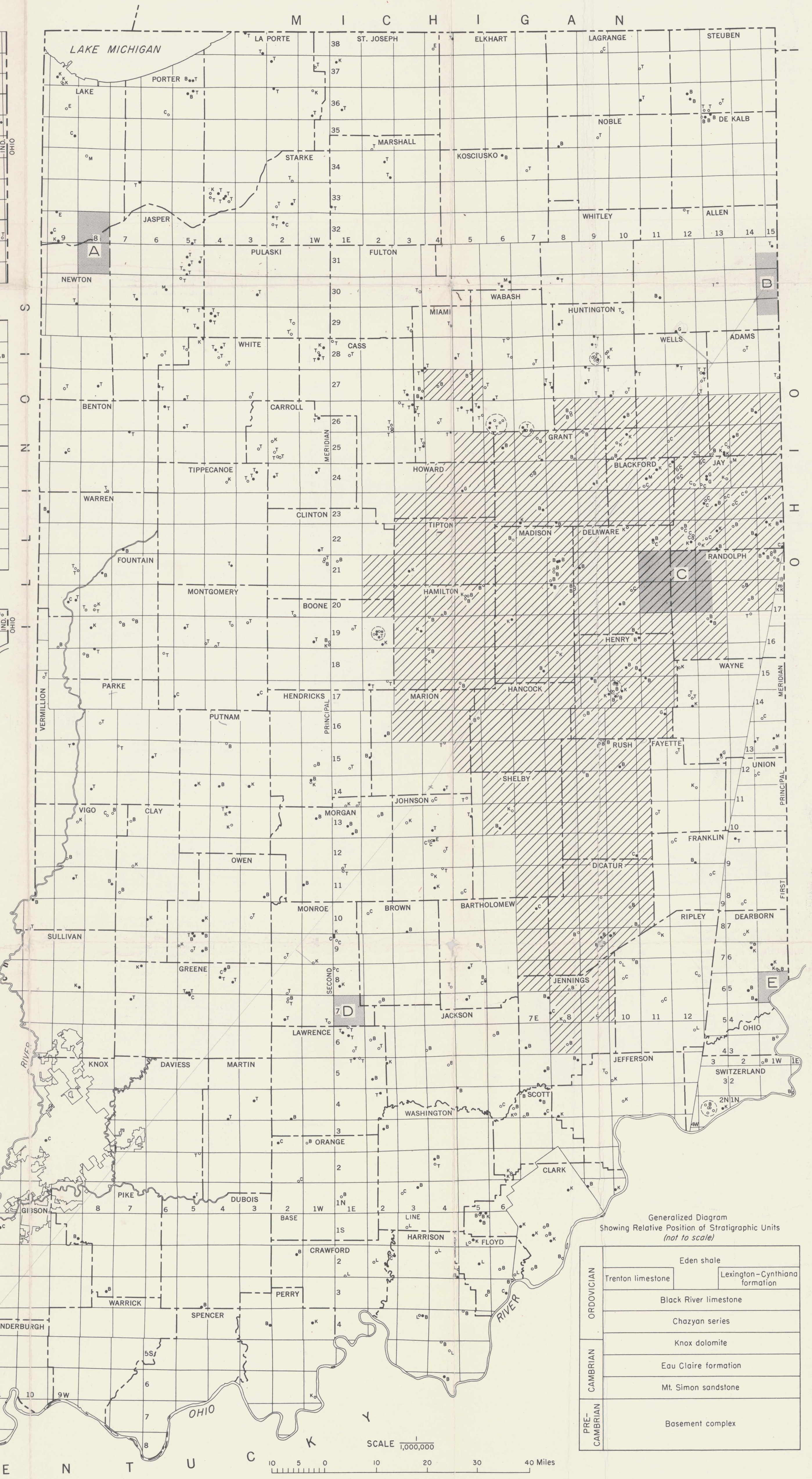
LIST OF TEST WELLS SHOWN ON MAP[1]

County	Location: Sec.	T.	R.	Operator and well name	Date completed	Elevation (feet above sea level)	Total depth (feet)	Samples available	Depth (feet) to top of stratigraphic unit: Trenton limestone	Black River limestone	Chazyan series	Knox dolomite	Eau Claire formation	Mt. Simon sandstone	Basement complex
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	8	27N	13E	Redwing No. 1 Gahman	44	837	1,150	X	(?)						
	19	27N	13E	Texas No. 1 James	44	854	1,185		1,136c						
	31	27N	13E	Texas No. 1 Speheger	44	868	1,283		1,135d						
White	33	26N	5W	North No. 1 Huff	50	736	1,171	X	1,114b						
	11	26N	6W	Ohio No. 1 Mathew	42	730	1,060	X	946b						
	33	27N	3W	McClain	93	677	1,073		1,010d						
	33	27N	5W	Oglesby No. 1 Helderle	51	699	1,054	X	1,003b						
	22	27N	6W	Hutcheson No. 1 Trachsel	45	717	1,030	X	938b						
	10	28N	4W	Garwood No. 1 Horner	52	674	927	X	880b						
	16	28N	4W	National No. 1 Brown	41	679	990	X	892b						
	21	28N	4W	Monon Well	12?	664	920		870d						
	35	28N	4W	Maguire No. 1 Clark	43	678	928		898d						
	1	28N	5W	Ohio No. 1 Mosley	41	675	1,638	X	877a	1,054a	1,235a	1,313a			
Whitley	3	30N	8E	Michiana No. 1 Bailey	39	805	1,375	X	1,331a						

[1] Includes all tests that penetrated the Black River limestone or deeper formations in the Trenton (Lima-Indiana) oil and gas field and all tests that penetrated the Trenton limestone or deeper formations elsewhere in Indiana, as of July 1, 1956. Certain information was contributed to the files of the Indiana Geological Survey by Mr. H. J. Bourne of Portland, Ind.
Sources of stratigraphic information are indicated as follows:
- a Sample study of present writer.
- b Sample study by Indiana Geological Survey.
- c Study of electric log by present writer.
- d Information from driller's log or other source.
- ? Sample study by present writer but depth questionable.
- (?) Unit probably present but depth to top of unit cannot be determined.

[2] Lexington-Cynthiana formation.
[3] Possibly Lexington-Cynthiana formation.
[4] Michigan Road Land section.





EXPLANATION

- • Location of test well for which samples are available at the Indiana Geological Survey
- ∘ Location of test well for which samples are not available at the Indiana Geological Survey

(Locations are generalized in areas of close drilling. Letter indicates deepest stratigraphic unit penetrated: T, Trenton limestone; L, Lexington-Cynthiana formation; B, Black River limestone; C, Chazyan series; K, Knox dolomite; E, Eau Claire formation; M, Mt. Simon sandstone; G, Basement complex)

- Dashed line encloses group of wells, all of which penetrate designated deepest stratigraphic unit
- Approximate area of Trenton oil and gas field in which only test wells that penetrate Black River limestone or deeper stratigraphic units are shown
- Area shown on inset map

Base modified from U. S. Geological Survey Base map of Indiana, 1950.

MAP OF INDIANA SHOWING LOCATION OF TEST WELLS THAT PENETRATE TRENTON LIMESTONE OR DEEPER FORMATIONS

By Allan M. Gutstadt

1958